EXPLORING REASONS FOR DIGITALIZATION NOT PERCOLATING INTO THE POWER SECTOR TO THE EXTENT EXPECTED IN INDIA AND SUGGESTING A FRAMEWORK TO EXPEDITE THE SAME

By

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Dedication

This work is dedicated to my beloved parents, the late Mr. PV Naidu and late Mrs. Chinnathalli, whose influence has shaped me into the person I am today. I also extend my heartfelt gratitude to my wife, Mrs. Radha, and my children, Mr. Manoj and Mrs. Manasa, whose unwavering support and inspiration continually invigorate our family.

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i. ICRAETS-International conference on recent advances in engineering, technology, and sciences, Tiruchirappalli, India, 17 June 2023,
ii. ICEESEN-International Conference on Energy, Environment and Energy Storage, Turkey, 21 Sep 2023,
iii. IPS-Indian Power Stations conference by NTPC, Raipur, India, Feb- 2024.

Heartfelt appreciation is expressed to the cross-functional and subject matter experts from engineering, operations, maintenance, ESG, IT, product developers, and service firms who contributed to the research work.

ABSTRACT

EXPLORING REASONS FOR DIGITALIZATION NOT PERCOLATING IN TO THE POWER SECTOR TO THE EXTENT EXPECTED IN INDIA AND SUGGESTING A FRAMEWORK TO EXPEDITE THE SAME

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Digitization, digitalization, or digital transformation represents an essential convergence of IT and OT (Operational Technology) crucial for various industries, including the power sector. This paradigm shift not only enhances business competitiveness but also fosters improved safety, reliability, and sustainability while reducing costs and errors. Digitalization reduces costs to one-third in fuel and one- fifth in operations and maintenance. Digitalization's role in integrating physical and digital realms, optimizing processes, and enhancing overall performance within the power sector is very evident.

Despite these obvious benefits, digitalization in the power sector, particularly in India, has not percolated to the anticipated extent. This research aims to delve into the reasons behind this shortfall, focusing on six key areas: strategy, operational excellence, regulatory landscape, technology, innovation, and economic considerations, collectively termed as 'SORTIE'. Additionally, it proposes a framework to expedite digitalization adoption by addressing these reasons. Through showcasing the effectiveness of the SORTIE framework in transitioning from trials to successful implementation, this study underscores the urgency and potential of digitalization in revolutionizing power generation.

By identifying and overcoming barriers to digitalization deployment, this research aims to drive significant change, inform strategic decision-making, and shape the future trajectory of the power sector towards sustainability and resilience in an increasingly digitized world.

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FOUNDATION TO THE STUDY

1.1 Introduction

The contemporary world is undergoing a pervasive transformation driven by the adoption of digitization, digitalization, and digital transformation. While each term carries distinct connotations, collectively, they represent a shift towards leveraging digital technologies to revolutionize various aspects of life. Digitization, as defined by (Gartner, Information Technology Glossary, 2019) involves the conversion of analog data into digital format. On the other hand, digitalization, as articulated by (Rachinger M et al, 2018) , encompasses the utilization of digital technologies to innovate business models. Broadening the scope further, digital transformation, as delineated by (Gartner, Information Technology Glossary, 2019)and (Hess T et al, 2016), encompasses a comprehensive overhaul, ranging from modernizing IT infrastructure to reshaping business models (Loebbecke C et al, 2015).

In this thesis, the term "digitalization" serves as a comprehensive concept, encapsulating elements of both digitization and digital transformation. Digitalization involves the convergence of physical and digital realms, comprising data processing, analytics, and connectivity layers (Chui, 2022).

Digitalization entails convergence and interaction between the physical and digital worldscomprising three layers as shown in Figure **1**.

- Data (Processed information/ perception / sensory layer),
- Analytics (actionable insights from models' layer) (Chui, 2022) and
- Connectivity (exchange of via communications networks, human to machine, Machine to machine, human to human application layer).

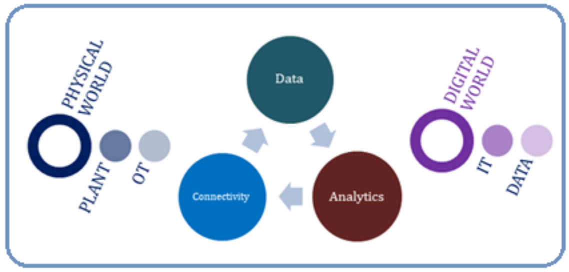

Figure 1
Interaction between physical and digital worlds

Across various industries, digitalization is becoming increasingly indispensable, and the energy and power sector is no exception. Digitalization in power generation entails a multifaceted integration of processes and technologies, spanning from data sensors to communication networks (BDEW, 2016).

In recent years, there has been a notable shift towards digitalization within the power sector, driven by advancements in technology and evolving market dynamics. This transformation holds immense potential for revolutionizing traditional power generation methods and meeting the evolving demands of a modern, interconnected world.

It is said that “it is easier to change the people than to change the people” i.e., sometimes a new vision requires new people to create it. New innovations and novel creations are ever evolving in digitalization (Foss, 2017).

Like electricity, digitalization is fast becoming a necessity of life. Digitalization encompasses one or more of deep learning, neural networks, machine learning and artificial intelligence and present-day AGI (artificial general intelligence). Chat-GPT, regenerative AI, ML are pervading the digital transformations happening across the industry- like financial services, healthcare & life services, automotive, manufacturing, media and entertainment, retail, telecom, travel & hospitality, consumer packaged goods , energy and power sector.

Digitalization in power sector entails end-to end integration of processes entailing both backward and forward integration of power generation value chain. At the ground level it entails probes, sensors, measuring devices, smart devices like meters, actuators, deployment methods, at operations level it encompasses SCADA-supervisory control and data acquisition, DAS-data acquisition system, DCS-digital control system , PCLs-programmable logic control , operation servers, engineering servers, operations clients, engineering clients, interfaces, AI enabled CCTV and real-time data processing and at connectivity level it involves IT-OT switches, firewall, LAN, WAN integrating the physical and digital worlds as depicted at Figure **1**.

Digitalization in the electricity sector has scope in the entire electricity value chain including mining, logistics, generation, trading, transmission and distribution, consumption, sustainability, compliances and system for forecasting and prediction (supervised data analytics), clustering (unsupervised data analytics), monitoring and diagnostics (both supervised and unsupervised), controlling and compliances etc.

Some of the digital applications in power sector could be digital worker(using NFC or wifi) , PADO, M&D, RCM, APM, OPM, Boiler tube health monitoring, Engineering services, training, trouble shooting, outage planning, operational intelligence (Firican, 2017), adaptive planning, transmission & distribution , availability enhancement, in-bound fuel logistics optimization, e-procurement, e-attendance, ERP, CMMS, OLMMS, finance controls, inventory control, document control, asset health index, simulator, what if analysis, coal yard management, scrap management, safety – audits, i-auditor, security management system, CC tv controls, fleet control, stores management, warehouse management, process optimization, intelligent soot blowing, condition monitoring, KPIs, SAMP-strategic asset management plans (Crespo Marquez, 2020) RAPP-risk assessment and priority planning etc (Ardebili, 2022). This list is not exhaustive.

Digitization breaks the silos and helps in bringing consistency, alignment, transparency, and compliance in place. It propagates 3D- decarburization, digitation, and decentralization of power. The implementation of digitalization in power plants typically progresses through five broad phases: initiation, exploration, expansion, optimization, and transformation. Additionally, the maturity of digitalization within an organization can be categorized into five levels: basic, opportunistic, systematic, differentiating, and transformational.

The implementation of digitalization has five broad phases, viz., initiation, exploration, expansion, optimization and transformation as shown below Figure **2** Implementation phases of digitalization.

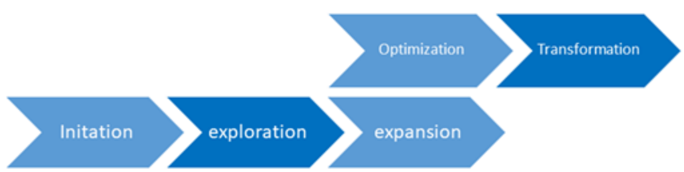

Figure 2
Implementation phases of digitalization

The concept of digitalization and its significance in the contemporary world, particularly within the energy and power sector is introduced and the functionalities, challenges, phases, and maturity levels associated with digitalization in power plants are outlined. Despite its potential benefits, the widespread adoption of digitalization in the power sector faces numerous challenges, ranging from data management complexities to regulatory constraints. Understanding and addressing these challenges are imperative for accelerating the deployment of digitalization in power plants.

1.2 Research Problem

Despite the evident benefits of digitalization, the power sector faces numerous challenges in its widespread adoption. These challenges range from technological complexities and regulatory constraints to organizational barriers and cost considerations. As a result, many power generation facilities struggle to fully leverage the potential of digitalization, leading to suboptimal performance and missed opportunities for innovation and growth.

Digitalization is ever pervading in all facets of life, at different maturity levels and transforming the way business is done. However, the tug-of war between the push factors like affordability on one hand the pull factors like need of flexibility and cost competition due to the penetration of renewables on the other hand necessitates a balancing act and opens a plethora of new avenues to accelerate the deployment of data analytics in power sector.

With the more and more renewable power joining the grid, the conventional coal fired power plants which are supposed to run as ‘base load’ plants are forced to face fluctuations in their load schedules calling for more flexibility in their controls systems and agility in their operation processes.

Digitization has an impeccable role to play in the power generation sector. It can facilitate seamless integration of decision siloes, bring in more transparency in the operations, enhance collaboration among various stake holders, reduce O&M costs, increase employee development and engagement, eliminate resource losses, incentivize lean management, optimize spares requirement, optimize maintenance activities and make them more cost effective, assure sustainability, overall enhance employee development and growth engagement with enhanced performance of people, plant and processes yielding more profits yet saving the planet. Digitization helps in providing better advanced process controller using evolutionary methods for optimization: PSO-Particle Swarm Optimization, BFPSO- Bacterial Foraging Particle Swarm Optimization, GA-Genetic Algorithm, BFO- Bacterial Foraging Optimization e and QFT- Question Formulation Technique based robust controller etc (Yu, 2010).The ‘euphoric GEAR power (green, efficient, affordable, and reliable power)’ , the contemporary connotations on “power for all” “business analytics”, “3D-decarbonization, digitation and decentralization of power”, “ESG” and “Net-Zero” can only be realized by adopting relevant digitization in the power plant value chain.

The ever increasing list of pathos of power generators necessitates digital deployment evermore. For example lower plant load factors, reduced efficiency at part load operations, delayed and meagre recoveries from DISCOMs (distribution companies) , non-availability of skilled and trained man power, aged man power, retiring experienced skill pool, mandatory stricter norms to adhere to emission controls asking for more capital infusion, mandatory guidelines to fire bio-mas co-firing in coal fired plants again requiring some operational regime changes and added fuel costs, never ending woes of achieving 100% ash utilization which again adds up to additional spending , ever increasing aspirations of work force for higher wages and salaries, not honouring PPA-power purchase agreements by some of the buyers (few state governments), ever increasing coal supply prices in both domestic as well as international coals, non-availability of spares from OEMs on account of discontinued productions, changed models/technology or grim geo-political situation prevailing(for example between India and China) , increased duties on imports to encourage domestic spares productions (Atmanirbhar Bharat) which is unable to gear up to the standards and requirements by the buyers compared to overseas suppliers, etc. is pushing the power sector against wall for survival on one hand and OFI (opportunity for improvement) and so on and so forth. This is an ever expanding list.

In this background the enthralling ethos of ‘power for all’ and minimizing the above omnipresent pathos across the sector is an uphill task. To increase resilience and bounce back to sustainable business operations, integration of various siloes in the power generation value chain is the need of the hour. Thus digitalization of power value chain is the dire need of the hour to reap economic as well as sustainability benefits. Despites its essentiality and offering a plethora of benefits, digitalization has not percolated to power sector to the extent it is expected. This opinion is corroborated by several articles written and published by many researchers, experts, consulting firms, institutions, OEMs.

This fact is corroborated by PWC’s report (Dr.Marcus, 2019) that only 2 per cent of utilities in the EMEA region (Europe, the Middle East, and Africa) have adopted digitization extensively. Further World Bank Digital Adoption Index-DAI given for India is 0.51 against 0.87 of Singapore in the scale of 0-1 reinforces the fact that there is a long way to go in digitization (World Bank, 2016).

During each phase of implementation (plaese refer Figure **2** Implementation phases of digitalization) digitlaization face numerous challenges. A pragmatic framework enabling faster deployment of digitization in power plants cannot be developed out without complete collation of reasons and diving deep into the same.

1.3 Motivation

The motivation behind this research stems from the recognition of the critical role that digitalization plays in shaping the future of the power sector. By addressing the challenges and barriers to digitalization, this study seeks to unlock the full potential of digital technologies within power generation facilities. The ultimate goal is to facilitate the transition towards more efficient, sustainable, and resilient energy systems that can meet the demands of an increasingly digitized world.

1.4 Purpose of Research

This research endeavours to comprehensively explore the impediments to digitalization in the power sector and develop a pragmatic framework to overcome these challenges. The study delineates six critical domains collectively referred to as SORTIE, encompass Strategy, Operational Excellence, Regulatory Compliance, Technological Advancements, Innovation, and Economic Considerations. These six areas evolved from focused discussions with subject matter experts, preliminary literature review, industry white papers etc.

By unravelling the constraints within these domains, the research aims to propose actionable strategies through a framework for accelerating digitalization deployment in power plants.

Various researchers, authors and academicians have probed into the reasons for digitalization not percolating into the power sector to the extent it is expected. But the reasons collated are found to be not mutually exclusive and collectively exhaustive. Hence, it is imperative to explore all the possible reasons for digitalization not percolating the power sector to the extent possible. Also, there is no readily usable comprehensive framework to overcome these reasons and expedite digitalization in power sector. Ergo it is aimed to develop one framework to this effect after uncovering all possible reasons.

In the dynamic landscape of modern business, navigating through various challenges and opportunities requires a comprehensive understanding of key areas that significantly influence organizational success. This research endeavours to explore and analyse six critical dimensions that serve as boundaries for organizational operations and strategic decision-making.

Each component within SORTIE represents a vital aspect that organizations must carefully assess and integrate into their overall framework to thrive in today's competitive environment. Strategy lays the foundation for long-term direction and goals, while Operational Excellence ensures efficient processes and resource utilization. Regulatory Compliance ensures adherence to legal and ethical standards, while Technological Advancements offer opportunities for growth and transformation.

Furthermore, Innovation fosters creativity and adaptation to changing market dynamics, while Economic Considerations provide insights into financial viability and sustainability. By examining these six interrelated areas, this research aims to provide valuable insights and practical recommendations for organizations seeking to enhance their performance and achieve sustainable success in an increasingly complex and interconnected global landscape.

The six elements of SORTIE are further described to get a more elaboarate perpsective of each of them.

1. Strategy : Realigning business processes for product/service delivery (Hess T et al, 2016). Mostly it has long time horizon with external focus under conditions of uncertainties. Three levels of strategy are looked into viz., corporate, business and functional level mainly in the energy sector.

2. Operational excellence: Realigning people, process, and tools with short or midterm horizon with internal focus following certain principles and rules limited to energy sector.

3. Regulations: Codes, standards, rules, mandates by government, regulators pertaining to power sector.

4. Technology: Technology is the application of conceptual knowledge in achieving practical goals. The information technology, operation technology and engineering technology deployed in power sector.

5. Innovations : ISO 56000:2020 defines innovation as "a new or changed entity, realizing or redistributing value". Innovation converts ideas creating new products or services that gel well with the needs of the power sector.

6. Economic considerations: Capex and opex, Investments, short/long term benefits, ROI, payback period for selected and implemented digitalization projects.

Exploring the concrete exhaustive list of constraints within the six boundaries as above is my primary research aim with a secondary aim to suggest a framework to overcome these constraints and speed up digitization deployment in power sector.

1.5 Significance of the Study

The significance of this study lies in its potential to drive meaningful change within the power sector and contribute to the broader discourse on digital transformation in energy systems. By elucidating the challenges and opportunities associated with digitalization, this research can inform strategic decision-making, policy formulation, and investment priorities within the industry. Ultimately, the findings of this study have the potential to shape the future trajectory of the power sector and pave the way for more sustainable and resilient energy systems.

World Bank the Digital Adoption Index-DAI on three dimensions of the economy on a 0-1 scale (World Bank, 2016) is shown in Table **1**
DAI table comparing India and Singapore.

Table 1
DAI table comparing India and Singapore

The Digital Adoption Index					
Country	Year	Digital Adoption Index DAI	Business Sub-index	People Sub-index	Government Sub-index
India	2014	0.442272395	0.430099308	0.160062328	0.736655533
India	2016	0.510771692	0.500528276	0.227437884	0.804348886
Country with highest DAI					
Country	Year	Digital Adoption Index DAI	Business Sub-index	People Sub-index	Government Sub-index
Singapore	2014	0.868270159	0.836006045	0.80476433	0.964040041
Singapore	2016	0.870592058	0.851721346	0.803051472	0.957003355

India is lagging behind Singapore in digital adoption on the three parameters.

- Business (increasing productivity and accelerating broad-based growth
- People (expanding opportunities and improving welfare), and
- Government (enhancing accountability of effective service delivery),

Only about 2 per cent of utilities in the EMEA region (Europe, the Middle East, and Africa) adopted considerable digitization while 45 per cent lag (Dr.Marcus, 2019). Similar has been the experience in India, based on the preliminary focused interviews and a Google survey with industry leaders.

Some support processes such as finance, administration, human resources, spares and service procurement, stores had digitalization in bits and pieces in some utilities but the core functions such as generation, transmission, distribution, coal procurement, ash utilization, trading, and sales are yet to gear up in adopting digital

A maiden literature review shows that past studies are predominantly concentrated on understanding and modeling a limited number of constraints, for example financial constraints, policy impediments, capacity limitations , siloes and legacy data assets, human capabilities, companies trust in data, focus on value delivery (INTEL, 2017), legal and governance framework, capital investments, collaboration among departments (Gerald C. Kane et al, 2017) , technological, contractual, resource, spatial, and information constraints etc.

Hence the research on "Exploring reasons for digitalization not percolating into the power sector the extent and suggesting a framework to expedite the same" is relevant and significant for power sector.

1.6 Research Purpose and Questions

Based on the authors self-experience, preliminary literature review, interactions with industry experts and deliberations with domain experts, it is found that there is a considerable gap in establishing the concrete exhaustive list of reasons for digitalization not percolating to the extent it is expected in the power sector. Limited progress has been made on capturing mutually exclusive and collective exhaustive list of reasons according to their characteristics in a comprehensive manner. The primary objective of this research is to identify the salient reasons for the limited adoption of digitalization in the power sector and devise a framework to expedite its deployment.

To achieve this objective, the study seeks to answer the following research questions:

1. What are the salient reasons for digitization not percolating to the extent it is expected to be in the power sector?
2. What is the framework to expedite the same?

These research questions serve as guiding principles for investigating the multifaceted challenges and proposing actionable framework to advance digitalization in the power sector.

Towards answering the above two research questions, the broad activities below are to be considered.

Analysis of company's limitations, constraints, challenges to leverage data to create value for utilities.

- Analysis of use cases in industry and other utilities.

- Understanding of new business models that are enabled by Big Data analytics applications. (Dijkman, R.M. et al, 2017)
- Analysis of other sectors like transmission and distribution, which are like utilities.
- Proposal of a business case or framework for better deployment of IT-OT marriage.

1.7 Organization of the study

This study is organized into several chapters, each focusing on different aspects of research on digitalization within the power sector.

- CHAPTER II: provides a comprehensive literature review, examining existing research on digital transformation in energy systems, and identifying key insights and gaps in the literature.
- CHAPTER III: presents the research methodology, outlining the approach taken to collect and analyses data, as well as the theoretical frameworks employed in the study.
- CHAPTER IV: presents the results, findings of the research, including an in-depth analysis of the challenges and barriers to digitalization within the power sector.
- CHAPTER V: proposes a strategic framework for overcoming these challenges and accelerating the adoption of digital technologies.
- CHAPTER VI: portrays some use cases deployed using the SORTIE framework. Finally,
- CHAPTER VII: offers concluding remarks and recommendations for future research.

- APPENDICES: Research results, survey questionnaire, participants list etc. are provided at appendices with appropriate cross-referencing in the document.

1.8 Summary

In summary, this introduction sets the stage for a comprehensive exploration of digitalization within the power sector. By examining the challenges, opportunities, and strategic considerations associated with digital transformation, this study aims to provide valuable insights and actionable recommendations for power generation facilities seeking to embrace the digital future.

CHAPTER II:
REVIEW OF LITERATURE

2.1 Theoretical Framework

The review of literature is like looking into the rear-view mirror, finding the gaps in what could have been done better; developing a vision through a wider fore windscreen, creating a new knowledge base to steer into the future.

Analyzing the past literature, getting actionable insights, preparing for the future with the actionable framework, and creating a new body of knowledge is the essence of the literature review. Acknowledging and respecting the work done by earlier authors, the tone of the insights written is moderated with due reference to them.

Development and spread of any technology provide both wounds (lessons learnt to maneuver risks) and wisdom (tactics to steer through opportunities). It is said that one must choose not to complain about the wounds, instead cherish the wisdom. Same is the story with digitalization in power sector.

It is intended to analyze the past work done, rebuild the knowledge available by reviewing numerous data sources, published papers, thesis in relevant domains and find gaps and opportunities for improvement on searched articles using forward search and backward search.

Despite a plethora of features and benefits, digitalization failed to penetrate to the extent it is expected to be in the power generation sector, particularly in India. This section has seen numerous challenges, barriers, hindrances, bottlenecks, blind spots, and anomalies in digital transformation process. Nevertheless, they are not exhaustive and hence will not suffice in framing a framework for digital implementation at a faster pace in the power sector.

Though some research was done to elicit the reasons for this in the past, a few gaps remained unanswered on why and how part attributable to these nuances. This literature review intended to analyze the past literature (Mostly between 2017 -2022) and prepare for the future research filling the gaps identified and creating a new body of knowledge along with a framework to accelerate the deployment of digitalization in power sector in India.

The Literature Review activity is taken up in the following three levels.

Level-1: Searching for relevant articles.

Scholarly databases were probed using the key words. The boundaries for the research work were set and the search was carried out using key words defined in an array of sources like Google Scholar, ResearchGate, Sodhganga, ScienceDirect, Elsevier, Springers, SSBM e-library, semanticscholar.org , academia.edu, national digital library of India (ndl.iitkgp.ac.in) , myresearchtopics.com, frontiersin.org, kaggle.com, findaphd.com, fardapaper.ir , annals-csis.org, Multidisciplinary digital publishing institute(MDPI) and other institutional libraries both academia and industry .

Key words used in searching the articles include but not limited to 'digital transformation', 'digitalization', 'digitization', 'IoT', 'Internet of Things', 'Industry 4.0', 'diagnostics', 'remote monitoring', 'smart factory', 'digital frameworks', 'digital transformation', 'digital transformation issues', 'digital transformation challenges', 'digital transformation failures. Boolean operators (AND, OR, NOT) were used to widen the scope of capturing relevant articles. Extra literature originated from "snowballing," i.e. papers that trickled from references of the initial search, was also analyzed.

Level-2: Filtering criteria

The search results were filtered by going through abstract and conclusion portions in the first go. Studies that covered and emphasized the challenges, issues, and bottlenecks for deployment of digitization/ digitalization/digital transformation in power sector were downloaded.

An excel sheet was prepared containing details like topic, author, source web-link, year of publication, hyperlink to the full paper etc.

Level-3: Studying downloaded articles.

More than 64 research papers were reviewed to find out the gaps in research in exploring the reasons for non-proliferation of digitalization in the power sector to the extent expected in six focus areas shown at Figure **3**
SORTIE-the Six Focus Areas of Study.

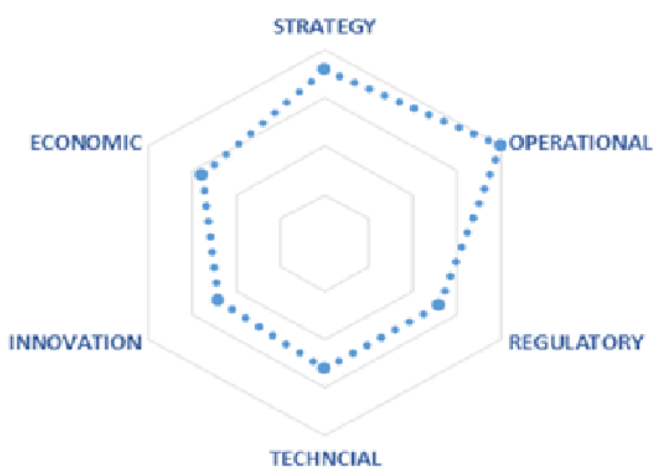

Figure 3
SORTIE-the Six Focus Areas of Study

The study outlines six critical spheres collectively referred to as SORTIE, encompass Strategy, Operational Excellence, Regulatory Compliance, Technological Advancements, Innovation, and Economic Considerations. These six areas evolved from focused discussions with subject matter experts, preliminary literature review, industry white papers etc.

2.2 Rationale for SORTIE bucket selection

During the preliminary literaure survey and discussions with industry experts it is observed that most authors and industry experts have highlighted challenges, but they often failed to categorize them into distinct buckets. However, through preliminary literature surveys and discussions, it becomes apparent that some challenges, such as those related to strategy, technology, and cost benefits, received more attention than others.

While it is realised that regulatory frameworks, innovation, and operational excellence too are essential for effectiveness of digital transformation efforts. Therefore, the rationale for selecting these six buckets lies in their fundamental importance and interdependence in driving successful digitalization initiatives:

1. Strategy:

Motive: Strategy sets the direction and vision for digital transformation initiatives. It provides a roadmap for aligning digitalization efforts with overall business objectives.

Rationale for Inclusion: Without a clear strategy, digitalization efforts may lack focus and coherence, leading to inefficiencies and wasted resources.

2. Operational Excellence:

Motive: Operational excellence ensures that digitalization efforts translate into tangible improvements in efficiency, reliability, and performance across power sector operations.

Rationale for Inclusion: Achieving operational excellence through digitalization is a primary goal, as it directly impacts the reliability and cost-effectiveness of delivering electricity to consumers.

3. Regulatory:

Motive: Regulatory frameworks shape the environment in which digitalization initiatives operate. Clear and supportive regulations can facilitate innovation and investment in the digital projects of power sector.

Rationale for Inclusion: Regulatory compliance and alignment are essential for the successful implementation of digital solutions, as regulations often dictate standards, data privacy requirements, and market structures.

4. Technology:

Motive: Technology forms the backbone of digitalization efforts, encompassing the hardware, software, and infrastructure necessary for implementing digital solutions in the power sector.

Rationale for Inclusion: Technological advancements drive innovation and enable new capabilities, but they also pose challenges such as interoperability issues, cybersecurity risks, and legacy system integration.

5. Innovation:

Motive: Innovation drives continuous improvement and adaptation to changing market dynamics. Embracing innovation in digitalization allows the power sector to stay competitive and responsive to evolving customer needs.

Rationale for Inclusion: Innovation is essential for driving transformational change and unlocking new cost effetive and agile opportunities in the power sector.

6. Economic Considerations:

Motive: Economic considerations are crucial for assessing the viability and return on investment of digitalization initiatives in the power sector.

Rationale for Inclusion: Economic factors such as cost-effectiveness, ROI, and financial sustainability are key drivers and constraints of digitalization efforts. Understanding and addressing these considerations are essential for ensuring the success and long-term viability of digital transformation initiatives in the power sector.

By addressing challenges and barriers across these six key areas, organizations in the power sector can develop comprehensive strategies that consider the multifaceted nature of digital transformation.

2.3 Understanding Strategy in Organizational Context

Understanding strategy in the organizational context is fundamental for achieving long-term goals and sustaining competitive advantage. Strategy encompasses the overarching plans and actions formulated by an organization to achieve its objectives and fulfill its mission. In this context, strategic management literature emphasizes the importance of aligning organizational resources and capabilities with external opportunities and threats, thereby enhancing the organization's ability to respond effectively to changing market dynamics. Scholars such as Michael Porter have contributed significantly to the field by introducing concepts like competitive advantage and the five forces frameworks, which help organizations analyses their industry environment and develop strategies to outperform rivals.

Though the literature is very euphoric on revenue increase from digitalization (Rachinger M et al, 2018), it is seldom acknowledged by the clients (Sarah Cheah et al, 2017)and increasingly difficult for the vendor to demonstrate the same.

Organizations face several challenges, and it is not a cake walk to undertake digital transformation (Caroline Jennings Saul et al, 2017) . The fact that digitalization has to pick up speed in the energy sector is illustrated by the fact that the energy sector is placed at 47 based on a survey in the overall digitalization in Germany indexed between 0 and 100 (Paul Wiegel, 2019)

Although there exist opportunities for applications of digital technology numerous organizational and business challenges associated with digitalization do coexist (Vinit Parida et al, 2018). There exist five common challenges faced in the process of digitalization (Michael Porter et al, 2015).

- Features with no benefits to customers. Reluctance to pay for that.
- Not addressing the customers' security and privacy concerns.
- Ignoring or not heeding to the superior functionalities of competitors
- Lacking sense of urgency and delaying the POC
- Inflated internal capabilities to undertake the digital transformation.

Managers face several dilemmas in the process of digitalization (Ciara Heavin & Daniel J. Power , 2018) .

- Priorities (competing and conflicting)
- Aggregate data or personalize (centralization vs. decentralization)
- Providing more resources to IT staff vs. more self-service analytics
- Storing all data vs. selecting data to store that serves a specific purpose.
- Work performed by people vs. computing machines.
- Security vs. accessibility
- Privacy of individuals vs. understanding of an individual

The digitalization business models need revised operational processes and activities, roles, and responsibilities to make the transformation process seamless. Value creation (bottom line) could be realized either through cost reduction or revenue enhancement (top line) (Vinit Parida et al, 2018).

Business model alignment is a necessity to plug in value leakages (Ritter et al, 2018) (Ritter T et al, 2018) where digitalization breaks the siloes and aligns the interested parties. Budgets on the client side and costs on vendor side are the first impediment for digitalization. A business model is a story about how an organization creates, delivers, and captures value (Saul Kaplan, 2012). Value creation, value capture and value delivery are the three imperative appendages of digitalization business model (Foss NJ, 2017). In profiteering from business model innovation, digitalization is only a journey and not a destination (Vinit Parida et al, 2018)

The digital technologies enable the circular economy in business models through a framework (Bressanelli et al, 2018) the circular business model aims at zero waste, reducing environmental impacts, and enhancing economic profit albeit some reported failures. Five factors that drive digital transformation effectively are (Sagayarajan, 2019).

- Leadership and culture,
- Employee involvement,
- Value chain, partners, and trends,
- Emerging technologies,
- BI and data science.

An appropriate risk management system is essential to mitigate the risks (Ehret M, 2017) emerging from uncertainty, complexity, biases, bottlenecks, gaps in understanding, anomalies and inconsistent eco system (Dellermann D et al, 2017).

Furthermore, strategy in the organizational context extends beyond mere planning to encompass the execution and continuous adaptation of plans in response to internal and external changes.

Effective strategy implementation requires strong leadership, clear communication, and the alignment of individual and departmental goals with the overarching strategic objectives of the organization. Additionally, contemporary approaches to strategy such as the resource-based view emphasize the significance of leveraging internal resources and capabilities to gain a sustainable competitive advantage.
Table 2
Perspective on Key Challenges -Strategy summarizes the key points.

Table 2
Perspective on Key Challenges -Strategy

Theme	Key Points	References
Importance of Strategy in Organizations	- Strategy is crucial for achieving long-term goals and sustaining competitive advantage. - Involves aligning resources and capabilities	Porter, M. et al (2015)

	with external opportunities and threats. - Concepts like competitive advantage	
Challenges in Digital Transformation	- Challenges include revenue increase euphoria versus actual client acknowledgment, difficulty in demonstrating benefits, and challenges in digitalization particularly in the energy sector. - Five common challenges: 1. Features without customer benefits 2. Security and privacy concerns 3. Competitor functionalities 4. Lack of urgency in Proof of Concept (POC) 5. Inflated internal capabilities.	Rachinger, M. et al (2018); Cheah, S. et al (2017); Jennings Saul, C. et al (2017); Wiegel, P. (2019); Parida, V. et al (2018); Heavin, C. & Power, D. J. (2018)
Managerial Dilemmas in Digitalization	- Managers face dilemmas in priorities, data aggregation, resource allocation, data storage, human vs. machine work, security vs. accessibility, and privacy vs. understanding.	Heavin, C. & Power, D. J. (2018)
Digital Business Models	- Digitalization requires revised operational processes, roles, and responsibilities for seamless transformation. - Value creation can be through cost reduction or revenue enhancement. - Business model alignment is crucial for plugging value leakages. - Business model is about creating, delivering, and capturing value. - Value creation, capture, and delivery are essential components. - Digitalization is a journey, not a destination. -	Parida, V. et al (2018); Ritter, T. et al (2018); Kaplan, S. (2012); Foss, N. J. (2017); Bressanelli, et al (2018)

	Circular business models aim at zero waste and environmental impact reduction.	
Drivers of Digital Transformation	- Effective digital transformation driven by leadership, employee involvement, value chain, emerging technologies, business intelligence, and data science.	Sagayarajan (2019)
Risk Management in Digitalization	- Effective risk management essential to mitigate uncertainties, complexities, biases, and other challenges arising from digitalization.	Ehret, M. (2017); Dellermann, D. et al (2017)

Overall, understanding strategy in the organizational context involves not only formulating strategic plans but also effectively executing and adapting them to achieve organizational success in dynamic and uncertain environments.

2.4 Operational Excellence: The Pursuit of Efficiency and Effectiveness

In the realm of power plant operations, the pursuit of efficiency and effectiveness is paramount to ensure optimal performance and resource utilization while meeting energy demands sustainably. Efficiency in a power plant context refers to the ability to generate electricity with minimal input of resources, such as fuel and water, thereby maximizing the output relative to the input. This pursuit often involves the implementation of advanced technologies, such as combined-cycle systems and cogeneration, which enable the extraction of more energy from the same amount of fuel. Additionally, optimizing the operational processes within the plant, such as turbine performance and heat recovery systems, plays a crucial role in enhancing efficiency and reducing environmental impacts, such as greenhouse gas emissions and water usage.

Digitalization has an impeccable and innocuous role to play in the power generation sector. It facilitates seamless integration of decision siloes, brings in more transparency in the operations, enhances collaboration among various stake holders, reduces O&M costs, increases employee development and engagement, eliminates resource losses, incentivizes lean management, optimizes spares requirement, optimizes maintenance activities and makes them more cost effective, assures sustainability, enhances employee development an engagement, enhances performance of people, plant and processes yielding more profits yet conserving the planet earth.

Digitalization helped many power plants in the effective functioning of integrated inventory management system, generation management, human resources information system, fuel management system, financial accounting system, E-procurement, facility management, stores and inbound/out bound logistics, ash management, water management, lube oil management, asset management and so on and so forth.

The role of actors (e.g. managers and technology) in endorsing alteration processes and choosing appropriate digital tools, while skillfully balancing the consideration and utilization of resources cannot be ignored (Hess T et al, 2016). A different set of challenges include in digital transformation are inability to monitor the production process, insufficient technology to work people from home, unrelated production with other sectors, unwillingness of employees for education and training, insufficient funds for digitization of the process, unable to contact existing users, unusable data for business analytics, resource duplication due to physical administration (Nikola Mićunović1 et al, 2021).FAST (frequently discussed, ambitious, specific and transparent) goals are preferred to SMART (specific, measurable, achievable, realistic and time bound) ones (Donald Sull et al, 2018). The same holds good for digital transformation goals. The digital pessimists throw their weight on showing digitalization as more entertainment-focused and a failure in economic performance. There have been very long lags from invention to widespread impact due to dearth of practical problem-solving, communication, collaboration, and adaptability worker skills in digitalization process in the past (BCAR, 2017).

On the skills front it emphasized that technical skills and analytical skills followed by business skills are paramount for the success of digitalization. On leadership traits, it says that experimentation mind-set, risk taking attitude are dominant ones followed by willing ness to speak out (challenge), desire to excel, emotional intelligence and resilience which can drive the digitalization to the desired level. Employee competence and organizational capacity pose significant challenges to digitalization (Rachinger M et al, 2018). The effective use of IT is strongly correlated to internal employee digital capabilities.

"Many organizations are still using manual process like spread sheets, email, and in-person meetings to govern structural changes across enterprise systems" (FEICanada, 2017). Oracle data management article mentions that manual entries and interventions in data updating may creep in errors due to lack consistency of data among enterprise's transactional systems, data warehouses, BA & BI, and ERP, APM solutions. PowerGen Plus article on "Why we yet must see the full value of digital power plant operations' clearly brings out 5 key factors that are limiting the digital deployment viz., emphasis on bringing perfection, focus on technology in place of value, ignoring user experience, lack of focus on change management, dearth of leadership commitment".

Effectiveness in power plant operations revolves around achieving the desired outcomes in terms of reliability, safety, and environmental stewardship. This encompasses the implementation of robust maintenance practices, stringent safety protocols, and adherence to regulatory standards to ensure the uninterrupted generation of electricity while minimizing risks to personnel and the surrounding environment.

Moreover, the effective management of waste streams and emissions through the utilization of pollution control technologies, such as scrubbers and selective catalytic reduction systems, is essential for mitigating environmental impacts and ensuring compliance with environmental regulations. Table 3
Perspective on Key Challenges –Operational Excellence summarizes the key points.

Table 3
Perspective on Key Challenges –Operational Excellence

Theme	Key Points	References
Efficiency in Power Plant Operations	- Efficiency entails maximizing electricity output while minimizing resource input, achieved through advanced technologies like combined-cycle systems and cogeneration. - Optimizing operational processes such as turbine performance and heat recovery systems is crucial for reducing environmental impacts.	
Digitalization in Power Generation Sector	- Digitalization facilitates integration of decision siloes, enhances transparency and collaboration, reduces costs, optimizes maintenance and inventory management, and ensures sustainability. - Implemented systems include inventory, generation and fuel management, financial	

	accounting, and facility management, among others.	
Challenges in Digital Transformation	- Challenges include insufficient monitoring technology, resistance to remote work, disconnected production from other sectors, employee reluctance for education and training, funding limitations, data usability issues, and resource duplication. - FAST (frequently discussed, ambitious, specific, transparent) goals are favored over SMART goals.	Hess, T. et al (2016); Mićunović, N. et al (2021); Sull, D. et al (2018); BCAR (2017)
Skills and Leadership Traits in Digitalization	- Technical and analytical skills, followed by business skills, are crucial for digitalization success. - Leadership traits such as experimentation mindset, risk-taking attitude, speaking out, desire to excel, emotional intelligence, and resilience drive digitalization. - Employee competence and organizational capacity are significant challenges.	Rachinger, M. et al (2018)
Manual Processes in Structural Changes	- Many organizations still rely on manual processes like spreadsheets and email for governing structural changes. - Manual data entries and interventions may lead to errors and lack consistency across enterprise systems.	FEICanada (2017); Oracle
Limiting Factors in Digital Deployment	- Limiting factors include a focus on perfection over value, technology-centric approach, neglect of user experience, insufficient focus on change	PowerGen Plus

	management, and lack of leadership commitment.	
Effectiveness in Power Plant Operations	- Effectiveness involves achieving desired outcomes in reliability, safety, and environmental stewardship. - Robust maintenance practices and adherence to safety protocols and regulations are essential. - Pollution control technologies aid in managing waste streams and emissions for environmental compliance.	

By prioritizing both efficiency and effectiveness, power plants can enhance their operational performance, reduce operational costs, and contribute to a more sustainable energy future. Digitalization has an impeccable contribution in enhancing the operational excellence.

2.5 Regulatory Framework-Navigating Legal and Ethical Boundaries

Navigating regulatory frameworks within the context of power plants is critical to ensure adherence to legal requirements and ethical standards while maintaining operational integrity. Power plants operate within a complex web of regulations set forth by government agencies at local, national, and international levels. These regulations cover various aspects, including environmental protection, safety standards, emissions control, and land use, among others. Compliance with these regulations is not only essential for avoiding legal repercussions but also for upholding ethical responsibilities towards the environment, neighboring communities, and future generations. Therefore, power plant operators must stay abreast of regulatory developments, conduct regular audits, and implement robust compliance management systems to navigate the intricate legal and ethical landscape effectively.

Corrigible barriers to the advancement of digitalization are regulation, data standardization and sharing, lack of sense of urgency, failure to do POC quickly, legacy systems, cyber security, and lack of talent (Greg Bean et al, 2020) . The extensive implementation of digital technologies in the energy sector is linked with a few technical challenges (deficiency of data governance and interoperability, limited availability of data, risk of cyber-attacks), regulatory and policy challenges (Dr. Lorna Christie, 2021). The adoption of analytics to improve businesses presents some challenges. "The biggest challenge has nothing to do with data science or mathematics or data storage, it has to do with legal and governance framework." The technology's adoption needs investments and efforts at all levels of the organization, legal system, and government. They also mentioned that 'nontechnical challenges also include collaboration between departments to deploy and operate the BD system effectively."

Report purposed for a joint G20 conference Berlin, Germany 2017 stated that "Advanced governance frameworks – building upon both existing public- and private-sector-led processes and new multi-stakeholder initiatives for the benefit of all – are necessary to effectively address the complexity of today's interlinked issues in successful Industry 4.0 development and deployment" (Christian Leyh et al, 2017). Same report further mentions that "…digitalization raises important policy challenges including privacy, security, consumer policy, competition, innovation, jobs, and skills, among others"

Moreover, ethical considerations play a crucial role in guiding decision-making processes within power plants. Beyond mere compliance with regulations, ethical behavior entails a commitment to transparency, accountability, and social responsibility.

Power plant operators must engage in stakeholder dialogue, including local communities, environmental groups, and regulatory authorities, to address concerns and mitigate potential conflicts. Ethical behavior also encompasses the promotion of fairness and equity in employment practices, as well as the prioritization of public health and safety.

Table 4

Perspective on Key Challenges –Regulatory summarizes the key points.

Table 4
Perspective on Key Challenges –Regulatory

Theme	Key Points	References
Regulatory Frameworks in Power Plants	- Power plants operate within a complex regulatory environment covering areas like environmental protection, safety standards, emissions control, and land use. - Compliance is essential to avoid legal repercussions and uphold ethical responsibilities towards the environment and communities. - Operators must stay updated on regulatory developments and implement robust compliance management systems.	Pothala KR 2024
Barriers to Digitalization in Power Plants	- Corrigible barriers to digitalization include regulation, data standardization and sharing, lack of sense of urgency, slow POC, legacy systems, cyber security, and talent shortage. - Technical challenges include data governance, interoperability, data availability, and cyber security risks. - Legal and	Bean, G. et al (2020); Christie, L. (2021)

	governance frameworks pose significant challenges to technology adoption. - Collaboration between departments is crucial for effective BD system deployment.	
Governance Frameworks for Industry 4.0	- Advanced governance frameworks, incorporating public- and private-sector initiatives, are necessary for successful Industry 4.0 development. - Policy challenges related to digitalization include privacy, security, consumer policy, competition, innovation, jobs, and skills.	Leyh, C. et al (2017)
Ethical Considerations in Power Plants	- Ethical behavior in power plants involves transparency, accountability, and social responsibility beyond regulatory compliance. - Stakeholder engagement is crucial for addressing concerns and conflicts. - Fairness, equity in employment, and prioritization of public health and safety are essential ethical considerations. - Effective navigation of legal and ethical boundaries fosters trust and goodwill within communities and contributes to sustainable development goals.	Pothala KR

By navigating legal and ethical boundaries effectively, power plants can foster trust and goodwill within their communities, mitigate reputational risks, and contribute positively to sustainable development goals.

2.6 Technological Advancements - Impact on Business Operations

Energy is essential for human survival and development. So has become digitalization. This paper intends to find out the reasons why the marriage between power plants and digitalization has not gone a long way. Analyzing the past literature, getting actionable insights, preparing for the future with the actionable framework, and creating a new body of knowledge is the essence of the literature review. Acknowledging and respecting the work done by earlier authors, the tone of the insights written is moderated with due reference to them. Digitalization is akin to electricity, a general-purpose technology, agnostic to sector and is ubiquitous in use (James Manyika et al, 2015). "Electricity changed nearly everything about the way we live and work—and that scale of transformation is possible with the Internet of Things." Ian Goldin, Director of Oxford Martin School, University of Oxford.

Development and spread of any technology provide both wounds (lessons learnt to man oeuvre risks) and wisdom (tactics to steer through opportunities). It is said that one has to choose not to complain about the wounds, instead cherish the wisdom. The same is the story with digitalization in the power sector. The customized features of digitalization resulted in several systems-oriented, customer-centric, technical, financial, and environmental benefits in the energy sector. For example, in the O & G industry, digitalization enhanced reservoir modeling, advanced processing of seismic data, effective use of sensors to name a few. In the mining sector, it made its way into geological modeling, worker safety, and health assurance, effective automation, enhanced process efficiency, and assured reliability via predictive analytics.

Digital technologies were deployed in the power sector at various levels. In power sector digitalization initiatives like access to data, interoperability, assimilation of renewables into the energy network, energy forecast in solar and wind plants, data management, flexibility in procurement, dynamic prices, DSM, network efficiency optimization, reduction in forced and unplanned outages, life extension of assets, and meeting the asset optimization goals via life cycle management with reduced TCO and enhanced LOS etc., (Crespo Marquez, 2020) have been in vogue sporadically.

Technological advancements have revolutionized power plant operations, driving efficiency, reliability, and sustainability across the industry. Innovations such as advanced sensors, predictive analytics, and machine learning algorithms have enabled power plants to monitor equipment performance in real-time, predict potential failures, and schedule maintenance proactively, thus minimizing downtime and optimizing asset utilization. Additionally, the integration of renewable energy sources, such as solar and wind power, into traditional power generation systems has been made possible through advancements in grid integration technologies and energy storage solutions. This diversification of energy sources not only reduces reliance on fossil fuels but also enhances the resilience and flexibility of power plant operations, enabling them to adapt to fluctuating demand and variable weather conditions. There are two high level themes for digital transformation (Swen Nadkarni et al, 2020) that encompass several salient sub-themes.

- Technology: pace of change and time to market, technology capability and integration, consumer and other stakeholders' interface, distributed value creation and capture, marker environment and rules of competition, and
- Actor: transformative leadership, managerial and organizational capabilities, company culture, work environment etc.

Technology impact lags, diffusion tardiness, skills mismatches, and inadequate digital infrastructure are the big-4 impediments to digital transformation (BCAR, 2017) . The safety of data due to its vulnerability to cyber-attacks is one of the major challenges that slow down the implementation of the industry 4.0 (IEA, 1017). Cyber-security and data-privacy are the top challenges to be overcome in carrying out the IoT projects, the heart of Industry 4.0 (Lane Thames et al, 2017). User privacy, standardization, architecture design, and IoT security, etc. are to be carefully designed to alleviate challenges in the IT implementation (Naser et al, 2020).

Cyber security threats include malware (to get unauthorized access to ICT), ransom ware (data hacking to exploit and extract ransom), Phishing/whaling, botnets etc. (IEA, 1017). Cyber security assurance revolves around three concepts viz., resilience, cyber hygiene, and security by design which is to be incorporated in all phases from the concept to commissioning of an IT project.

Each layer of the three layers has challenges in deployment of IoT in power sector (Guneet Bedi et al, 2018). The lack of situational intelligence in the sensors and associated cyber security issues in the sensory layer, the lack of interoperability and presence of compatibility and co-existence issues the connectivity layer, accuracy of predictions, ensuring proper machine learning (both super vised and non-supervised), providing actionable insights to the end user in analytics layer are a few examples of the challenges in IoT deployment. (ITU , 2012)

Industry 4.0-qualified personnel are the need of the hour and companies have to proactively invest in the learning and development of their low qualified and elderly employees make them digitalization friendly (Sjodin et al, 2018). The research gaps in the industry prevailing to the industry 4.0 such as self-configuration, self-optimization, awareness, predictive maintenance, real time response etc. (J Qin et al, 2016).

Both industry and academia are struggling to sort out a clear road map to the industry 4.0 fulfillment (J Qin et al, 2016). Though small progress is seen from then, still there is a long way to go. A power plant continuously generates data with 10 V's- Validity, Velocity, Value, Veracity, Variability, Visualization, Volatility, Volume, and Vulnerability (Firican G. , 2017). Associated challenges involved in data capture, storage, and transmission, curation (reuse, preservation, value addition, retrieval, quality assurance, and discovery) also affect the speed of deployment. Balancing all these 10 V's effectively converging towards IT efficacy enhancement is also another challenge.Absence of technical infrastructure, inadequate cross-departmental collaboration, cyber security problems, insufficient time for the transformation, day-to-day business means that resources do not have the capacities for the transformation project, but there is also a high cost and price pressure in the market, unproductive project and change management, insufficient preparation and training of staff for the digitization are some challenges face during digital transformation (Olawole, 2019)

Technology may be simple, but individuals are not. The greatest technical challenges of digital transformation are more likely to be a particular combination of implementing new technologies, utilizing data science and IOT as the driver for business enhancement (Krotov V, 2017), and the difficulties with legacy systems. Legacy systems that do not communicate with each other and share information, and frequently contain distorted data, could create real barriers (Sagayarajan, 2019).The challenges faced by IOT are akin to the challenges faced by any other business technological transformation and even worse in power sector as it spreads across rural areas too for the last mile connectivity. The digital technology should complement human capabilities and not compete by replacing them in the value-creation process (Sjodin, 2019).

The digital technologies range from AI & ML, AR, VR, automation and digital workflow, block chain & distributed ledgers , cloud computing, coding, cyber security, data visualization, distributed computing, unmanned aerial vehicles, to drones and IoT etc. (Greg Bean et al, 2020).

The IEA, Digitalization & Energy, 2017, report dichotomized deployment of digital technologies and strategies in industry as on premise and beyond premise.

- On-premises deployment has two tiers i.e., industrial equipment (smart sensors, 3D printing, industrial robotics) and analytics enabled workforce (APC, DSS, digital twin, AI).
- Beyond the plant premises or cloud deployment consist of the connectivity layer with remote controlled operations, cloud connected workers, connected industrial equipment, and connected supply value chains (Ferran V et al, 2017).

Table 5

Perspective on Key Challenges –Technology summarizes the key points.

Table 5
Perspective on Key Challenges –Technology

Theme/Topic	**Key Insights**	**Authors/Year**
Overview	- Digitalization is comparable to electricity in its transformative potential. - The Internet of Things (IoT) holds promise for significant societal and industrial change.	Manyika et al. (2015)
Benefits of Digitalization in Energy	- Customized digitalization in energy sector yields various benefits including system improvements,	Crespo Marquez (2020)

Sector	customer-centric services, and environmental advantages. - Specific examples include enhanced reservoir modeling in O & G industry and worker safety in mining.	
Technological Advancements in Power Plants	- Advanced sensors, predictive analytics, and machine learning enhance efficiency and reliability in power plants. - Integration of renewable energy sources diversifies energy generation, enhancing resilience.	Nadkarni et al. (2020)
Challenges to Digital Transformation	- Impediments include technology impact lag, diffusion tardiness, skills mismatches, and inadequate digital infrastructure. - Cyber security threats, data privacy, and infrastructure challenges hinder Industry 4.0 adoption.	BCAR (2017), IEA (2017), Thames et al. (2017)
Deployment Challenges of IoT in Power Sector	- Challenges include situational intelligence and cyber security at the sensory layer, interoperability at the connectivity layer, and accuracy of predictions in the analytics layer.	Bedi et al. (2018), ITU (2012)
Workforce Development for Industry 4.0	- Investment in training is essential for preparing the workforce for digitalization. - Research gaps exist in areas like self-optimization and predictive maintenance.	Sjodin et al. (2018), Qin et al. (2016)
Roadmap to Industry 4.0	- Industry and academia struggle to develop a clear roadmap for Industry 4.0 adoption. - Progress has been made, but significant	Qin et al. (2016)

	challenges remain.	
Data Challenges in Digital Transformation	- Data management presents challenges including capture, storage, transmission, and quality assurance. - Balancing various aspects of data efficacy enhancement is critical.	Firican (2017), Olawole (2019)
Legacy Systems and Integration Challenges	- Legacy systems pose integration challenges due to data incompatibility and distortion. - IoT challenges in power sector are exacerbated by rural connectivity requirements.	Krotov (2017), Sagayarajan (2019)
Human-Centric Approach to Digitalization	- Digital technologies should complement human capabilities rather than replace them.	Sjodin (2019)
Range of Digital Technologies	- Various digital technologies including AI, ML, AR, VR, blockchain, and IoT contribute to digital transformation in the power sector.	Bean et al. (2020)
Deployment Strategies	- Digitalization strategies include on-premises deployment with industrial equipment and analytics-enabled workforce, and beyond premises deployment with cloud-connected operations and supply chains.	IEA (2017), Ferran V et al. (2017)
Automation in Power Plant Operations	- Automation technologies like SCADA and advanced control algorithms enhance operational efficiency and reduce human error. - IoT and cloud platforms enable real-time data analysis and decision-making.	Ferran V et al. (2017)

Overview	- Digitalization is comparable to electricity in its transformative potential. - The Internet of Things (IoT) holds promise for significant societal and industrial change.	Manyika et al. (2015)
Benefits of Digitalization in Energy Sector	- Customized digitalization in energy sector yields various benefits including system improvements, customer-centric services, and environmental advantages. - Specific examples include enhanced reservoir modeling in O & G industry and worker safety in mining.	Crespo Marquez (2020)
Technological Advancements in Power Plants	- Advanced sensors, predictive analytics, and machine learning enhance efficiency and reliability in power plants. - Integration of renewable energy sources diversifies energy generation, enhancing resilience.	Nadkarni et al. (2020)
Challenges to Digital Transformation	- Impediments include technology impact lag, diffusion tardiness, skills mismatches, and inadequate digital infrastructure. - Cyber security threats, data privacy, and infrastructure challenges hinder Industry 4.0 adoption.	BCAR (2017), IEA (2017), Thames et al. (2017)
Deployment Challenges of IoT in Power Sector	- Challenges include situational intelligence and cyber security at the sensory layer, interoperability at the connectivity layer, and accuracy of predictions in the analytics layer.	Bedi et al. (2018), ITU (2012)
Workforce	- Investment in training is essential for preparing	Sjodin et al. (2018), Qin

Development for Industry 4.0	the workforce for digitalization. - Research gaps exist in areas like self-optimization and predictive maintenance.	et al. (2016)
Roadmap to Industry 4.0	- Industry and academia struggle to develop a clear roadmap for Industry 4.0 adoption. - Progress has been made, but significant challenges remain.	Qin et al. (2016)
Data Challenges in Digital Transformation	- Data management presents challenges including capture, storage, transmission, and quality assurance. - Balancing various aspects of data efficacy enhancement is critical.	Firican (2017), Olawole (2019)
Legacy Systems and Integration Challenges	- Legacy systems pose integration challenges due to data incompatibility and distortion. - IoT challenges in power sector are exacerbated by rural connectivity requirements.	Krotov (2017), Sagayarajan (2019)
Human-Centric Approach to Digitalization	- Digital technologies should complement human capabilities rather than replace them.	Sjodin (2019)
Range of Digital Technologies	- Various digital technologies including AI, ML, AR, VR, blockchain, and IoT contribute to digital transformation in the power sector.	Bean et al. (2020)
Deployment Strategies	- Digitalization strategies include on-premises deployment with industrial equipment and analytics-enabled workforce, and beyond premises deployment with cloud-connected	IEA (2017), Ferran V et al. (2017)

	operations and supply chains.	
Automation in Power Plant Operations	- Automation technologies like SCADA and advanced control algorithms enhance operational efficiency and reduce human error. - IoT and cloud platforms enable real-time data analysis and decision-making.	Ferran V et al. (2017)

Furthermore, digitalization and automation have streamlined various aspects of power plant operations, from control room management to maintenance scheduling. Automation technologies, such as SCADA (Supervisory Control and Data Acquisition) systems and advanced control algorithms, enable centralized monitoring and control of plant processes, improving operational efficiency and reducing human error. Moreover, the Internet of Things (IoT) devices and cloud-based platforms facilitate data collection, analysis, and decision-making, empowering plant operators to make informed choices in real-time. Overall, technological advancements continue to reshape the landscape of power plant operations, offering unprecedented opportunities for optimization, innovation, and sustainability in the pursuit of reliable and affordable energy supply.

2.7 innovation-Driving Growth and Adaptation

Innovation serves as a catalyst for driving growth and adaptation in power plants by fostering the development of new technologies, processes, and business models that enhance efficiency, reliability, and sustainability. One significant way innovation contributes to the power sector is through the advancement of renewable energy technologies, such as solar, wind, and hydroelectric power. These innovative solutions offer cleaner alternatives to traditional fossil fuel-based generation, thereby reducing greenhouse gas emissions and mitigating environmental impacts. Additionally, innovation in energy storage technologies enables better integration of intermittent renewable energy sources into the grid, enhancing grid stability and reliability.

Digitalization enables the creation of value through ecosystem orchestration with consistency, complementing sub-system functionalities, enhancing collaboration, and enriching coordination among the interested parties. Studies demonstrate that an innovative approach to digitalization would open newer opportunities for improvement with digital value being the prime mover (Luz, 2018)

Furthermore, innovation plays a crucial role in improving the efficiency and performance of existing power generation technologies. Through research and development initiatives, power plant operators can enhance the efficiency of thermal power plants, optimize combustion processes, and reduce emissions of pollutants such as sulphur dioxide and nitrogen oxides. Moreover, innovations in smart grid technologies enable more efficient energy transmission and distribution, reducing losses and improving overall system reliability. Additionally, advancements in digitalization, data analytics, and artificial intelligence enable predictive maintenance, asset optimization, and demand forecasting, further enhancing operational efficiency and reducing costs.

Table 6

Perspective on Key Challenges –Innovation summarizes the key points.

Table 6
Perspective on Key Challenges –Innovation

Theme/Topic	**Key Insights**	**Authors/Year**
Role of Innovation in Power Plants	- Innovation serves as a catalyst for growth and adaptation in power plants by fostering the development of new technologies, processes, and business models.	Luz (2018)
Impact of Innovation on Renewable Energy	- Innovation in renewable energy technologies, such as solar, wind, and hydroelectric power, offers cleaner alternatives to fossil fuels, reducing greenhouse gas emissions and environmental impacts.	IEA (2017)
Innovation in Energy Storage Technologies	- Energy storage innovations enable better integration of intermittent renewable energy sources into the grid, enhancing stability and reliability.	IEA (2017)
Digitalization and Value Creation	- Digitalization facilitates ecosystem orchestration, complementing subsystem functionalities, and enhancing collaboration among stakeholders.	Luz (2018)
Improving Efficiency of Power Generation	- Innovation enhances efficiency of thermal power plants, optimizes combustion processes, and	IEA (2017)

	reduces emissions of pollutants like sculpture dioxide and nitrogen oxides.	
Advancements in Smart Grid Technologies	- Smart grid innovations improve energy transmission and distribution efficiency, reducing losses and enhancing system reliability.	-SMART grid
Benefits of Digitalization and Data Analytics	- Digitalization, data analytics, and AI enable predictive maintenance, asset optimization, and demand forecasting, enhancing operational efficiency and reducing costs.	-Pothala KR (2024)

Overall, innovation drives growth and adaptation in power plants by continuously improving technology and processes, ultimately contributing to a more sustainable and resilient energy infrastructure.

2.8 Economic Considerations In Strategic Decision Making

Economic considerations play a pivotal role in strategic decision-making within power plants, influencing various aspects of operations, investment decisions, and long-term planning. One significant economic factor is the cost of energy production, which encompasses not only the initial capital investment required to build and operate power plants but also on-going operational expenses such as fuel, maintenance, and labour costs. Power plant operators must carefully evaluate these costs to ensure competitiveness in the energy market while maintaining profitability.

A power plant could save in costs as high as 28% in fuel, 20% in maintenance, and 19.5% in operations using digital technologies (Livia Wiley, 2020). Digitalization enhanced the efficacy of smart demand response, integration of renewables and conventional power sources, flexibilization of thermal power plants, smart charging of electric vehicles, DER, smart grid, mini-grids, and "prosumers" (IEA, 1017). Advanced process controller (APC) using evolutionary methods like PSO, BFPSO, GA, BFO, and QFT based robust controller etc., could yield still superior results (Yu, 2010). It is reported that an O&M cost reduction of up to 5%, plant efficiency enhancement of up to 2% and output enhancement of up to 5% is possible using digital technologies in the power sector (IEA, 1017). Customer expectations, regulations, and investments are the three challenges faced in IoT deployment (Ramamurthy et al, 2017).

Lack of effective strategy, absence of strategic alignment, silos with no integration, technological disruption, inapt strategy for people role, unclear responsibilities, non-conducive org. structure, pitfalls in cross functional collaboration, missing top management engagement, improper knowledge management strategies, absence of change management culture, project team capabilities, IT infrastructure are notable challenges in digitalization transformation (Faisal M et al, 2019)

A misaligned financial incentive especially in regulated markets where the investments in digital technologies cannot be capitalized could act as a deterrent in the pace of digitalization. A holistic assessment and evaluation of digital applications (Weigel et al, 2019) in the energy sector helps in prioritizing and budget allocations. A combination of multi-criteria analysis (MCA), life cycle assessment (LCA), and semi-structured expert interviews be used for the same.

The organizational needs to foster quicker digitalization are identified as improvement in strategy and innovation, talent development, digital capabilities, agility, and financial commitments (Gerald et al, 2017). The same survey also articulated that the most important aspects that contributed to success/failure of digitalization are strategy and vision, culture, budget, digital knowledge, implementation effectiveness, communication and change management, talent, technology etc., in descending order of significance.

The pace of technology diffusion has been attributed to location and finance effects (Bureau of Communications and Arts Research, BCAR-Australia (2017). The product development and IT infrastructure constitute a lion's share of the digitalization efforts (Dijkman et al, 2015).Energy consumption patterns in the three segments of ICT: Datacentres (hyperscale, cloud and traditional), Data transmission networks and Connected devices, also have some influence on digitalization agility and economics.

Data centres need circa 1% of global power demand depending on data centre's power usage effectiveness. For instance, the best hyper scale data centre has PUE values of around 1.1 (i.e., 0.1 kilowatt hours used for cooling/power provision for every 1 kWh used for IT equipment). Data transmission networks need circa 1% of global energy demand and two thirds of which is for mobile data networks. The latest mobile technologies have better energy efficiency. For example, 4G is 50 times more efficient than 2G, 4G consumes around 0.5 kWh per GB against 25 kWh per GB by 2G technology (IEA, 1017). Digital connected devices consume circa 30-50% of energy in usage –operations phase and 70% to 50% in their production phase.

Policies must aim to promote device manufacturing with more efficient and sustainable practices, like eco-labels. Ergo the digitalization plan has to shake hands with energy consumption for digitalization, e-waste disposal and sustainability and security before execution. Green IoT minimizes the challenges like high energy consumption by the connected billions of devices and their associated electronic waste generation

(Rushan et al, 2017) Deployment of energy-efficient routing techniques result in energy optimization (Rachid et al, 2021).

Most IoT systems depend on centralized cloud systems and any fault here could jeopardize its functioning (Bedi et al, 2018). Block chain (distributed ledger technology) can be of help here (Dorri et al, 2017), (Francesco et al, 2018). Wi-Fi, (Wireless Fidelity) technology is not the best solution in the energy sector due to its high-power consumption (Kabalci et al, 2019) Low power WAN communication technologies to be used in the energy sector. Process automation and SCADA became the order of the day in 1990s (Ramamurthy et al, 2017). Data non-availability and opaqueness on the pretext of commercial confidentiality is another hurdle to overcome. This could be alleviated, to some extent, by regulatory assurance to protect confidentiality.

The digitalization capabilities in intelligence, connectivity, and analytics add value in value creation in digitalization efforts (Lenka et al, 2017). Huge investments in the coming couple of years in cloud computing (82%), Advanced analytics (75%), IoT (74%), Mobile Apps and Devices (65%), Robots (32%) (Joe Bert et al, 2020).Based on the 'future jobs survey 2018', by the World economic forum, companies are slated to adopt big data analytics by 85%, IoT by 75%, ML by 75%, AR/ VR by 58%, block chain by 45%, 3D printing by 41% humanoid robots by 23% areal an underwater robots by19% by the year 2022 (Greg Bean et al, 2020).

Additional deliberation on the digitalization program is required, to get insights on how digital initiatives are changing existing business models (Joao Reis et al, 2020) . Digital agility forges operational risk resilience (Livia Wiley, 2020). To overcome the unnerving challenges in digital transformation, an unwavering commitment and organizational capability are essential. Digitalization can be taken up incremental way or radical way availing the economic benefits (Vinit Parida et al, 2018) as per the suitability to the prevailing organizational context.

Moreover, economic considerations extend beyond operational expenses to include market dynamics, regulatory requirements, and financial risks. Power plants operate within a dynamic market environment influenced by factors such as energy demand, fuel prices, and competition from alternative energy sources. Strategic decisions regarding capacity expansion, fuel procurement, and pricing strategies must take into account market trends and projections to mitigate risks and maximize returns on investment. Additionally, regulatory compliance entails costs associated with meeting environmental standards, obtaining permits, and implementing pollution control technologies. Table 7

Perspective on Key Challenges –Economic Considerations summarizes the key points.

Table 7
Perspective on Key Challenges –Economic Considerations

Economic Considerations in Power Plants	- Economic factors heavily influence strategic decision-making in power plants, impacting operations, investment decisions, and long-term planning. - Key considerations include the cost of energy production, market dynamics, regulatory compliance, and financial risks.	- Pothala KR (2024)
Cost Reduction with Digital Technologies	- Digital technologies offer significant cost savings in fuel, maintenance, and operations for power plants. - Advanced process controllers and digital optimization methods further	Wiley (2020), IEA (2017), Yu (2010)

	enhance cost-effectiveness.	
Challenges in Digitalization Transformation	- Challenges include lack of effective strategy, organizational alignment, technological disruptions, and inadequate change management culture. - Deployment challenges in IoT stem from customer expectations, regulations, and investments.	Faisal M et al. (2019), Ramamurthy et al. (2017)
Financial Incentives and Budget Allocation	- Misaligned financial incentives, especially in regulated markets, hinder the pace of digitalization. - Holistic assessment and evaluation of digital applications aid in prioritizing and budget allocations.	Weigel et al. (2019)
Organizational Needs for Digitalization	- Organizational requirements for successful digitalization include strategy improvement, talent development, agility, and financial commitments. - Success/failure factors include strategy, culture, budget, digital knowledge, and talent.	Gerald et al. (2017)
Energy Consumption in Digitalization	- Energy consumption patterns in ICT segments affect digitalization economics. - Efforts to minimize energy consumption include promoting energy-efficient device manufacturing and implementing green IoT solutions.	Bureau of Communications and Arts Research (BCAR) - Australia (2017)
Technology Solutions and	- Technologies like blockchain, low-power WAN	Dorri et al. (2017),

Challenges	communication, and process automation address challenges in digitalization. - Data availability and transparency are hurdles that regulatory assurance can alleviate.	Kabalci et al. (2019), Bedi et al. (2018)
Value Creation and Investment Trends	- Digitalization capabilities in intelligence, connectivity, and analytics contribute to value creation. - Investments in cloud computing, analytics, IoT, and robotics are increasing.	Lenka et al. (2017), Bert et al. (2020)

By integrating economic considerations into strategic decision-making processes, power plant operators can effectively manage financial risks, optimize resource allocation, and capitalize on opportunities for growth and diversification in the energy sector.

2.9 Integrating SORTIE Framework: A Synthesis of Key Findings

Integrating the SORTIE framework involves synthesizing key findings across the six critical areas of strategy, operational excellence, regulatory compliance, technology, innovation, and economic considerations. Through this integration, organizations gain a comprehensive understanding of the interdependencies and synergies among these dimensions, allowing for more informed decision-making and strategic planning. By examining how each element of the SORTIE framework interacts with and influences the others, organizations can identify opportunities for optimization and improvement across their operations.

One of the primary benefits of integrating the SORTIE framework is its ability to provide a holistic perspective on organizational performance and resilience. By considering multiple dimensions simultaneously, organizations can uncover potential trade-offs and synergies that may not be apparent when examining each area in isolation. For example, strategic decisions related to technology investments may have implications for both operational efficiency and regulatory compliance, highlighting the importance of taking a cross-functional approach to decision-making.

Furthermore, by aligning strategies and initiatives with the overarching goals and values encapsulated within the SORTIE framework, organizations can foster a culture of innovation, sustainability, and continuous improvement, positioning them for long-term success in a rapidly evolving business landscape.

2.10 Critical Analysis of Existing Research in SORTIE Dimensions.

The existing research in SORTIE dimensions reflects a comprehensive understanding of the multifaceted challenges and opportunities present in the power generation sector. Digitalization emerges as a significant theme, with studies highlighting its potential to revolutionize various aspects of power plant operations. Digital technologies, ranging from advanced process controllers to IoT platforms (Hossain M et al, 2020), offer promises of efficiency gains, cost savings, and enhanced decision-making capabilities. However, while the benefits of digitalization are well-documented, several challenges hinder its widespread adoption, particularly in regions like India.

One notable challenge is the gap between the potential of digital technologies and their actual implementation. Despite the reported benefits, many power plants struggle to fully integrate digital solutions into their operations due to factors such as inadequate reskilling of internal resources, reliance on outdated IT infrastructure, and resistance to change. Additionally, issues like data quality, standardization, and cyber security pose significant barriers to the effective deployment of digital technologies. These challenges underscore the need for a more holistic approach to digital transformation, one that addresses not only technological considerations but also organizational and cultural factors.

Moreover, the literature emphasizes the importance of aligning digitalization efforts with broader strategic objectives and regulatory frameworks. While digital technologies hold immense promise for improving operational efficiency and sustainability, their successful implementation requires careful consideration of regulatory compliance, economic viability, and ethical implications.

Furthermore, the power sector's transition towards a more digitalized and interconnected future necessitates collaboration among stakeholders, including policymakers, industry players, and technology providers. Overall, the critical analysis of existing research in SORTIE dimensions highlights the complex interplay between technological innovation, regulatory constraints, and organizational dynamics shaping the future of power generation.

2.11 Emerging Trends and Future Directions in SORTIE Research.

Emerging trends and future directions in SORTIE research are poised to further revolutionize the power generation sector, offering unprecedented opportunities for innovation and optimization. One notable trend is the increasing integration of artificial intelligence (AI) and machine learning (ML) algorithms into power plant operations. These technologies enable predictive maintenance, real-time monitoring, and autonomous decision-making, leading to enhanced asset performance, reduced downtime, and improved overall efficiency. Additionally, AI-driven analytics facilitate advanced forecasting and optimization strategies, enabling power plants to adapt to dynamic demand patterns, integrate renewable energy sources, and optimize resource allocation more effectively.

Furthermore, the proliferation of Internet of Things (IoT) devices and sensors is expected to drive significant advancements in SORTIE research.

The interconnectedness of devices and systems within power plants enables comprehensive data collection, enabling a deeper understanding of operational processes and performance metrics. This data-driven approach empowers operators to identify inefficiencies, diagnose issues in real-time, and implement proactive maintenance strategies, ultimately leading to cost savings and improved reliability.

Additionally, the integration of IoT technologies with emerging concepts such as digital twins and smart grids (Yasin Kabalci et al, 2019) promises to further enhance operational visibility, resilience, and sustainability in the power generation sector. As research in SORTIE dimensions continues to evolve, these emerging trends are likely to shape the future landscape of power plant operations, driving continuous innovation and optimization efforts.

2.12 Results of the Literature Review

The literature review was carried out on 64 resources like reports published from academia, companies, institutes, press releases, white papers, asset management sites, research papers etc. At first, relevant articles and papers were searched using key words, then they were shortlisted using filtering criteria and finally a deep dive was made into the shortlisted articles to collate reasons. The topic wise number of articles/papers studied is provided at Table **8**

SORTIE Bucket wise Papers Reviewed.

Table 8

SORTIE Bucket wise Papers Reviewed

S	O	R	T	I	E
16	12	5	17	5	9

The number of reasons collated bucket wise are given at Table **9**
SORTIE Bucket wise Reasons Collated.

Table 9

SORTIE Bucket wise Reasons Collated

S	O	R	T	I	E
18	20	13	13	12	14

2.12 Summary of the Literature Review

It is evident from the literature review that there are numerous reasons for the non-proliferation of digitalization in the power sector to a greater extent. But a material comprehensive list with a goal to astound them and make the digitalization deployment quicker in power sector has remained a glaring gap. Upon carrying out structured interviews, collations from the literature review and discussions with SMEs a mutually exclusive and collectively exhaustive list of reasons is developed that cause the percolation of digitalization slow in the power sector and act as input to phase two and three of research leading to development of a framework to facilitate smooth and agile deployment of digitalization in the power sector.

A list of few collated reasons that act as challenge / barrier/ bottleneck for digitalization, technology adoption, and deployment in power sector include, but not limited to

- Regulation: Barriers due to regulatory constraints impacting digitalization efforts.
- Data Standardization and Sharing: Difficulty in standardizing data formats and sharing protocols across different systems and organizations.
- Lack of Sense of Urgency: Absence of a pressing need or motivation to prioritize digital transformation.
- Slow Proof of Concept (POC): Delays in the validation phase of new digital solutions or technologies.
- Legacy Systems: Outdated technology infrastructure that hampers integration and modernization efforts.
- Cyber-security: Risks associated with protecting digital assets and sensitive information from cyber threats.
- Talent Shortage: Insufficient skilled workforce available to drive digital initiatives.
- Data Governance: Challenges in defining and implementing policies for data management and usage.

- Interoperability: Issues related to integrating and ensuring seamless communication between different systems and platforms.
- Data Availability: Limited access to required data for analysis and decision-making processes.
- Legal and Governance Frameworks: Legal complexities and governance structures hindering technology adoption.
- Departmental Collaboration: Inadequate cooperation and communication between various departments essential for effective deployment of business development systems.
- Insufficient Monitoring Technology: Lack of adequate tools for monitoring and evaluating digitalization efforts.
- Resistance to Remote Work: Challenges in transitioning to remote work setups and virtual collaboration.
- Disconnected Production: Lack of integration between production processes and other sectors.
- Employee Reluctance for Education and Training: Resistance or hesitance among employees towards acquiring new skills and knowledge.
- Funding Limitations: Constraints in financial resources allocated for digital transformation initiatives.
- Data Usability Issues: Difficulties in effectively utilizing data for actionable insights and decision-making.
- Resource Duplication: Wastage of resources due to redundant efforts or duplication of processes.

- Preference for FAST Goals over SMART Goals: Focus on frequently discussed, ambitious, specific, and transparent goals rather than traditional SMART goals.
- Data Management Challenges: Issues related to capturing, storing, transmitting, and ensuring the quality of data.
- Balancing Data Efficacy Enhancement: Striking a balance between different aspects of enhancing the effectiveness of data usage.
- Revenue Increase Euphoria vs. Client Acknowledgment: Discrepancy between anticipated revenue growth and actual recognition or acceptance from clients.
- Difficulty in Demonstrating Benefits: Challenges in showcasing the tangible benefits or returns on investment from digital initiatives.
- Challenges in Digitalization, especially in Energy Sector: Sector-specific obstacles hindering digital transformation efforts in the energy industry.
- Features without Customer Benefits: Development of product features that do not directly translate into customer benefits or value.
- Security and Privacy Concerns: Addressing worries and risks related to data security and privacy.
- Competitor Functionalities: Pressure to match or surpass functionalities offered by competitors in the market.
- Inflated Internal Capabilities: Overestimation of internal capabilities, leading to unrealistic expectations and planning.
- Lack of Effective Strategy: Absence of a clear and comprehensive strategy for digital transformation.

- Organizational Alignment: Challenges in aligning organizational goals, structures, and processes with digital objectives.
- Technological Disruptions: Disruptions caused by rapid advancements and changes in technology landscapes.
- Inadequate Change Management Culture: Lack of a supportive culture for managing and adapting to organizational change.
- Deployment Challenges in IoT: Obstacles specific to deploying Internet of Things (IoT) solutions, including managing customer expectations, navigating regulations, and securing investments.
- Technology Impact Lag: Delayed realization of the impact and benefits of technological implementations.
- Diffusion Tardiness: Slow spread or adoption of innovative technologies across industries or markets.
- Skills Mismatches: Mismatch between the skills demanded by digitalization efforts and those available in the workforce.
- Inadequate Digital Infrastructure: Insufficient or outdated infrastructure to support digital initiatives effectively.
- Data Privacy: Persistent risks posed by cyber-security threats and concerns regarding data privacy.
- Infrastructure Challenges in Industry 4.0 Adoption: Hurdles related to upgrading infrastructure to support the adoption of Industry 4.0 technologies.
- Situational Intelligence: Challenges related to gathering and analysing real-time data for informed decision-making while ensuring cyber-security.

- Interoperability Challenges: Difficulties in ensuring seamless communication and integration between different systems and devices at the connectivity layer.
- Accuracy of Predictions: Concerns regarding the reliability and precision of predictive analytics and forecasts at the analytics layer etc.

These challenges encompass a broad spectrum of issues encountered during various stages of digitalization, technology adoption, and deployment efforts across different industries and sectors. To alleviate an ivory tower, care was exercised by involving SMEs, OEMs, industry specialists, domain specialists, power plant professionals, and academicians in the interactions, interviews, and surveys.

CHAPTER III:
METHODOLOGY

3.1 Overview of the Research Problem

The percolation of digitalization in the power sector, despite offering numerous benefits, has not reached its full potential. Learning from past experiences and understanding the reasons behind this limited penetration is crucial for overcoming barriers and maximizing the advantages of digital deployment. Just as electricity revolutionized human life, digitalization holds the potential to transform various aspects of society and industry. However, harnessing this potential requires addressing the challenges hindering its widespread adoption in the power sector.

Energy is fundamental to human survival and progress, and so has become digitalization integral to modern life. The development of any technology brings both challenges and opportunities. Learning from past setbacks and leveraging acquired wisdom is essential for navigating risks and capitalizing on opportunities. Rather than dwelling on the obstacles encountered in the initial stages of digital deployment, it is imperative to focus on extracting valuable insights and strategies to propel further advancement.

Digitalization is often compared to electricity due to its transformative potential and widespread applicability across sectors. Just as electricity revolutionized society, the Internet of Things (IoT) has the capacity to bring about significant changes in various industries, including the power sector. Recognizing the parallels between these two transformative forces underscores the importance of accelerating the adoption of digital technologies in the power sector to unlock their full potential.

This research aims to comprehensively examine the reasons behind the limited penetration of digitalization in the power sector and develop a framework to expedite its adoption. By identifying and addressing the underlying factors inhibiting digital deployment, this study seeks to pave the way for leveraging digital technologies to enhance efficiency, reliability, and sustainability in the power sector. Ultimately, by understanding the challenges and opportunities associated with digitalization, stakeholders can formulate informed strategies to drive progress and innovation in the industry.

3.2 Operationalization of Theoretical Constructs

Operationalizing the theoretical concept of agile deployment in the power sector involves translating the abstract notion of agility into tangible actions and strategies that can be implemented by stakeholders across various levels of the industry. Firstly, agility in this context refers to the ability of power sector entities to adapt quickly and effectively to changing circumstances, technologies, and customer demands. This could involve streamlining bureaucratic processes, fostering a culture of innovation and collaboration, and implementing flexible technologies and systems that can easily accommodate changes and updates.

To operationalize agile deployment, specific actions can be taken at different levels of the industry. For end users, this might involve investing in smart grid technologies that enable real-time monitoring and control of energy consumption, allowing for greater flexibility and responsiveness to fluctuations in demand.

Additionally, end users can be encouraged to participate in demand response programs that incentivize them to adjust their energy usage patterns in response to price signals or grid conditions. At the customer end, agile deployment entails offering customizable energy solutions tailored to individual needs and preferences. This could involve the development of digital platforms or mobile apps that allow customers to track their energy usage, receive personalized recommendations for energy efficiency improvements, and easily switch between different service providers or energy sources.

For technology vendors, agile deployment requires developing and deploying solutions that are modular, scalable, and interoperable with existing infrastructure. This enables rapid deployment and integration of new technologies and allows for seamless upgrades and expansions as needed. Additionally, technology vendors can adopt agile development methodologies such as scrum or kanban to accelerate the pace of innovation and respond quickly to customer feedback and market changes.

The pragmatic framework developed to expedite digitalization in the power sector focuses on fostering a culture of urgency and innovation while overcoming legacy issues and bureaucratic hurdles. This involves identifying and prioritizing key areas for digital transformation, establishing clear goals and metrics for success, and empowering stakeholders to take ownership of the digitalization process. By emphasizing value creation and customer-centricity, the framework aims to drive meaningful change and deliver tangible benefits to end users, customers, and technology vendors alike.

3.3 Research Purpose and Questions

The purpose of this study is to explore and collate the reasons behind the limited adoption of digitization in the power sector in India. Despite existing research on this topic, the reasons identified thus far have not been mutually exclusive and collectively exhaustive within the specified research boundaries. Therefore, this research aims to address this gap by focusing on six key areas identified as critical for understanding the challenges hindering digitization in the Indian power sector.

These areas, termed as "SORTIE" (Strategy, Operational excellence, Regulations, Technology, Innovations, and Economic considerations), will serve as the framework for investigating the underlying reasons for the slow uptake of digitalization in the industry.

Research Questions (RQ):

1. What are the salient reasons for digitization not percolating to the extent it is expected to be in the power sector?
2. What is the framework to expedite the same?

These research questions will guide the exploration and analysis of factors contributing to the non-percolation of digitalization in the power sector, with a focus on understanding the challenges within each of the SORTIE focus areas. By addressing these questions, the study aims to provide insights that can inform strategies and interventions to accelerate the adoption of digital technologies in the Indian power sector, thereby enhancing efficiency, reliability, and sustainability in the industry.

3.4 Research Design

The methodology employed in this research embraced an exploratory research nature, chosen deliberately over explanatory or descriptive approaches, to delve deeply into the reasons for the limited penetration of digitalization in the power sector. Given the constantly evolving and diverging nature of these reasons, an exploratory approach allowed for a flexible and comprehensive investigation into the complex factors at play.

Abductive reasoning served as the primary logical framework for this research, contrasting with inductive and deductive methods. Abductive reasoning was deemed appropriate as the research began with an incomplete set of observations and aimed to propose the most plausible explanations for the compiled set of reasons. This approach facilitated the exploration of potential causal relationships and underlying mechanisms driving the non-percolation of digitalization in the power sector. The methodology summary is depicted at Figure **4**

Research Design elements.

A qualitative research design was chosen to align with the exploratory and abductive nature of the study. Qualitative research is well-suited for inductive or abductive approaches, allowing for the generation of new theories from the collected data. Unlike quantitative designs, which focus on relationships between variables, qualitative designs focus on understanding the relationships between entities such as people, companies, products, or services, making it ideal for uncovering nuanced insights in this context.

The research strategy employed a combination of survey, structured interviews, and the Delphi method. Surveys were utilized to ensure a proper sampling size and robust data collection process, enabling the capture of diverse perspectives within the power sector. Structured interviews were conducted using a predetermined and standardized set of questions, providing valuable insights into the prevailing circumstances and contextual factors influencing digitalization efforts. Care was taken to mitigate biases on both the interviewer and interviewee sides, ensuring the integrity and reliability of the data gathered.

Additionally, the Delphi method was employed to solicit expert opinions and consensus on critical issues (Arash Habibi et al, Delphi technique in framework qualitative', 2014) related to digitalization in the power sector. This iterative approach involved multiple rounds of data collection and feedback, allowing for the refinement and validation of emerging themes and hypotheses. By incorporating multiple research methods, this study aimed to triangulate findings and enhance the credibility and robustness of the conclusions drawn.

Overall, the methodology employed in this research was designed to foster a comprehensive and nuanced exploration of the challenges and barriers hindering the widespread adoption of digitalization in the power sector. By embracing an exploratory, abductive, and qualitative approach, this study sought to uncover underlying patterns and drivers, ultimately informing strategies and interventions to accelerate digital transformation in the industry.

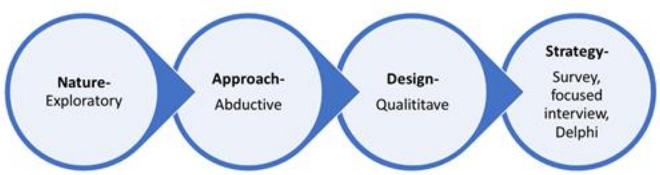

Figure 4
Research Design elements

3.5 Population and Sample

To determine an appropriate sample size for the research on digitalization in the power sector, it's essential to consider the total population of relevant experts who can contribute to the study. In this case, the population comprises individuals from thermal power plants and digital technology players, totaling 286 experts. These experts are expected to provide valuable insights into the reasons for the slow adoption of digitalization in the sector.

Given the size of the population, it's important to select a representative sample that can accurately reflect the opinions and perspectives of the entire population. For this research, a sample size of 78 experts would be suitable at a 90% confidence level and a margin of error of 8%. This sample size allows for a sufficient level of precision while ensuring that the research remains manageable and feasible within the constraints of time and resources.

However, if a higher level of confidence is desired, a larger sample size may be necessary. For instance, at a 95% confidence level, the sample size would increase to 99 experts. This higher confidence level provides greater assurance that the findings from the sample accurately represent the views of the entire population, albeit at the cost of a larger sample size and potentially increased resource requirements.

Ultimately, the choice of sample size depends on various factors, including the research objectives, available resources, and desired level of confidence. By carefully considering these factors and selecting an appropriate sample size, researchers can ensure that their findings are robust and reliable, providing valuable insights into the challenges and opportunities of digitalization in the power sector.

3.6 Participant Selection

Participant selection is a crucial aspect of research design, ensuring that the chosen sample accurately represents the diversity within the population of interest. In this study on the slow adoption of digitalization in the power sector, participant selection was carefully conducted to ensure fair representation across various parameters such as fuel type, unit size, configuration, and geographic location.

To achieve this goal, approximately 100 sample plants were selected from the total population of thermal power plants in India. These sample plants were chosen based on their representation of different fuel types (e.g., coal, natural gas, oil), unit sizes (e.g., large-scale, medium-scale, small-scale), configurations (e.g., combined cycle, cogeneration), and geographical locations (e.g., different states or regions). By considering these factors, the sample plants provide a comprehensive overview of the diversity present within the population, thus enhancing the generalizability of the research findings.

In addition to plant selection, participants for focused group interviews and Delphi technology were chosen from a pool of subject matter experts and domain experts. These experts were identified based on their expertise, experience, and contributions to the field of power sector digitalization. The selection criteria ensured that participants possessed the necessary knowledge and insights to provide valuable input on the research questions and objectives.

Overall, participant selection in this study was guided by the principles of fairness, diversity, and expertise, aiming to create a sample that accurately reflects the characteristics of the population while also ensuring the quality and relevance of the data collected. By employing rigorous participant selection procedures, the research can generate robust findings and insights into the challenges and opportunities of digitalization in the power sector. Total participants list is provided at Appendix B.

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3.7 Data Collection Procedures

There are four broad phases of research follwed as shown in Figure **5** The Four Phases of Research.

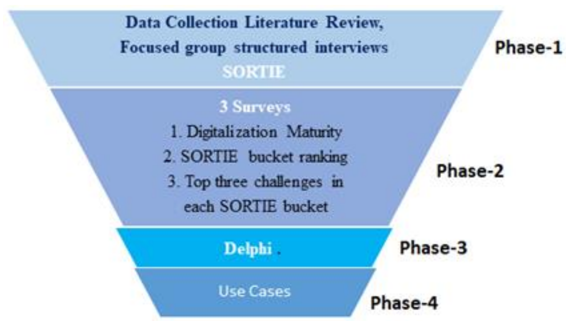

Figure 5
The Four Phases of Research

3.7.1 Phase-1

Phase 1 of the research focused on data collection and SORTIE classification, spanning from December 2021 to June 2022. During this phase, the reasons for the slow adoption of digitalization in the power sector were collated based on surveys, structured interviews, and a thorough review of literature and primary and secondary sources.

The research was conducted within the predefined boundaries of six focus areas, namely Strategy, Operational Excellence (OE), Regulations, Technology, Innovations, and Economic Considerations (SORTIE). Survey questionnaires and structured interviews were administered to various stakeholders including clients, power plant professionals, customers, vendors, end-users, domain experts, and subject matter experts (SMEs) to gather insights into the challenges faced in each SORTIE category.

3.7.2 Phase-2

In Phase 2, which occurred from May 2022 to October 2022, three surveys were conducted to delve deeper into the issues identified in Phase 1.

Survey 1 aimed to assess the maturity level of digitalization in organizations within the power sector. Out of 86 organizations approached, 65 (76%) responded, providing valuable insights into their current digitalization status.

Survey 2 involved structured interviews with a focused group to rank the SORTIE buckets based on their perceived importance. Nine professionals from prominent organizations such as NTPC, Adani, CESC, KSK, and Black & Veatch participated in the discussion, offering their perspectives on the prioritization of Strategy, OE, Regulations, Technology, Innovations, and Economic Considerations.

Survey 3 aimed to identify the top three challenges in each SORTIE bucket through a Google Forms questionnaire sent to a target population of 95 individuals. Around 68 (72%) respondents provided feedback, highlighting the most pressing issues hindering digitalization in the power sector.

Overall, these phases represent a comprehensive approach to understanding the complexities surrounding digitalization in the power sector. By combining data collection, classification, and in-depth surveys, the research aims to identify key challenges and develop strategies to expedite the adoption of digital technologies in this critical industry.

The questionnaire is sent in Google forms to over 95 target population. Out of 95 reached out, around 68 (72%) respondents provided feedback. The list of questions for each of the SORTIE bucket is provided at appendices-E1 to E6, along with cross-referencing at appropriate sections.

1. STRATEGY:

Strategy (Realigning business process and delivery of products/services), please refer APPENDIX E1.

https://docs.google.com/forms/d/e/1FAIpQLSdY5U6oerpjADe6LZiA_VoJSRVaj3HDlao1BVLpm_PZly-EQw/viewform?usp=sf_link

2. Operational Excellence

OE (Realigning People, Process, and Plant/tools), please refer APPENDIX E2.

https://docs.google.com/forms/d/e/1FAIpQLSd2AiXXscAZwqkxQICU0pRVm5EBHXBkCOIz5JJXASKen4t0Ig/viewform?usp=sf_link

3. Regulation

Regulations (codes, standards, rules, mandates by government, regulators), please refer APPENDIX E3.

https://docs.google.com/forms/d/e/1FAIpQLScHQ9n_frHumzMth0MtdshHruaeFGHPHR2zySQNj2fCw7z27w/viewform?usp=sf_link

4. Technology (IT-OT-ET convergence), please refer APPENDIX E4.

https://docs.google.com/forms/d/e/1FAIpQLSfmPfEiW7Asl2JBeNpS3QaO8tuP_P_YwlMW5xeYq-GHRizVWw/viewform?usp=sf_link

5. Innovation

Innovation (that gel well with the needs of the power sector), please refer APPENDIX E5.

https://docs.google.com/forms/d/e/1FAIpQLSfsKb_BpVFSa8xyBuJ1mFU0c5_ddtio-G4kA9XXI50dlIElwg/viewform?usp=sf_link

6. Economic considerations

Economic considerations (investment, short term and long term benefits, ROI), please refer APPENDIX E6.

https://docs.google.com/forms/d/e/1FAIpQLSenYyIe4X1QNxeAeWTHLZ6XhYYyDeIgXHJR_sb204bKPDyGDw/viewform?usp=sf_link

3.7.3 Phase-3

In phase 3 in addition to surveys and structured interviews, the research also utilized the Delphi method to gather insights from a panel of experts. The Delphi method is a systematic, interactive forecasting technique that relies on a panel of experts to iteratively develop a consensus on a complex issue (Fish L et al, 2005). It involves multiple rounds of questionnaires or surveys, with feedback provided anonymously to the participants between rounds. This method allows for the exploration of diverse perspectives and the refinement of opinions over successive iterations.

The Delphi process in this research was conducted in Phase 3, which took place from November 2022 to February 2023. The goal was to further refine the identified challenges and potential solutions by soliciting input from a group of subject matter experts (SMEs) and industry professionals. The Delphi panel consisted of individuals with extensive experience and expertise in the power sector, digitalization, and related fields.

As illsutrated at Figure **6**

Delphi Flow Process**Error! Reference source not found.** of the Delphi method used in the research:

1. Selection of Expert Panel: The first step involved the careful selection of experts to participate in the Delphi process. Criteria for selection included relevant experience, expertise, and diversity of perspectives.

2. Round 1 Questionnaire: In the initial round, participants were provided with a questionnaire that outlined the key challenges identified in previous phases of the research. Participants were asked to rank these challenges based on their perceived importance and provide additional comments or insights.

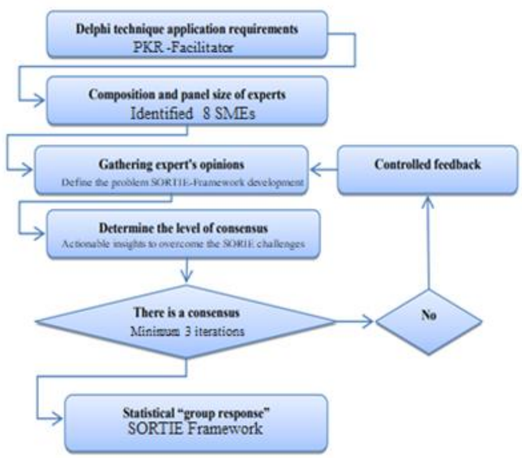

Figure 6
Delphi Flow Process

3. Feedback and Analysis: Responses from Round 1 were compiled and analyzed to identify areas of agreement and divergence among participants. Anonymized feedback was then provided to the participants, allowing them to reconsider their responses in light of the group's collective input.

4. Round 2 Questionnaire: Based on the feedback from Round 1, a revised questionnaire was developed for the second round of the Delphi process. Participants were asked to reassess their rankings and provide further feedback on the refined set of challenges.

5. Consensus Building: The iterative nature of the Delphi process allowed for the gradual convergence of opinions among participants. Subsequent rounds were conducted as needed until a consensus was reached on the most critical challenges and potential solutions.

6. Final Report: The findings from the Delphi process were synthesized and integrated with the results from other research phases to inform the development of recommendations and strategies for accelerating digitalization in the power sector.

Through the Delphi method, the research was able to harness the collective expertise of industry professionals and subject matter experts to gain valuable insights and consensus on the challenges and opportunities associated with digitalization in the power sector.

A Delphi Survey is a structured method that involves multiple rounds of questionnaires designed to gather insights from a panel of experts on a particular issue. Throughout the process, participants provide feedback on the responses given in previous rounds, allowing for the development and refinement of ideas over time. This iterative approach helps to converge on a framework or consensus regarding the topic under investigation.The size of a Delphi panel can vary, ranging from as few as three members to as many as eighty. In this research, a panel of eight members was selected from the pool of participants listed in the Appendix-B.

Reason for digitalization not percolating in the power sector	Description

1) Context and relevance not clear	1. The context and relevance are unclear, leading to uncertainty in digitalization initiatives.
2) Not willing to be the first movers.	2. There is a reluctance to be pioneers in adopting digital technologies.
3) Notion that digitation is for services and not for plants.	3. The misconception persists that digitization is more suited for services rather than power plant operations.
4) Decision maker’s dilemma	4. Decision-makers face dilemmas in choosing the right digitalization strategies.
5) Disconnect between management, business processes, and user.	5. There is a disconnect between management, business processes, and end-users.
6) Consumer and other stakeholder’s interface	6. Effective interfaces with consumers and other stakeholders are lacking.
7) Transformative leadership	7. Transformative leadership is needed to drive successful digital transformation.
8) Company culture	8. Company culture plays a crucial role in embracing digitalization efforts.
9) Work environment	9. The work environment may not be conducive to digital innovation and adaptation.
10) Resilience (enterprise risk resilience)	10. Resilience, particularly in terms of enterprise risk, is essential for sustainable digitalization.
11) Customer expectations	11. Meeting customer expectations is a critical aspect of successful digital initiatives.
12) Lack of effective strategy	12. Many organizations struggle with formulating effective digitalization strategies.
13) Absence of strategic alignment	13. Strategic alignment is often absent, hindering the implementation of digital initiatives.
14) Missing top management engagement	14. Top management engagement is often lacking, impeding progress in digitalization efforts.
15) Improper knowledge management strategies	15. Inadequate knowledge management strategies hinder the effective use of digital technologies.
16) Absence of change management culture	16. A lack of change management culture can lead to resistance and inefficiencies in digital transformation.
17) Lack of common thread among strategy, vision, leadership, culture, and staff	17. The absence of a common thread among strategy, vision, leadership, culture, and staff complicates digitalization efforts.

18) Business model alignment	18. Ensuring alignment with the business model is crucial for successful digitalization.
19) Managerial and organizational capabilities	19. Managerial and organizational capabilities may be insufficient to drive digitalization initiatives forward.
20) Collaboration between departments to seamless implementation	20. Collaboration between departments is crucial for the seamless implementation of digital solutions.
21) Lack of Conviction- that digitization supports efficiency and sustainability.	21. Many stakeholders lack conviction that digitization can improve efficiency and sustainability.
22) Effort expectancy	22. Effort expectancy may hinder the adoption of digital technologies.
23) Dearth of capabilities and skills in-house	23. In-house capabilities and skills may be lacking for successful digitalization.
24) Lack of historic data for making the machine learning faster	24. Historical data scarcity may impede the effectiveness of machine learning applications.
25) Mindset of experience silos, lack of KT	25. Siloed mindsets and lack of knowledge transfer hinder digitalization efforts.
26) Perceived complexity of use	26. Perceived complexity of use may discourage adoption of digital technologies.
27) Perceived loss of power/authority	27. Perceived loss of power or authority may lead to resistance to digitalization.
28) Privacy breach qualms	28. Concerns about privacy breaches can hinder the implementation of digital solutions.
29) Siloes and legacy systems.	29. Siloed and legacy systems pose challenges for digital integration.
30) Standardization issues affecting custom-tailored needs.	30. Standardization issues may impede customization of digital solutions.
31) Threat to job security	31. Job security concerns may discourage workforce buy-in for digital initiatives.
32) Trust in data by the company	32. Trust in data quality is essential for successful digitalization.
33) Inflated internal capabilities to undertake the digital transformation.	33. Internal capabilities may be overestimated, leading to unrealistic expectations for digital transformation.
34) Lacking sense of urgency, POC delays	34. Lack of urgency and delays in proof of concept can slow digitalization efforts.

35) Skills mismatch	35. Skills mismatches may hinder the effective implementation of digital technologies.
36) Lack of talent	36. Talent shortages pose challenges for recruiting skilled personnel for digital initiatives.
37) Dearth of practical problem-solving	37. Practical problem-solving skills may be lacking in the workforce.
38) Low qualified and elderly employees	38. Low-qualified and elderly employees may struggle to adapt to digital technologies.
39) The dearth of regulations;	39. Regulatory dearth creates uncertainty and obstacles for digitalization.
40) Misaligned financial incentive especially in regulated markets;	40. Misaligned financial incentives in regulated markets can impede digitalization efforts.
41) Absence of policies that encourage;	41. Absence of policies that encourage digital innovation hampers progress.
42) Central (federal) vs. state concurrencies;	42. Competing central and state regulations complicate digitalization efforts.
43) Infrastructure, eco system from government;	43. Government support in infrastructure and ecosystem development is lacking.
44) Single window approvals;	44. Simplified approval processes can expedite digitalization initiatives.
45) Tax benefits;	45. Tax benefits can incentivize investment in digital technologies.
46) Deficiency of data governance;	46. Deficiencies in data governance hinder effective data management.
47) Subsidies and incentives for startups;	47. Subsidies and incentives can encourage adoption of digital solutions.
48) Not addressing the customers' security and privacy concerns;	48. Addressing customer security and privacy concerns is essential for successful digitalization.
49) Data ownership and IP rights;	49. Clarifying data ownership and IP rights is crucial for digital initiatives.
50) Privacy of individuals vs. understanding of an individual;	50. Balancing individual privacy with data understanding is a regulatory challenge.
51) Market rules of competition.	51. Market competition rules impact digitalization strategies and investments.
52) Adequacy of existing IT infrastructure;	52. The adequacy of existing IT infrastructure can affect digitalization readiness.

53) Compatibility among existing and proposed technologies/devices;	53. Compatibility among technologies affects the integration of digital solutions.
54) Cyber security apprehensions;	54. Cyber security concerns pose risks to digitalization efforts.
55) Domain expertise gaps between IT and OT experts;	55. Domain expertise gaps between IT and operational technology experts create challenges.
56) Edge vs. Fog vs. cloud deployment dilemma;	56. Choosing between edge, fog, and cloud deployment presents dilemmas.
57) Technology diffusion tardiness;	57. Delayed technology diffusion slows digitalization progress.
58) Inadequate digital infrastructure;	58. Inadequate digital infrastructure constrains digitalization initiatives.
59) Technology capability and integration;	59. Technology capability and integration challenges affect digitalization projects.
60) Architecture design;	60. Architecture design considerations impact digital solution implementation.
61) Lack of situational sensor intelligence;	61. Situational sensor intelligence may be lacking for effective decision-making.
62) Compatibility and co-existence issue the connectivity layer;	62. Compatibility and co-existence issues at the connectivity layer hinder integration.
63) Security vs. accessibility;	63. Balancing security with accessibility is a technological challenge.
64) Lack of collaboration in IT, ET, and OT.	64. Collaboration between IT, operational technology, and engineering teams is essential.
65) ML/AI based use cases to enhance reliability and efficiency;	65. ML/AI use cases can enhance reliability and efficiency in power plants.
66) Products to support flexibility in operations;	66. Flexibility-supporting products drive innovation in power plant operations.
67) Demonstrability of results;	67. Demonstrating results is crucial for gaining buy-in for digital initiatives.
68) Latency in technology adoption;	68. Latency in technology adoption hampers digitalization progress.
69) Energy efficient apparatus/ products;	69. Energy-efficient apparatus and products contribute to sustainability goals.
70) Intelligent sensors;	70. Intelligent sensors enable data-driven decision-making in power plants.

71) Waiting for use cases, proofs, and references;	71. Waiting for use cases and proofs delays digitalization efforts.
72) Ignoring or not heeding to the superior functionalities of competitors;	72. Ignoring competitor functionalities can hinder competitiveness.
73) Work performed by people vs. computing machines;	73. Balancing work between people and machines is a challenge for digitalization.
74) Providing more resources to IT staff vs. more self-service analytics;	74. Allocating resources between IT staff and self-service analytics impacts digital strategies.
75) Technology impact lags;	75. Technology impact lags hinder digitalization benefits realization.
76) Pace of change and time to market.	76. The pace of change and time-to-market pressures affects digitalization initiatives.
77) Balance sheet not supporting (financial constraints);	77. Financial constraints on the balance sheet hinder digitalization investments.
78) Disincentives for investment due to policy paralysis by the governments;	78. Policy paralysis by government's disincentives investment in digital technologies.
79) Low load factors due to onslaught of renewables resulting low revenues;	79. Low load factors due to renewables impact revenue streams in power plants.
80) Huge dues remain to be realized constraining working capital;	80. Outstanding dues constrain working capital for digitalization investments.
81) Tangibility of benefits is difficult to demonstrate;	81. Demonstrating tangible benefits of digitalization can be challenging.
82) Features with no benefits to customers. Reluctance to pay for that;	82. Features without customer benefits may hinder adoption of digital solutions.
83) Aggregate data or personalize (centralization vs. decentralization);	83. Centralization versus decentralization impacts data management strategies.
84) Storing all data vs. selecting data to store that serves a specific purpose;	84. Selective data storage for specific purposes is essential for efficient digitalization.
85) Distributed value creation and capture;	85. Distributed value creation and capture pose challenges for digitalization strategies.
86) Investments friendly POCs;	86. Investments-friendly proof of concepts facilitates digitalization initiatives.

87) Insufficient funds for digitization of the process;	87. Insufficient funds constrain digital process digitization efforts.
88) Digital technologies enable a circular economy;	88. Digital technologies enable circular economy initiatives in the power sector.
89) Priorities (competing and conflicting);	89. Competing and conflicting priorities impact digitalization strategies.
90) Payments from savings-based investments.	90. Payments from savings-based investments drive digitalization funding.

APPENDIX B These individuals were chosen based on their expertise in the field of study and their willingness to engage in multiple rounds of questions or interactions on the topic of digitalization in the power sector. By drawing on the knowledge and insights of these experts, the Delphi Survey served as a valuable tool for refining the research findings and identifying key challenges and potential solutions in the pursuit of accelerating digitalization within the industry.

The Delphi process followed seven sequential steps to gather insights and refine ideas regarding the development of a framework to expedite digitalization in the power sector. Step 1 involved selecting a facilitator, with the group choosing one member to lead the process. This individual would guide the discussions and ensure the smooth progression of the Delphi Survey. Step 2 focused on identifying eight subject matter experts (SMEs) who possessed relevant knowledge and expertise in the field of digitalization within the power sector. These experts would serve as participants in the Delphi Survey. In Step 3, the problem statement was clearly defined: to develop a framework that would facilitate faster, better, and more robust digitalization in the power sector. Step 4 entailed the development of questions for the first round of the Delphi Survey. These questions aimed to gather insights on the steps involved in both internal and external processes, the necessary inputs for the framework, the key attributes to focus on, and actionable insights for implementation. After sending out and analysing the responses to the first round of questions in Step 5, Step 6 involved refining the questionnaire for the second round based on the feedback received. This round aimed to explore how the identified reasons, challenges, and enablers could be connected to produce solutions and how these could be incorporated into a pragmatic framework.

This process was iterated thrice, with each round of the questionnaire refined based on the feedback received, until a consensus was reached among the experts.

Finally, in Step 7, the outcomes of the Delphi Survey were analysed to evaluate the pros and cons of the suggested framework, identify any anomalies or gaps, and ultimately derive the SORTIE framework aimed at accelerating digitalization in the power sector.

3.7.4 Phase-4

In phase-4 frameowrk is deployed in implementation of digitalization mainly focussing on control, optimisation, visulaization, and automation both in technical fucntions like operations, maintenance, techncial services, engineering, and support fucntions like human resouces, sourcing and procurement, finaince, safety, security, health, environment etc. t

Thus all the four phases **Figure 5**

The Four Phases of Research are undertaken systematically in a planned manner following a schedule validating and anlysisng results of each pahse which act as inputs the subsequnet phase.

3.8 Data Analysis

In the SORTIE research, data analysis plays a crucial role in understanding the factors affecting digitalization in the power sector. Statistical methods are employed to determine the top three reasons within each SORTIE bucket identified in survey-3. By analysing the responses from participants, statistical techniques such as mode and averages are utilized to identify the most commonly cited reasons across each category. This quantitative analysis helps prioritize the challenges faced in different aspects of digitalization, providing valuable insights into where interventions may be most beneficial.

Additionally, in survey-1, statistical analysis is employed to assess the maturity level of digitalization within organizations in the power sector. Through quantitative measures, such as averages and standard deviations, the level of digitalization across different organizations is evaluated. This analysis allows researchers to understand the current state of digital adoption within the sector, identifying areas of strength and weakness that can inform future strategies and interventions.

In survey-2, statistical methods are used to rank the significance of SORTIE buckets based on input from the focused group interviews. By applying statistical techniques to the responses, such as calculating mean ranks or conducting chi-square tests, researchers can determine the relative importance of each bucket in driving digitalization efforts. This analysis provides a structured approach to understanding which areas require the most attention and resources in order to accelerate digital transformation within the power sector.

Furthermore, alongside statistical analysis, the SORTIE research incorporates insights from a comprehensive literature review. By synthesizing existing research and industry knowledge, researchers can contextualize their findings within the broader landscape of digitalization in the power sector. This qualitative analysis coupled with Delphi (Arash Habibi et al, Delphi technique in framework qualitative , 2014)helps validate quantitative findings and provides a deeper understanding of the underlying drivers and barriers to digital adoption. Overall, the combination of statistical analysis and literature review allows for a robust and comprehensive examination of digitalization challenges and opportunities in the power sector, enabling informed decision-making and strategy development.

3.9 Research Design Limitations

While the chosen research design and methodology offer a structured approach to investigating the reasons behind the limited adoption of digitalization in the power sector, there are inherent limitations that need to be acknowledged. One such limitation is the risk of subjectivity or ambiguity in the assessment criteria used to evaluate the responses gathered from surveys, interviews, and other data collection methods. The interpretation of key words or phrases selected by participants could vary, potentially leading to inconsistencies in the analysis and findings.

Moreover, the research design may be subject to limitations in its ability to capture the full complexity of the issue at hand. Despite efforts to develop a comprehensive framework and methodology, there may still be aspects of the digitalization challenge that are overlooked or not adequately addressed. This could result in gaps in the research findings and recommendations.

Additionally, practical constraints such as time availability of subject matter experts (SMEs) and respondents could impact the data collection process and the depth of insights gathered. Limited availability of participants may restrict the sample size and diversity, potentially affecting the representativeness of the findings. Furthermore, ethical considerations such as biases, conflicts of interest, and competition among vendors may introduce distortions in the data or influence the responses provided.

To mitigate these limitations, rigorous quality control measures and validation procedures should be implemented throughout the research process. This includes carefully designing survey instruments and interview protocols, providing clear instructions to participants, and conducting thorough data analysis to identify and address any inconsistencies or biases. Additionally, transparency and reflexivity in reporting findings can help mitigate potential biases and enhance the credibility and reliability of the research outcomes. Overall, while research design limitations are inevitable, proactive measures can be taken to minimize their impact and enhance the validity and robustness of the study.

3.10 Conclusion

In conclusion, the methodology adopted for this research has proven to be effective in yielding pragmatic results regarding the challenges and opportunities surrounding digitalization in the power sector. Through a combination of exploratory research, abductive reasoning, qualitative data collection methods, and statistical analysis, valuable insights have been obtained into the factors influencing the adoption of digital technologies in power generation and distribution.

Across the industry, it is widely acknowledged that digitalization efforts aimed at process optimization and asset performance enhancement have led to positive outcomes, including increased plant availability, reliability, and process efficacy. These findings underscore the importance of further research and investment in digital transformation initiatives within the power sector to address existing challenges and unlock new opportunities for efficiency and sustainability.

Moving forward, it will be essential to build upon the insights gained from this research to develop actionable strategies and frameworks for fostering faster, more robust digitalization in the power sector. By addressing the limitations of current approaches and leveraging emerging technologies and best practices, stakeholders can drive meaningful progress towards a more digitally-enabled and resilient energy ecosystem.

Overall, this research methodology has provided a solid foundation for understanding the complexities of digitalization in the power sector and has laid the groundwork for future investigations and interventions aimed at accelerating the adoption of digital technologies for the benefit of all stakeholders involved.

CHAPTER IV:
RESULTS

4.1 Introduction

Based on the extensive research conducted on the reasons hindering the percolation of digitization in the Indian power sector, the results and findings including the framework developed to expedite the adoption of digitization are provided here adderessing the two research questions.

Research Question 1: "What are the salient reasons for digitization not percolating to the extent expected in the power sector in India?"

The research identified around ninety (90) key factors hindering the anticipated penetration of digitization within the Indian power sector, categorized into six buckets using the acronym "SORTIE": Strategy, Operational Excellence, Regulatory, Technical, Innovation, and Economic Considerations.

Surveys conducted revealed insights into the maturity level of digitization in the power sector and the prioritization of factors influencing digitization efforts. Strategy emerged as the most critical pillar, followed by economic considerations and regulatory support. The research findings further converged on eighteen (18) salient reasons among the total ninety (90) challenges hindering digitization in the power sector, requiring multifaceted solutions and collaborative efforts across stakeholders.

Research Question 2: What is the framework to expedite percolation of digitalization in the power sector?

The research developed a comprehensive framework to expedite the adoption of digitization in the power sector. The framework emphasized strategic alignment, regulatory reform, capacity building, technology infrastructure, and collaboration as key components for accelerating digitization efforts.

4.2 Research Question One

Research Question 1: "What are the salient reasons for digitization not percolating to the extent expected in the power sector in India?"

This research question sought to explore the factors hindering the anticipated penetration of digitization within the power sector in India. Additionally, examined the specific challenges faced by different stakeholders, such as government entities, utilities, and consumers, could provide valuable insights into understanding the complexities of digitization within the Indian power sector. The six key areas of investigation discovered ninety (90) SORTIE reasons at Table 10

Bucket wise reasons collated that impede the percolation of digital technologies in the power sector, are categorized as below.

1. Strategy:

   18 reasons including lack of willingness to be early adopters, misconceptions about digitization, and decision-maker dilemmas were identified as primary obstacles in strategy bucket. Pease refer Table 11

   Total reasons strategy & OE .

2. Operational Excellence:

   20 reasons including challenges such as functional siloes, legacy systems, perceived complexity of use, and privacy concerns were discovered as prominent barriers in operational excellence bucket. Pease refer Table 11

   Total reasons strategy & OE .

3. Regulatory:

   13 reasons including misaligned financial incentives, data ownership issues, and inadequate policy frameworks were found to impede digitization efforts in

regulatory bucket. Please refer Table 12

Total reasons Regulatory & Technology.

4. Technology:

   13 reasons including gaps in expertise between IT and OT professionals, compatibility issues, and technology integration challenges were identified as key hurdles in the technology bucket. Please refer Table 12

   Total reasons Regulatory & Technology.

5. Innovation:

   12 reasons including difficulties in demonstrating results, technology lag, and reluctance to adopt ML/AI-based solutions were highlighted as significant barriers in the innovation bucket. Please refer Table 13

   Total reasons Innovation & EC.

6. Economic Considerations:

   14 reasons including tangibility of benefits, low load factors due to renewables, and financial constraints hindered investment in digitization initiatives in the economic considerations bucket. Please refer Table 13

   Total reasons Innovation & EC.

Table 10
Bucket wise reasons collated

S (strategy)	O (operational)	R (regulatory)	T (technical)	I (innovation)	E (economic)
18	20	13	13	12	14

Table 11
Total reasons strategy & OE

Strategy- Realigning BP for product/service delivery	Operational Excellence- Realigning people, process, and tools
1. Context and relevance not clear 2. Not willing to be the first movers. 3. Notion that digitation is for services and not for plants. 4. Decision maker's dilemma 5. Disconnect between management, business processes, and user. 6. Consumer and other stakeholder's interface 7. Transformative leadership 8. Company culture 9. Work environment 10. Resilience (enterprise risk resilience) 11. Customer expectations 12. Lack of effective strategy 13. Absence of strategic alignment 14. Missing top management engagement 15. Improper knowledge management strategies 16. Absence of change management culture 17. Lack of common thread among strategy, vision, leadership, culture, and staff 18. Business model alignment	19. Managerial and organizational capabilities 20. Collaboration between departments to seamless implementation 21. Lack of Conviction- that digitization supports efficiency and sustainability. 22. Effort expectancy 23. Dearth of capabilities and skills in-house 24. Lack of historic data for making the machine learning faster 25. Mindset of experience silos, lack of KT 26. Perceived complexity of use 27. Perceived loss of power/authority 28. Privacy breach qualms 29. Siloes and legacy systems. 30. Standardization issues affecting custom-tailored needs. 31. Threat to job security 32. Trust in data by the company 33. Inflated internal capabilities to undertake the digital transformation. 34. Lacking sense of urgency, POC delays 35. Skills mismatch 36. Lack of talent 37. Dearth of practical problem-solving 38. Low qualified and elderly employees

Table 12
Total reasons Regulatory & Technology

Regulatory- codes, standards, rules, mandates by government, regulators	Technology-IT-OT-ET convergence
39. The dearth of regulations; 40. Misaligned financial incentive especially in regulated markets; 41. Absence of policies that encourage; 42. Central (federal) vs. state concurrencies; 43. Infrastructure, eco system from government; 44. Single window approvals; 45. Tax benefits; 46. Deficiency of data governance; 47. Subsidies and incentives for startups; 48. Not addressing the customers' security and privacy concerns; 49. Data ownership and IP rights; 50. Privacy of individuals vs. understanding of an individual; 51. Market rules of competition.	52. Adequacy of existing IT infrastructure; 53. Compatibility among existing and proposed technologies/devices; 54. Cyber security apprehensions; 55. Domain expertise gaps between IT and OT experts; 56. Edge vs. Fog vs. cloud deployment dilemma; 57. Technology diffusion tardiness; 58. Inadequate digital infrastructure; 59. Technology capability and integration; 60. Architecture design; 61. Lack of situational sensor intelligence; 62. Compatibility and co-existence issue the connectivity layer; 63. Security vs. accessibility; 64. Lack of collaboration in IT, ET, and OT.

Table 13
Total reasons Innovation & EC

Innovations that gel well with the needs of the power sector	**Economic Considerations-Investment, short/long term benefits, ROI**
65. ML/AI based use cases to enhance reliability and efficiency; 66. Products to support flexibility in operations; 67. Demonstrability of results; 68. Latency in technology adoption; 69. Energy efficient apparatus/ products; 70. Intelligent sensors; 71. Waiting for use cases, proofs, and references; 72. Ignoring or not heeding to the superior functionalities of competitors; 73. Work performed by people vs. computing machines; 74. Providing more resources to IT staff vs. more self-service analytics; 75. Technology impact lags; 76. Pace of change and time to market.	77. Balance sheet not supporting (financial constraints); 78. Disincentives for investment due to policy paralysis by the governments; 79. Low load factors due to onslaught of renewables resulting low revenues; 80. Huge dues remain to be realized constraining working capital; 81. Tangibility of benefits is difficult to demonstrate; 82. Features with no benefits to customers. Reluctance to pay for that; 83. Aggregate data or personalize (centralization vs. decentralization); 84. Storing all data vs. selecting data to store that serves a specific purpose; 85. Distributed value creation and capture; 86. Investments friendly POCs; 87. Insufficient funds for digitization of the process; 88. Digital technologies enable a circular economy; 89. Priorities (competing and conflicting); 90. Payments from savings-based investments.

4.2.1 The top three reasons in each SORTIE bucket

Further to identify the top three reasons in each bucket a Google survey (survey 3) was carried out among 110 SMEs, OEMs, end users, and academicians. Participants were asked to rank 1 to 6 based on their perceived significance on each of the reason in each bucket. 95 responses received. Based on the average of all respondents and mode (most frequently given score against each reason) the top three reasons were selected.

1. **STRATEGY:**

The survey 3 Google from questionnaire is provided at APPENDIX E1**.**

Statistical results using mode and average of scores against each reason are tabulated in descending order at **Table 14**

Strategy bucket top three reasons scoring.

Table 14
Strategy bucket top three reasons scoring

No. STRATEGY - RESPONSES	Mode	Average
2. Not willing to be the first movers	6	5
3. Notion that digitation is for services and not for plants	5	4.75
4. Decision maker's dilemma	5	4.5
15. Improper knowledge management strategies	3	4.353
14. Missing top management engagement	4	4.25
12. Lack of effective strategy	3	4.25
17. Lack of common thread among strategy, vision, leadership, and staff	3	4.25
1. Context and relevance not clear	4	4
7. Transformative leadership	5	3.5
10. Resilience (enterprise risk resilience)	5	3.5
18. Business model alignment	5	3.5
5. Disconnect between management, business processes and user	4	3.5

Inference of results:

It is observed that for the causes 2, 3 and 4, their mode and average reinforce the fact that they are the prime causes in strategy basket that are attributable for delayed propagation of digitalization in power sector.

Cause 2. Not willing to be the first movers.

Cause 3. Notion that digitation is for services and not for plants,

Cause 4. Decision maker's dilemma

'Who bells the cat?' is the attitude several deplorers had in mind. The second myth was that digital transformation is for services and not suitable for processing plants. Added to this. Decision makers had no clarity and conviction to go ahead and take decision to identify, select, and deploy digital tools.

It is seen that for the causes 15,14,12 and 17 the averages are higher, though the mode values lag behind compared to the causes 7, 10, 18, 1 and 5 .

Cause 15. Improper knowledge management strategies

Cause 14. Missing top management engagement

Cause 12. Lack of effective strategy

Cause 17. Lack of common thread among strategy, vision, leadership, culture and staff

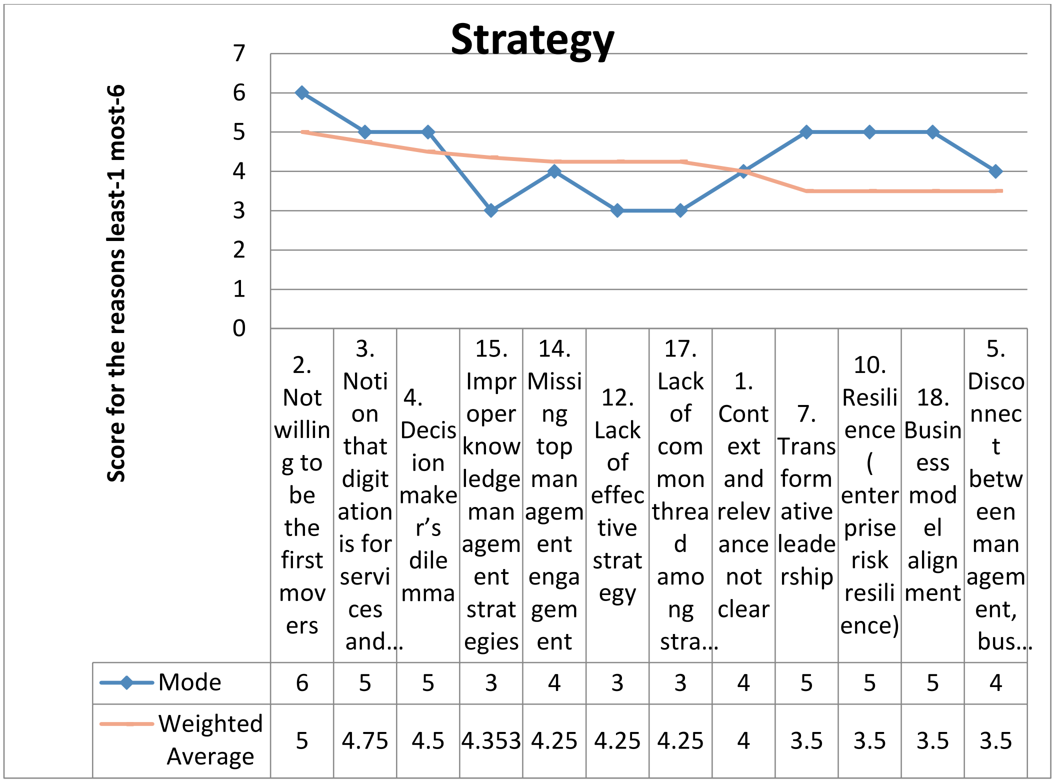

Figure 7

Graph showing Strategy reasons scores

The top 3 reasons emerged in strategy bucket are as depicted at Figure 7 Graph showing Strategy reasons scores:

- Not willing to be the first movers,
- Decision maker’s dilemma,
- Notion that digitation is for services and not for plants.

2. Operational Excellence:

The survey 3 Google from questionnaire is provided at APPENDIX E2.

Statistical results using mode and average of scores against each reason are tabulated in descending order at Table 15

OE bucket top three reasons scoring.

Table 15
OE bucket top three reasons scoring

No. OE RESPONSES	Mode	Average
29. Siloes and legacy systems	6	4.5
26. Perceived complexity of use	5	4.5
27. Perceived loss of power/authority	5	4.5
22. Effort expectancy	4	4.5
28. Privacy breach qualms	6	4
33. Inflated internal capabilities to undertake the digitalization.	5	4
37. Dearth of practical problem-solving	5	4
21. Lack of Conviction- that supports efficiency , sustainability	5	3.5
23. Dearth of capabilities and skills in-house	4	3
34. Lacking sense of urgency delaying the POC	4	3
38. Low qualified and elderly employees	4	3
24. Lack of historic data for making the machine learning faster	3	2.5

It is observed that for the causes 29, 26, 27, 28, 33 and37 their mode and average reinforce the fact that they are the prime causes in OE basket that are attributable for delayed propagation of digitalization in power sector.

Cause 29. Siloes and legacy systems.

Cause 26. Perceived complexity of use

Cause 27. Perceived loss of power/authority

Cause 28. Privacy breach qualms

Cause 33. Inflated internal capabilities to undertake the digital transformation.

Cause 37. Dearth of practical problem-solving

Opaqueness and preset narrowed mindsets leading to siloes legacy outlook is the major cause of restraint in operational excellence. There is a perception of usability being typically difficult. Several leaders and managers apprehended that the y lose power if digitalization takes the helm. Many are afraid of privacy issues.

It is found that for cause 22 the averages are higher, though the mode values lag behind compared to the causes cause 28, 33 and 37.

Cause 22. Effort expectancy

The top 3 reasons in operational excellence bucket as depicted in Figure 8 OE reasons scores.

- Perceived complexity of use,
- Privacy breach qualms,
- Siloes and legacy systems.

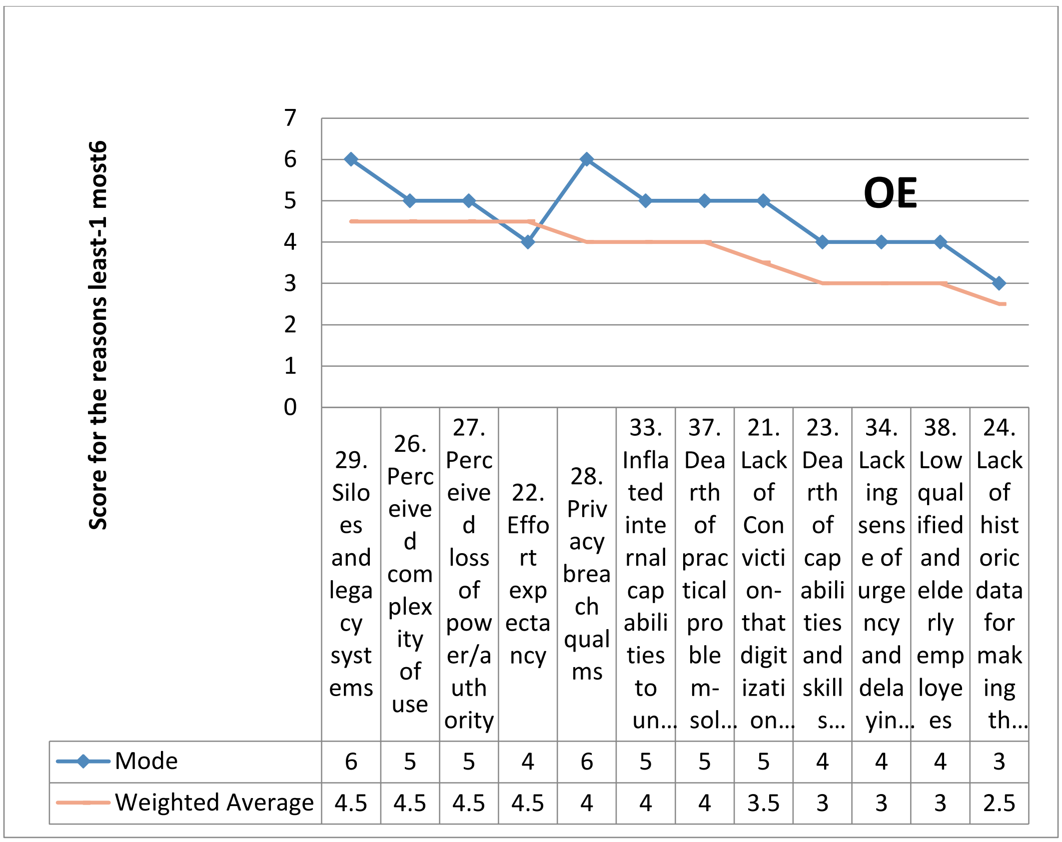

Figure 8
OE reasons scores

3. **Regulatory:**

The survey 3 Google from questionnaire are provided at APPENDIX E3.

Statistical results using mode and average of scores against each reason are tabulated in descending order at Table 16

Regulatory bucket tope three reasons scores.

Table 16

Regulatory bucket tope three reasons scores

No. REGULATORY RESPONSES	Mode	Average
49. Data ownership , intellectual property rights	6	5.7
40. Misaligned financial incentive especially in regulated markets	6	5.3
48. Not addressing the customers' security and privacy concerns.	6	4.7
46. Deficiency of data governance and interoperability	5	4.3
51. Market environment ,rules of competition	5	4.3
39. Dearth of regulations that promote digitalization	5	4.0
47. Subsidies and incentives for startups	6	4.0
41. Absence of policies that encourage sustainability	6	3.7
44. Single window approvals by the government	6	3.7
43. Infrastructure, eco system support from government	6	3.3
42. Central (federal) vs. state concurrencies	5	3.3
45. Tax benefits	4	3.0

It is observed that for the causes 49, 40 and 48, their mode and average reinforce the fact that they are the prime causes in Regulation basket that are attributable for delayed propagation of digitalization in power sector.

Cause 49. Data ownership and intellectual property rights

Cause 40. Misaligned financial incentive especially in regulated markets.

Cause 48. Not addressing the customers' security and privacy concerns.

In the area of regulatory aspects, data residing on premise vs. on cloud has been a big debate due to the apprehensions of data breaches, ownership, and IP rights issues. Moreover, in a regulated market, the dearth of financial incentives doesn't motivate and drive digital efforts.

It is seen that for the cause 47, 41, 44 and 43 the averages are lower, though the mode values lead higher compared to the causes cause 49, 40, and 48.

Cause 47. Subsidies and incentives for startups

Cause 41. Absence of policies that encourage sustainability.

Cause 44. Single window approvals facilitation by the governments

Cause 43. Infrastructure, eco system support from government

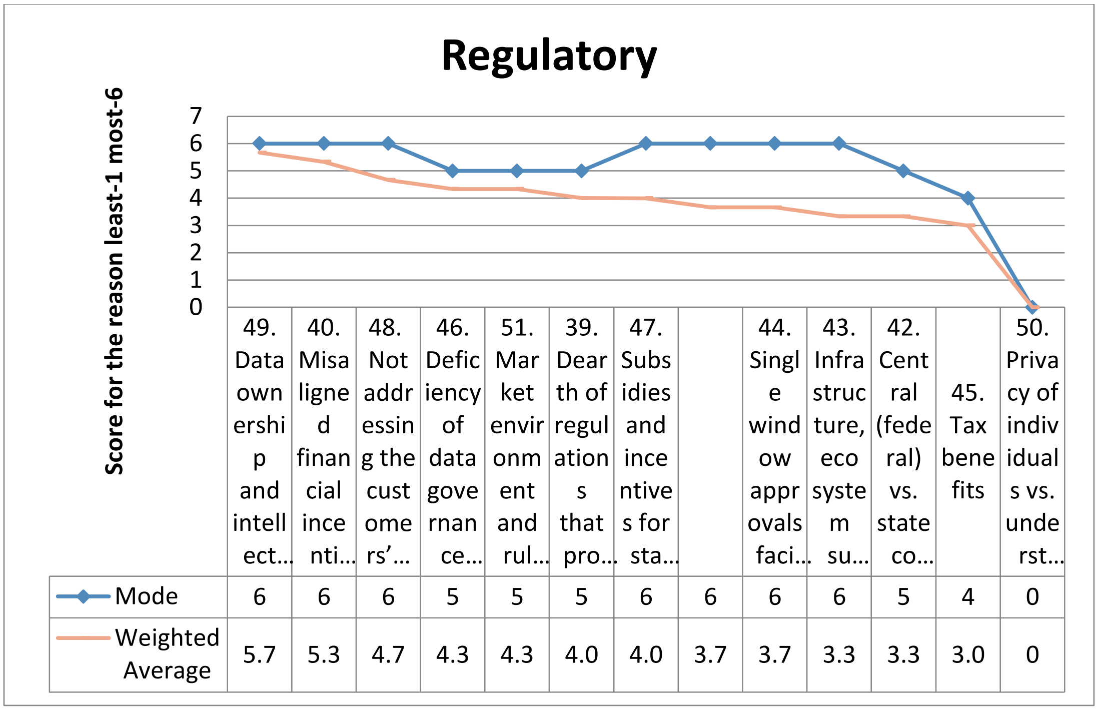

Figure 9
Regulatory bucket reasons scores

The top 3 reasons in regulatory bucket as depicted at Figure 9 Regulatory bucket reasons scores.

- Misaligned financial incentive in regulated markets,
- Data ownership, and IP rights,
- Not addressing the customers' security and privacy concerns.

4. Technology:

The survey 3 Google from questionnaire is provided at APPENDIX E4.

Statistical results using mode and average of scores against each reason are tabulated in descending order at Table 17

Technology bucket top three reasons scores.

Table 17
Technology bucket top three reasons scores

No. **TECHNOLOGY**	Mode	Average
55. Domain expertise gaps between IT and OT experts	4	4.5
59. Technology capability and integration	4	4.5
53. Compatibility among existing and proposed technologies/devices	6	4
61. Lack of situational intelligence in the sensors	5	4
62. Compatibility and co-existence issues the connectivity layer	4	4
63. Security vs. accessibility	4	4
54. Cyber security apprehensions	5	3.5
60. Architecture design	5	3.5
64. Absence of technical collaboration between IT, ET and OT	5	3.5
57. Technology diffusion tardiness	4	3.5
56. Edge vs. Fog vs. cloud dilemma	3	3.5
52. Adequacy of existing IT infrastructure	2	2

It is observed that for the causes 55, 59, 53, and 61, their mode and average reinforce the fact that they are the prime causes in Technology basket that are attributable for delayed propagation of digitalization in power sector.

Cause 55. Domain expertise gaps between IT and OT experts

Cause 59. Technology capability and integration

Cause 53. Compatibility among existing and proposed technologies/devices

Cause 61. Lack of situational intelligence in the sensors

Coming to technology, there are wider gaps between expertise needed both among IT and OT professionals working in the process plants. Compatibility qualms arise between the existing and proposed technologies.

It is seen that for the cause 54, 60 and 64 the averages are lower, though the mode values lead higher compared to the causes cause 55, 59, 53 and 61.

Cause 54. Cyber security apprehensions

Cause 60. Architecture design

Cause 64. Absence of technical collaboration between IT, ET and OT

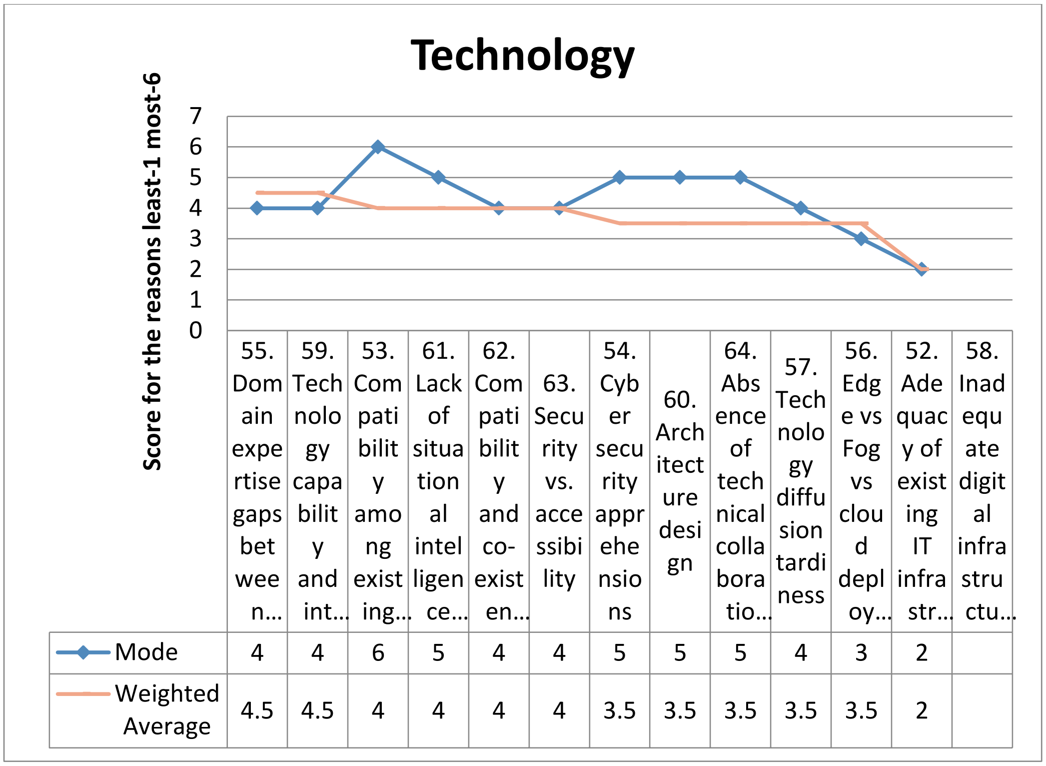

Figure 10
Technology reasons scores

The top 3 reasons in technology bucket as depicted at Figure 10 Technology reasons scores.

- Compatibility among existing & proposed technologies,
- Domain expertise gaps between IT and OT experts,
- Technology capability and integration

5. **Innovation:**

The survey 3 Google from questionnaire is provided at APPENDIX E5.

Statistical results using mode and average of scores against each reason are tabulated in descending order at Table 18

Innovation bucket reasons scores.

Table 18
Innovation bucket reasons scores

No. INNOVATION	Mode	Average
67. Demonstrability of results	5	5
75. Technology impact lags	6	4.7
72. Ignoring or not heeding to the superior functionalities of competitors	3	4.3
65. ML/AI based use cases to enhance reliability and efficiency	6	4.3
73. Work performed by people vs. computing machines	5	4.0
74. Providing more resources to IT staff vs. more self-service analytics	5	4.0
69. Energy efficient apparatus/ products	5	4.0
68. Latency in technology adoption	4	4.0
76. Pace of change and time to market	4	4.0
71. Waiting for use cases, proofs and references	3	3.7
70. Intelligent sensors	4	3.7
66. Products to support flexibility in operations	4	3.0

It is observed that for the causes 67, 75, and 65, their mode and average reinforce the fact that they are the prime causes in Innovation basket that are attributable for delayed propagation of digitalization in power sector.

Cause 67. Demonstrability of results

Cause 75. Technology impact lags

Cause 65. ML/AI based use cases to enhance reliability and efficiency.

Proof of expected results is very difficult to demonstrate when it comes to innovation aspects of digital tools. Industry looks for proof, references, and use cases for all innovations. It is egg and chicken story for innovators to convince to implement first, then ask to experience the result.

It is seen that for the cause 73, 74 and 69 the averages are lower, though the mode values lead higher compared to the causes cause 67, 75, 65.

Cause 73. Work performed by people vs. computing machines.

Cause 74. Providing more resources to IT staff vs. more self-service analytics

Cause 69. Energy efficient apparatus/ products

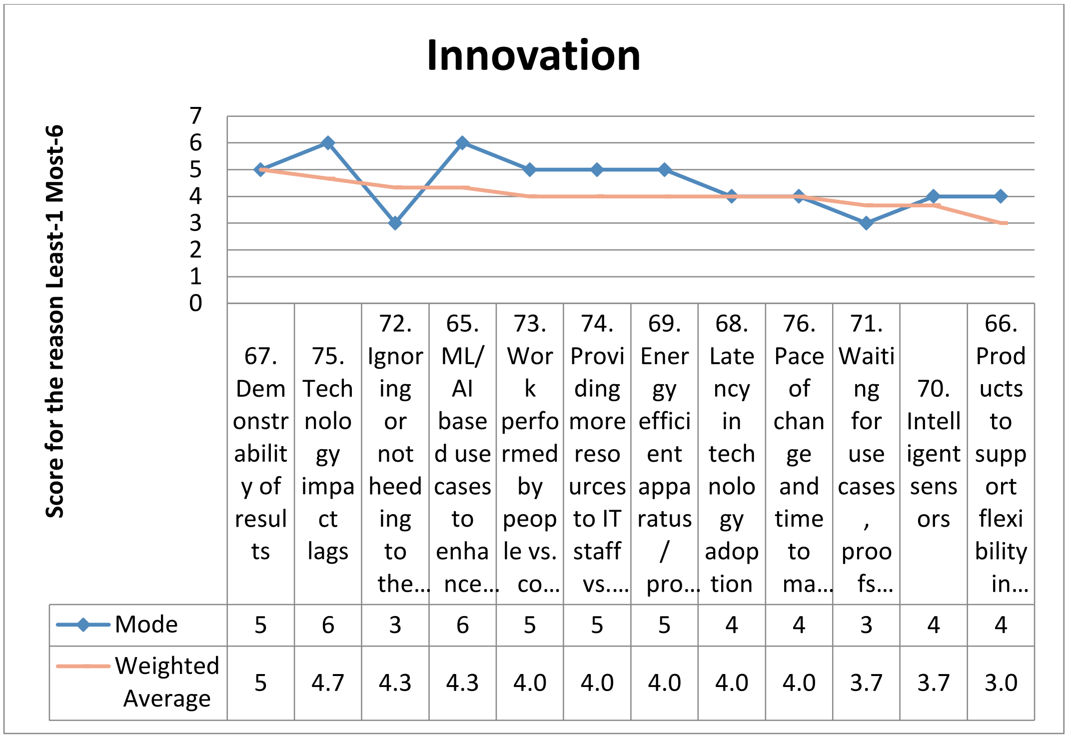

Figure 11
Innovation bucket reasons scores

The top 3 reasons in innovation bucket depicted at Figure 11 Innovation bucket reasons scores.

- ML/AI based use cases to eenhance reliability & efficiency,
- Demonstrability of results,
- Technology impact lags.

6. **Economic considerations:**

The survey 3 Google from questionnaire is provided at APPENDIX E6.

Statistical results using mode and average of scores against each reason are tabulated in descending order at Table 19

Economic considerations reasons scores.

Table 19
Economic considerations reasons scores

No. **ECONOMIC CONSIDERATIONS**	Mode	Average
79. Low load factors because of renewables resulting low revenues	5	5.0
80. Huge dues remain to be realized constraining working capital	5	4.7
81. Tangibility of digitization benefits is difficult to demonstrate	5	4.3
82. Features with no benefits to customers. Reluctance to pay for that.	5	4.0
87. Insufficient funds for digitization of the process	5	4.0
78. Disincentives for investment due to government policy paralysis	4	4.0
85. Distributed value creation and capture	4	4.0
88. Digital technologies enable the circular economy	4	3.3
83. Aggregate data or personalize (centralization vs. decentralization)	3	3.3
86. Investments friendly POCs.	3	3.0
84. Storing all data vs. selecting to store data to serves specific purpose	2	3.0
77. Balance sheet not supporting (financial constraints)	1	2.7

It is observed that for the causes 79, 80,81,82 and 87, their mode and average reinforce the fact that they are the prime causes in Economic considerations basket that are attributable for delayed propagation of digitalization in power sector.

Cause 79. Low load factors due to onslaught of renewables resulting low revenues

Cause 80. Huge dues remain to be realized constraining working capital.

Cause 81. Tangibility of digitization benefits is difficult to demonstrate.

Cause 82. Features with no benefits to customers. Reluctance to pay for that.

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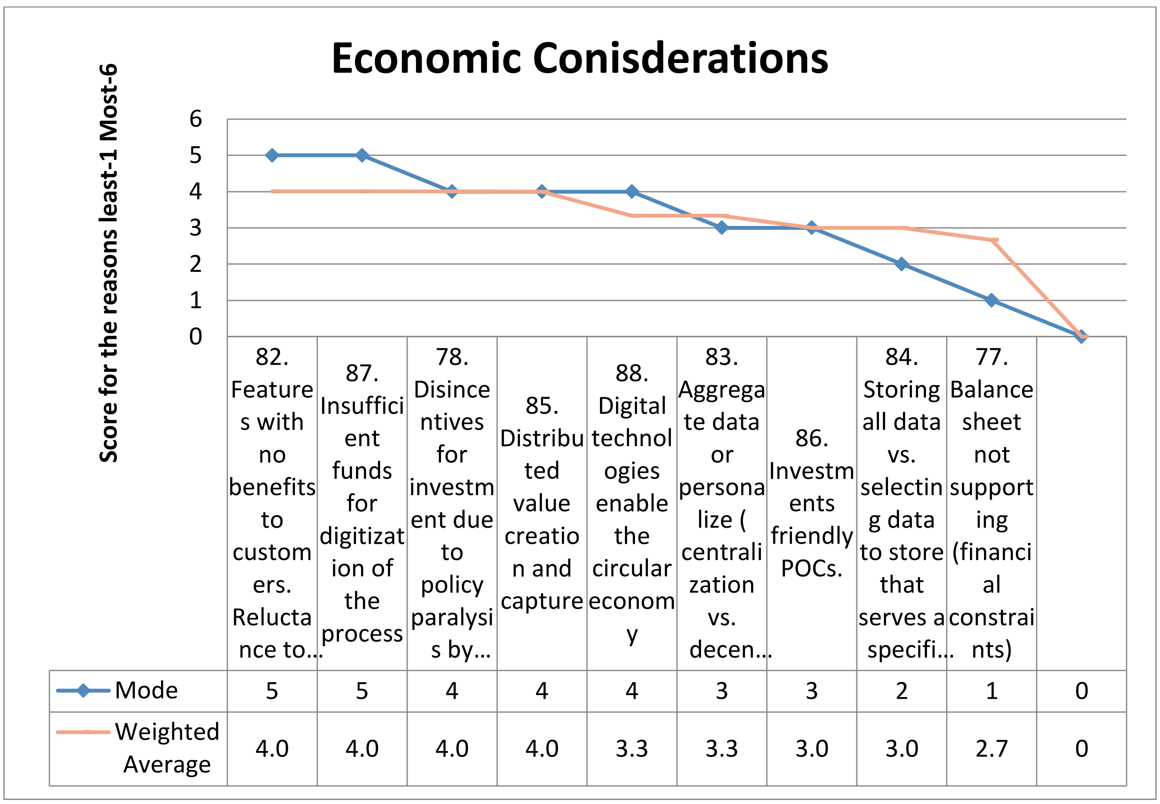


Figure 12
Economic considerations reasons scores

The top 3 reasons in economic considerations bucket as depicted at Figure 12 Economic considerations reasons scores.

- Tangibility of benefits is difficult to demonstrate,
- Low load factors due to onslaught of renewables resulting low revenues,
- Huge dues remain to be realized constraining working capital.

4.2.2 The top eighteen (18) reasons out of total ninety (90) reasons.

The below eighteen (18) reasons emerged taking top three from each of the six SORTIE buckets as the most significant ones among the total ninety (90) reasons that are responsible for non-percolation of digitalization in the power sector to the extent expected.

Cause 2. Not willing to be the first movers.

Cause 3. Notion that digitation is for services and not for plants.

Cause 4. Decision maker's dilemma

Cause 26. Perceived complexity of use

Cause 27. Perceived loss of power/authority

Cause 28. Privacy breach qualms

Cause 49. Data ownership and intellectual property rights

Cause 40. Misaligned financial incentive especially in regulated Markets.

Cause 48. Not addressing the customers' security and privacy concerns.

Cause 55. Domain expertise gaps between IT and OT experts

Cause 59. Technology capability and integration

Cause 53. Compatibility among existing and proposed technologies/devices

Cause 67. Demonstrability of results

Cause 75. Technology impact lags

Cause 65. ML/AI based use cases to enhance reliability and efficiency.

Cause 79. Low load factors due to onslaught of renewables resulting low Revenues.

Cause 80. Huge dues remain to be realized constraining working capital.

Cause 81. Tangibility of digitization benefits is difficult to demonstrate.

Each of these top 18 causes at

Table 20

The top 18 out of 90 reasons are to be dealt well through SORTIE framework primarily in first cut before deep diving into the rest of 72 reasons subsequently.

While carrying out the Delphi process for the framework evolution, these eighteen (18) salient reasons were delved on for brainstorming.

1. Cause 2: Not willing to be the first movers.

   Organizations are hesitant to adopt new digital technologies due to a reluctance to be pioneers in their industry. This hesitancy may stem from fear of uncertainty or potential risks associated with being early adopters.

2. Cause 3: Notion that digitization is for services and not for plants.

   Some decision-makers perceive digital transformation as more suited for service-oriented industries rather than traditional manufacturing or plant operations. This misconception may hinder investment in digital technologies for improving operational efficiency in industrial settings.

3. Cause 4: Decision maker’s dilemma.

   Decision-makers face challenges in committing to digital transformation initiatives due to uncertainties regarding the return on investment, potential disruptions, or conflicting priorities within the organization.

4. Cause 26: Perceived complexity of use.

   Stakeholders perceive digital solutions as complex to implement and use, which may deter adoption. This perception could arise from a lack of understanding of the technology or inadequate support and training provided to users.

5. Cause 27: Perceived loss of power/authority.

   Resistance to digital transformation may arise from concerns among decision-makers about potential loss of control or authority over processes and operations once automated or digitized.

6. Cause 28: Privacy breach qualms.

   Concerns about privacy breaches and data security issues inhibit the adoption of digital technologies. Organizations may hesitate to digitize processes due to fears of unauthorized access to sensitive information.

7. Cause 49: Data ownership and intellectual property rights.

   Uncertainty about data ownership and intellectual property rights creates barriers to digital transformation. Organizations may be reluctant to share or utilize data without clear policies and agreements in place.

8. Cause 40: Misaligned financial incentive especially in regulated markets.

   In regulated industries, financial incentives may not align with the adoption of digital technologies. Regulatory constraints or incentives may discourage investments in digitization efforts.

9. Cause 48: Not addressing the customers' security and privacy concerns.

   Failure to address customer concerns about security and privacy when implementing digital solutions can hinder adoption. Organizations must prioritize addressing these concerns to build trust and confidence among stakeholders.

10. Cause 55: Domain expertise gaps between IT and OT experts.

    Domain expertise gaps between Information Technology (IT) and Operational Technology (OT) professionals can impede the successful integration of digital solutions. Collaboration and knowledge-sharing between these two domains are crucial for effective digital transformation.

11. Cause 59: Technology capability and integration.

    Challenges arise from the limitations of technology capabilities and the complexity of integrating various systems and solutions. This includes issues related to interoperability, scalability, and the adaptability of technologies to meet specific organizational needs.

12. Cause 53: Compatibility among existing and proposed technologies/devices.

    The compatibility between existing technologies and newly proposed solutions presents a significant obstacle to digital transformation efforts. Mismatched systems can lead to inefficiencies, data silos, and increased costs associated with integration and customization.

13. Cause 67: Demonstrability of results.

    Difficulty in demonstrating tangible results or benefits from digital transformation initiatives hampers their acceptance and adoption. Clear and measurable outcomes are essential for gaining stakeholder buy-in and securing ongoing support for digital projects.

14. Cause 75: Technology impact lags.

    Delays in realizing the full impact of technology implementations hinder the perception of their effectiveness. Factors such as slow adoption rates, implementation challenges, and unforeseen barriers contribute to these lags in technology impact.

15. Cause 65: ML/AI based use cases to enhance reliability and efficiency.

    Leveraging Machine Learning (ML) and Artificial Intelligence (AI) for improving reliability and efficiency presents opportunities but also challenges. These include the need for high-quality data, expertise in algorithm development, and addressing ethical considerations surrounding AI applications.

16. Cause 79: Low load factors due to onslaught of renewables resulting in low revenues.

    The increasing integration of renewable energy sources into the grid leads to lower utilization or "load factors" for traditional energy generation facilities. This results in reduced revenues for energy providers, posing financial challenges and impacting investment in digital technologies.
17. Cause 80: Huge dues remain to be realized constraining working capital. Outstanding dues or debts constrain the availability of working capital, limiting the organization's ability to invest in digital transformation initiatives. Financial constraints hinder progress and innovation in adopting new technologies and upgrading existing infrastructure.

18. Cause 81: Tangibility of digitization benefits is difficult to demonstrate.

    Despite the potential benefits of digitization, proving its tangible value and return on investment can be challenging. Quantifying the impact on productivity, cost savings, and other key performance indicators is essential for justifying investments in digital transformation.

Table 20
The top 18 out of 90 reasons

Realigning BP for product/service delivery	Realigning people, process, and tools
1. Not willing to be the first movers. 2. Notion that digitation is for services and not for plants. 3. Decision maker's dilemma	4. Perceived complexity of use 5. Perceived loss of power/authority 6. Privacy breach qualms
Codes, standards, rules, mandates by government, regulators	**IT-OT-ET convergence**
7. Misaligned financial incentive especially in regulated markets; 8. Not addressing the customers' security and privacy concerns; 9. Data ownership and IP rights;	10. Compatibility among existing and proposed technologies/devices; 11. Domain expertise gaps between IT and OT experts; 12. Technology capability and integration;
Innovations that gel well with the needs of the power sector	**Investment, short/long term benefits, ROI**
13. ML/AI based use cases to enhance reliability and efficiency; 14. Demonstrability of results; 15. Technology impact lags;	16. Low load factors due to onslaught of renewables resulting low revenues; 17. Huge dues remain to be realized constraining working capital; 18. Tangibility of benefits is difficult to demonstrate;

4.2.3 The 90 Reasons and RQ1 response summary.

These specific challenges and considerations associated with each cause provide actionable insights highlighting their impact on digital transformation efforts within organizations. All the 90 reasons are enlisted at APPENDIX A also to get a separate printable sheet.

One of the key factors identified is the inherent complexity of integrating digital technologies into existing infrastructure and processes within the sector. This complexity often leads to challenges in compatibility, interoperability, and scalability, hindering the seamless adoption of digital solutions.

Additionally, regulatory constraints and compliance requirements emerge as significant barriers to digitization efforts. The intricate web of regulations, standards, and mandates imposed by government agencies and regulatory bodies creates uncertainty and adds layers of bureaucracy, slowing down the implementation of innovative digital solutions.

Moreover, the lack of a cohesive digitalization strategy and vision across stakeholders within the power sector exacerbates the challenges. Fragmentation in approach and divergent priorities among utilities, technology providers, and policymakers result in inefficiencies and missed opportunities for collaboration and knowledge sharing.

Furthermore, economic considerations play a crucial role in shaping the pace and scale of digitization initiatives. Limited capital investment, uncertain returns on investment, and competing priorities for budget allocation often deter organizations from making the necessary investments in digital transformation.

Lastly, cultural and organizational barriers, including resistance to change, skills gaps, and legacy mind-sets, pose significant challenges to the adoption of digital technologies in the power sector. Overcoming these barriers will require concerted efforts to promote a culture of innovation, invest in workforce development, and foster collaboration and knowledge exchange across industry stakeholders.

In summary, the research findings underscore the multifaceted nature of the challenges inhibiting the widespread adoption of digital technologies in the power sector in India. Addressing these challenges will require a holistic approach that combines regulatory reforms, strategic planning, investment incentives, and capacity-building efforts to create an enabling environment for digital transformation.

4.3 Research Question Two

Research Question 2: “What is the framework to expedite percolation of digitalization in the power sector?"

This research question aimed to develop a comprehensive framework for accelerating the adoption of digitization within the power sector. The research involved identifying best practices, lessons learned from successful digitization initiatives in similar contexts, and assessing the specific needs and challenges of the power sector in terms of technological infrastructure, regulatory frameworks, human capital, and financial investments.

The findings from phase one and phase two of the research including the answers of the research question one paved the foundation for developing SORTIE framework. Existing frame works, IEEE framework for example, were brainstormed in the Delphi workshop to initiate the evolution and refinements to converge on the SORTIE framework in three iterations. The research has culminated in the development of a comprehensive framework aimed at accelerating the adoption of digitization in the power sector. This framework is designed to address the multifaceted challenges identified in Research Question 1 and provide a roadmap for stakeholders to navigate the complexities of digital transformation effectively.

Three facets of Framework development were involved:

1. Inputs
    a. Research question 1 repsonses- 90 reasons including the 18 salient ones.
    b. Feedback and outcomes form the three surveys.
    c. IEEE framewrok for digital deployment

d. Inputs collated from focused dicussions with SMEs, Domain experts, Academacians, Software developers, Service providers etc.

2. Delphi

   a. Through structured deliberations in a Delphi workshop, the initial framework underwent refinement and iteration. The second iteration incorporated feedback and insights gathered from stakeholders, resulting in a revised framework aimed at enhancing simplicity and impact. Key components, such as the Performance Optimization Group (POG) and the closed feedback loop, were introduced to streamline implementation and ensure continuous improvement.

   b. In the final iteration, the SORTIE framework was further refined to prioritize clear objectives, process transformation, business model transformation, domain transformation, cultural/organizational transformation, and securing buy-in and funding. Additionally, a digital transformation roadmap was developed to guide the implementation process, ensuring alignment with organizational goals and desired outcomes.

3. Final SORTIE Framework

4.3.1 Inputs facet

Before venturing to development of a framework , three surveys were taken up so that inputs from these surveys could be used in Delhi technique to develop a framework . The three survey questionnaires, google forms etc are provided at Appendices –C to E.

Suvey-1: Inference from the maturity level data:

Please refer to the survey 1 at APPENDIX C. The results are summarized at Table 21 Digitalization Maturity Level.

Table 21
Digitalization Maturity Level

Level-1 Basic	Level-2 Opportunistic	Level-3 Systematic	Level-4 Differentiating	Level-5 Transformational
31	23	8	2	1
47.7%	35.4%	12.3%	3.1%	1.5%

Based on the survey results, several key inferences can be drawn regarding the current state of digitalization in the power sector in India:

1. Distribution across Digitalization Levels: The survey indicates a distribution of organizations across different levels of digitalization. Approximately half of the population surveyed is still at level 1, indicating a basic or minimal level of digitalization. About one-third have progressed to level 2, while only 12% have reached level 3, signifying a moderate level of digitalization.
2. Limited Advancement: The findings reveal that there are only a few organizations operating at higher levels of digitalization. Specifically, only a couple of organizations have reached level 4, representing a high degree of digital maturity. Additionally, the fact that only one organization is at level 5 highlights the rarity of highly advanced digitalization in the sector.

3. Long Road Ahead: Overall, the survey underscores the substantial gap that exists between the current state of digitalization in the Indian power sector and the desired level of advancement. The predominance of organizations at lower levels suggests that there is still a significant distance to cover in terms of fully embracing digital technologies and practices across the sector.
4. Need for Accelerated Progress: The survey results emphasize the urgent need for concerted efforts to accelerate digital transformation initiatives within the power sector. Organizations, policymakers, and stakeholders must prioritize investments in digital infrastructure, technology adoption, and skill development to bridge the existing gap and propel the sector towards higher levels of digital maturity.

In conclusion, the survey outcomes serve as a stark reminder of the imperative for comprehensive and accelerated digitalization efforts in the Indian power sector to unlock its full potential and meet the evolving demands of the digital age.

Survey 2: To rank the SORTIE buckets from 1 to 6 basis their significance to digitalization:

Please refer to the survey 2 at APPENDIX D.

The significance of SORTIE buckets lies in their role in guiding and prioritizing digitalization efforts within an organization or sector. The rankings provided by the focus group highlight the perceived importance of each bucket in driving digital transformation. The buckets are arranged in order of significance basis the survey 2 ranking results, shown at Figure 13
SORTIE buckets ranking.

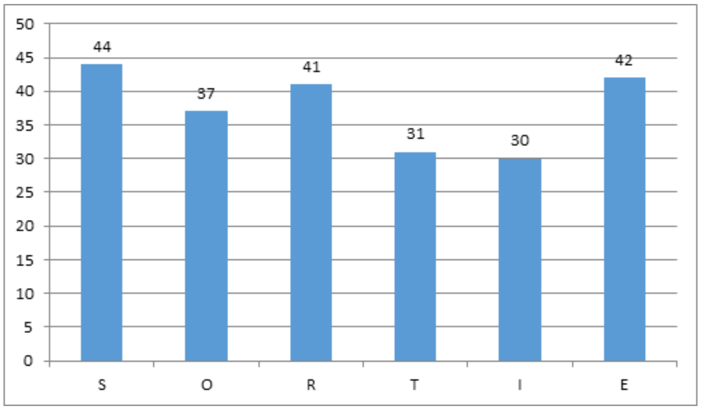


Figure 13
SORTIE buckets ranking

1. Strategy: Strategy is deemed the most critical aspect of digitalization, occupying the number one position. This underscores the importance of having a clear and comprehensive strategy that aligns digital initiatives with organizational goals and objectives. A well-defined strategy provides direction, ensures resource allocation, and facilitates effective decision-making throughout the digital transformation journey.
2. Economic Considerations: Economic considerations are ranked second, highlighting the significance of assessing the financial implications and potential returns on investment associated with digitalization efforts. Understanding the economic impact helps organizations justify investments, optimize resource allocation, and prioritize initiatives that offer maximum value and long-term sustainability.
3. Inadequate Regulatory Support: Regulatory support, or the lack thereof, is recognized as a critical factor influencing digitalization efforts, ranking third in importance. Inadequate regulatory frameworks or barriers can hinder innovation, impede the adoption of new technologies, and create uncertainty

for organizations operating in regulated industries. Addressing regulatory challenges is essential for creating an enabling environment conducive to digital transformation.

4. Operational Excellence: Operational excellence is placed fourth in the ranking, highlighting its role in optimizing processes, enhancing efficiency, and driving continuous improvement. Achieving operational excellence involves streamlining workflows, leveraging data-driven insights, and fostering a culture of innovation and collaboration across the organization.
5. Technology: While technology is a fundamental enabler of digitalization, it is ranked fifth in importance. This emphasizes the need to view technology not as an end in itself, but as a means to achieve strategic objectives and deliver value to stakeholders. Selecting the right technologies, ensuring interoperability, and mitigating risks associated with implementation are critical considerations within the digitalization journey.

6. Innovation: Innovation is positioned as the last priority in the ranking, highlighting its role as a complementary factor rather than a primary driver of digital transformation. While innovation plays a vital role in driving competitive advantage and fostering creativity, it must be supported by a solid strategy, conducive economic conditions, and a supportive regulatory environment to yield tangible outcomes.

Thus the ranking provided is as below.

1. Strategy
2. Economic considerations
3. Inadequate regulatory support
4. Operational excellence
5. Technology
6. Innovation

In summary, the SORTIE buckets ranking provides valuable insights into the key factors influencing digitalization efforts, guiding organizations in prioritizing their focus areas and allocating resources effectively to achieve successful digital transformation.

Suvey-3: Top three reasons in each SORTIE bucket:

It is already dealt in the previous section 4.2.2. Please refer to the Table 20
The top 18 out of 90 reasons.

In addition to the considering the outcomes from the above three surveys, aspects from industry were also considered for evolving a SORTIE framework.

4.3.2 Delphi process and framework development facet

The development of the digital deployment framework in three iterations reflects a meticulous process aimed at addressing the multifaceted challenges hindering the adoption of digitization in the power sector in India.

4.3.3 Ineration-1 in framework development

In the first iteration, the SORTIE framework was introduced, encompassing six key areas—strategy, operational excellence, regulatory landscape, technology, innovation, and economic considerations initiating with evaluating the existing frameworks in the market, IEE frame work for digital deployment, for example. Please refer Figure 14

FRAMEWORK for digital deployment iteration-1.

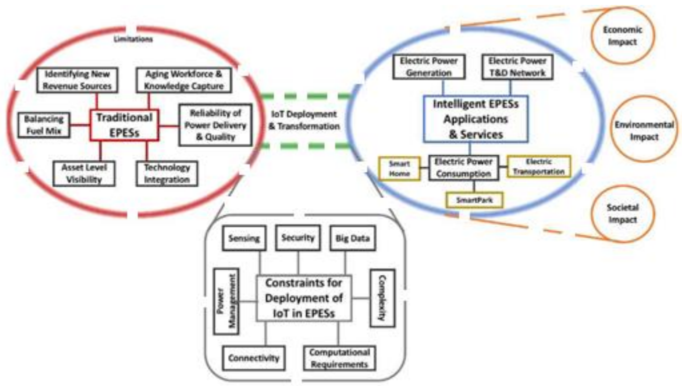


Figure 14
FRAMEWORK for digital deployment iteration-1

IEEE internet of things journal, Review of Internet of Things (IoT) in Electric Power and Energy Systems summarized the integrated digitalization limitations, constraints coupled with impacts in IT-OT deployment and transformation. Electric power and energy systems (EPESs) are undergoing a transformative shift towards clean distributed energy for sustainable global economic growth. The Internet of Things (IoT) plays a pivotal role in this transformation, offering real-time monitoring, situational awareness, control, and cyber security capabilities. This framework laid the foundation for identifying barriers and proposing strategies to expedite digitalization adoption. Through structured deliberations in a Delphi workshop, the initial framework underwent refinement and iteration.

By digitizing EPESs with IoT, asset visibility improves, distributed generation is managed optimally, energy wastage is reduced, and savings are created. Despite its potential, deploying IoT for EPESs comes with challenges that need viable solutions for continued growth.

Advancements in computational intelligence can further enhance IoT systems, mimicking biological nervous systems and enabling cognitive computation, streaming analytics, and distributed analytics at various levels, including edge and device levels.

Further on iterations it was revised, basically encompassing the SORTIE six wings converging with an eco-system stakeholders on the right-hand side fan blades, and implementers down below with a closed feedback loop back to SORTIE focus areas.

As a foundation to the concept of the framework, below points of view emerged from the subject matter experts, who ratified the research findings on reasons and ways to overcome those reasons for digitalization not percolating into the power sector to the extent expected.

- Digital expertise building.
- Access to timely, robust, and verifiable data.
- Flexible policies to accommodate new technologies and developments.
- Experiment, encourage POCs.
- Incorporate digital resilience by design into research, development, and product manufacturing.
- Provide a level playing field to allow a variety of companies to compete and serve consumers better.
- Learn from others and use cases.
- Prioritize use cases based solely on individual interest instead of business value, like prioritizing digital worker over asset management module (Nour, 2021). An end-to-end digital transformation consists of use cases that are designed, built, piloted, and rolled out (Crespo Marquez, 2020).
- Focus on implementing new tools—but neglect new ways of working, processes and standards and procedures.

- Dependence and reliance on small, siloes IT teams with inadequate reskilling or up skilling of internal resources.
- Lack of focus to build a model power plant, digital twin early limiting each asset's role in the transformation.
- An effective digital monitoring and maintenance solution requires an ideal balance and blend of people, processes, and digital tools.
- Data quality and structure
- Inadequate data quality including the frequency and detail of collected data,
- Non standardized data across assets within one company, and Non accessibility of data outside the plant perimeters

Operational excellence challnges are reolved at buiness and fuctnional level. Regulatory issues are addressed aptly by the consultatnts and concened officlas. Technology issues are reolved with repsect to usability, compatability, upgradation, domain experitse , engineering and operational aspects integrating ET-OT and It. To alleviate the issue of technolgy lag, a tab is kept on innovation and latest features are incorporated as the solution evolves.

Finally the cost benefit analysis, payback period are the ones that decide the go ahead on a chosen project. The curx of this framework is collaboration and proactively pre-empting apprehensions and possbile percpetual issues with regard to the design, implementation and operational apsctes. A performance optimiation group, POG, is the life of this framework.

In the iterative process of digital deployment framework evolution, continual improvement objective serves as the backbone, providing structure and guidance for each stage of the journey.

4.3.4 Ineration-2 in framework development

In iteration-2, the focus shifts towards refining and enhancing the digital solutions based on insights gained from the initial deployment. The framework for iteration-2 encompasses several key elements thoroughly followed:

1. Evaluation and Analysis: Began by conducting a thorough evaluation of the digital solutions deployed in iteration-1. Analyzed performance metrics, user feedback, and any observed challenges or bottlenecks to identify areas for improvement.
2. Iterative Development: Broke down the enhancements into manageable increments allowing for continuous feedback and adaptation throughout the development process.
3. Stakeholder Engagement: Engaged stakeholders, including end-users, decision-makers, and subject matter experts, in the refinement process.
4. Continual improvement and Quality Assurance: Implemented rigorous quality assurance protocols to validate the functionality, reliability, and performance of the refined digital solutions.
5. Data-Driven Insights: Leveraged data analytics and insights gained from iteration-1 to take informed decisions and prioritize enhancements in iteration-2.
6. Scalability and Flexibility: Ensured that the refined digital solutions are scalable and flexible to accommodate evolving business needs and requirements.
7. Training and Change Management: Provided comprehensive cross functional training and awareness programs for the end-users and stakeholders to

facilitate the adoption of the refined digital solutions. Implemented change management strategies to address any resistance or challenges encountered during the deployment process and foster a culture of continuous learning and improvement getting buy-in from each POG team member involved.

8. Monitoring and Performance Tracking: Established robust monitoring mechanisms to track the performance and impact of the refined digital solutions post-deployment.

By following this process during the iteration-2, value adds was ensured in framework refinement. Please refer to Figure 15

FRAMEWORK for digital deployment iteration-2.

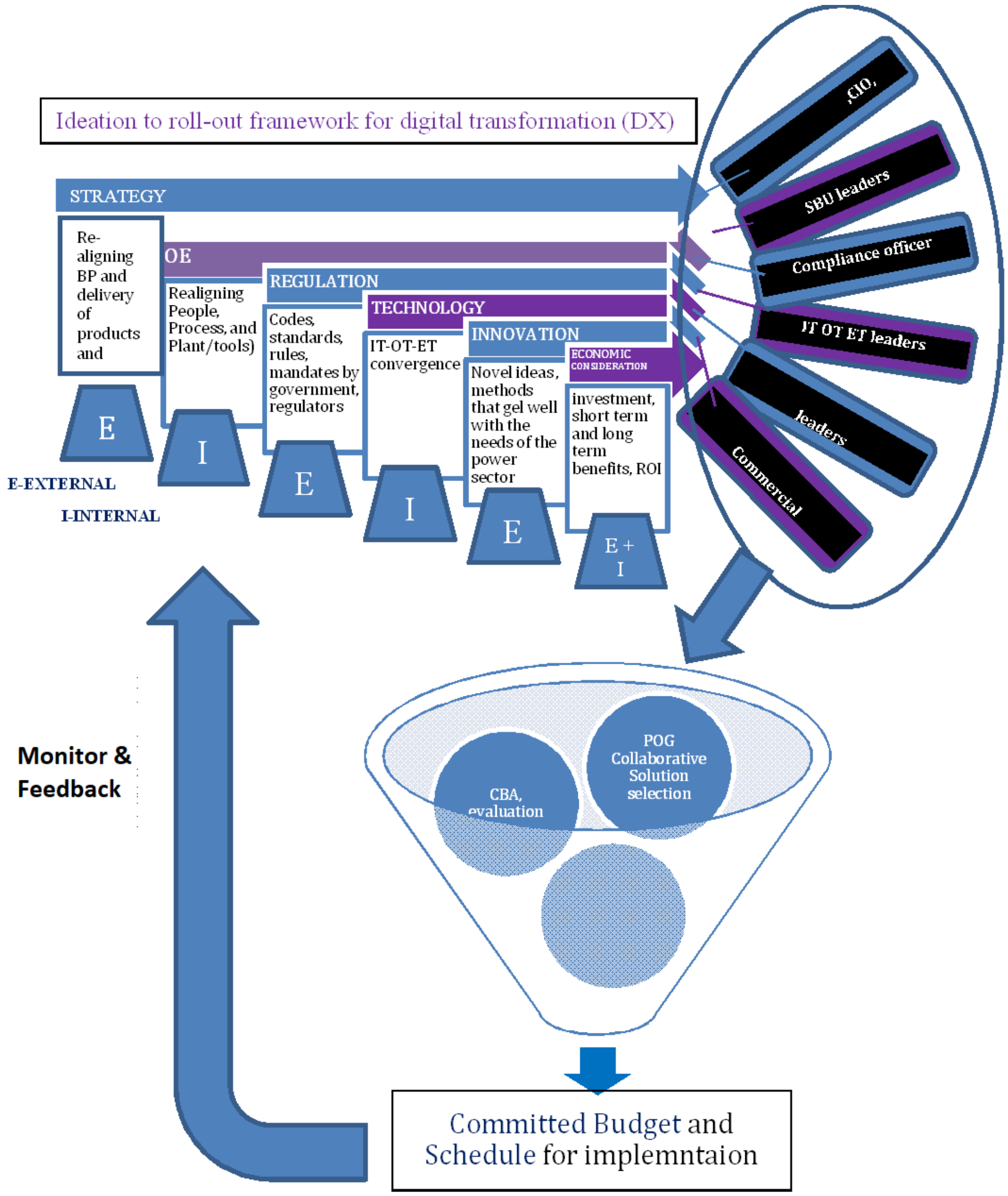


Figure 15
FRAMEWORK for digital deployment iteration-2

4.3.5 Ineration-3, the final iteration in the framework development

In the final iteration, the SORTIE framework underwent significant refinement to prioritize key pillars essential for successful digital transformation in the power sector. Clear objectives, process transformation, business model transformation, domain transformation, cultural/organizational transformation, and securing buy-in and funding emerged as focal points, ensuring a holistic approach to digitization. Additionally, a digital transformation roadmap was meticulously crafted to provide a structured guide for implementation, aligning initiatives with organizational goals and desired outcomes. Throughout the iterative process, collaboration, stakeholder engagement, and strategic alignment were emphasized to overcome barriers and harness the full potential of digitization. The resulting framework offers a comprehensive and systematic approach, serving as a valuable resource for policymakers, industry stakeholders, and other relevant actors seeking to accelerate digitization adoption in the power sector.

The formation of a Performance Optimization Group (POG), comprised of cross-functional team members, marks a proactive step towards addressing challenges and barriers across the six pillars of the SORTIE framework. Each pillar's respective area leaders, symbolized in the fan wings on the right-hand side, will collaboratively tackle issues hindering digital transformation efforts. By fostering open communication and leveraging diverse expertise, the POG aims to identify and resolve obstacles effectively, ensuring a robust foundation for successful digitization initiatives.

Following the identification and resolution of issues, the POG will undertake the critical task of selecting a solution that meets stringent criteria. This solution will undergo rigorous verification to ensure usability, authenticity, and alignment with minimum functional specifications. By scrutinizing features and benefits, the POG aims to ascertain the solution's suitability for addressing identified challenges, thereby laying the groundwork for effective digital transformation in the power sector.

A comprehensive cost-benefit analysis will then be conducted to evaluate the proposed solution's economic viability and potential returns on investment. Upon finalizing the solution, the POG will commit to a budget and schedule, signifying a firm commitment to driving forward digital transformation initiatives. Kick-off meetings with vendors will mark the commencement of implementation, with ongoing progress reviews and periodic reports serving to monitor implementation progress and address any emerging barriers effectively. Through these concerted efforts, the POG endeavors to navigate complexities, optimize performance, and propel the power sector towards a digitally empowered future. Digitalization helps power generation companies to adopt new business models (Dijkman, R.M. et al, 2017) and improve business processes considering new market dynamics and greater regulatory demands.

The framework undergone a subtle refinement, maintaining its fundamental elements and processes while aiming for a simpler and more impactful structure. This refinement involved the strategic inclusion of stakeholders within the six SORTIE focus areas, encompassing both internal and external challenge perspectives. By superimposing stakeholders onto the framework, it becomes more aligned with the diverse needs and perspectives within the organization and the broader external environment. This approach enhanced the framework's effectiveness by fostering a deeper understanding of the challenges and opportunities associated with digital transformation, ultimately facilitating more targeted and collaborative efforts towards achieving digitalization goals in the power generation sector.

Pease refer to Figure 16 SORTIE framework interation-3.

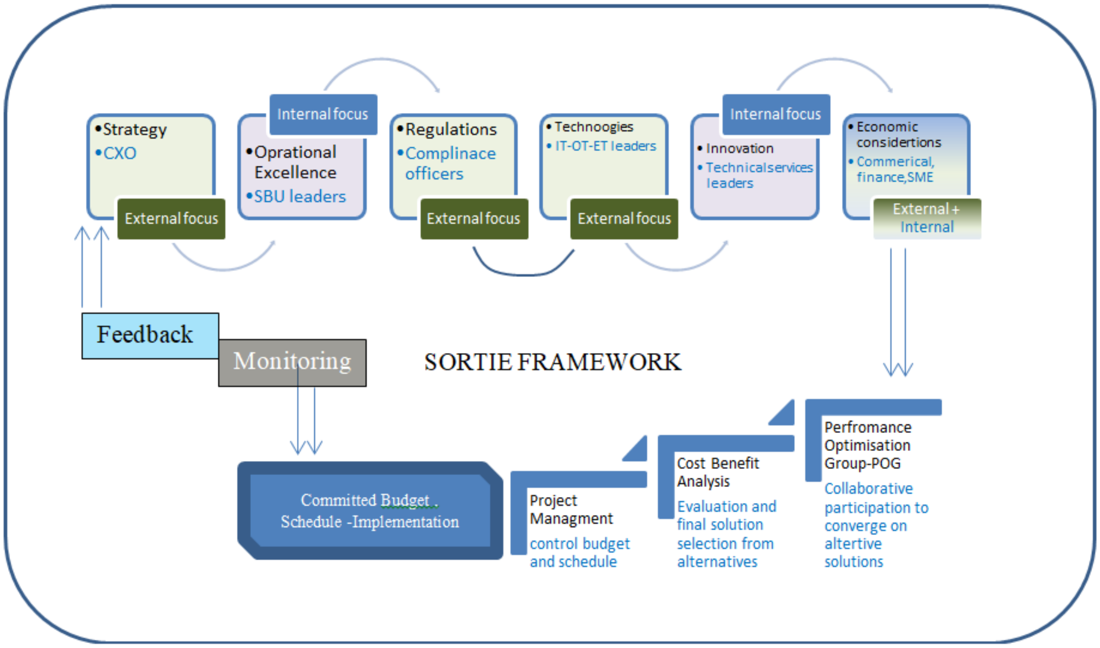


Figure 16
SORTIE framework interation-3

A closed feedback loop to the six SORTIE teams is to be provided by the POG team both during implementation and post-implementation to validate whether the value for money is realized, functionalities promised are delivered. After establishing the effective functioning of the solution, and closing any punch points that arose during commissioning, the solution is handed over to the user and IT department to take care of operation and maintenance aspects.

POG shall take care of change management, process and standards updating, training needs, hand holding if required etc. till the team becomes familiar and comfortable with the solution.

Brief processes that are undertaken by POG in the SORTIE framework include:

- Set clear objective:
- Process Transformation.
- Business Model Transformation.
- Domain Transformation.
- Cultural/Organizational Transformation
- Get buy-in. Before you can start building your digital transformation framework, you need buy-in from the top down.
- Secure funding.
- Assess your current state.
- Identify your goals and desired outcomes.
- Conduct a gap analysis.
- Create a digital transformation roadmap.
- Monitor & control the project.
- Roll out and handover to the O&M team.

Monitoring is based both qualitative parameters like user satisfaction, efficiency of usage, ease of utility etc and quantitative parameters cost and time metrics etc.

4.4 Conclusion

The digitization of India's power sector faces numerous hurdles, including a lack of comprehensive strategy, infrastructure challenges, regulatory hurdles, skill gaps, data security concerns, and financial constraints. A total of 90 reasons that hinder the effective adoption of digital technologies and limit the sector's ability to capitalize on emerging opportunities were collated.

Addressing these challenges requires a multifaceted approach that involves strategic planning, regulatory reform, capacity building, infrastructure upgrades, collaboration, and incentives to foster innovation and drive digital transformation.

To expedite digitization efforts in the power sector, a comprehensive framework is deveoped using three iterations for refinement. This framework emphasizes strategic alignment, collaboration, and stakeholder engagement. Key components include strategic planning to develop a cohesive digitalization strategy, regulatory reform to create a supportive policy environment, capacity building to enhance workforce skills, technology infrastructure upgrades, and collaboration and partnerships to drive innovation and collective action. By implementing this framework, stakeholders can overcome barriers and unlock the full potential of digital technologies to drive sustainable growth and enhance operational efficiency in the power sector.

As a dedicated researcher and practitioner of the SORTIE framework, I played a pivotal role in advancing digital transformation initiatives within his organization. My efforts have involved researching existing IT and OT systems, exploring emerging technologies relevant to SORTIE, and leading significant digital projects aimed at improving operational efficiency and enabling predictive maintenance. Leveraging the SORTIE framework, I have devised and implemented digital projects while considering critical factors such as data interoperability, security, scalability, and usability. Additionally, I have contributed to the creation of a knowledge repository capturing valuable insights, lessons learned, challenges faced, and best practices, which serves as a valuable resource for future digital transformation endeavors. During this journey my mentor and other peers contributed in reviews and getting insights and perspectives with a collective point of view in each phase of the research.

CHAPTER V:
DISCUSSION

5.1 Discussion of Results

The research results highlights the complex landscape surrounding the adoption of digitization in the Indian power sector. The findings reveal a multitude of interrelated challenges, ranging from technological complexities and regulatory constraints to cultural and organizational barriers. These obstacles underscore the need for a coordinated and holistic approach to digital transformation. Strategic planning, regulatory reforms, capacity building, investment in technology infrastructure, and fostering collaboration emerge as key priorities to expedite digitization adoption. Additionally, the significance of addressing economic considerations, such as investment incentives and demonstrating tangible benefits, cannot be overstated. The proposed framework provides a roadmap for stakeholders to navigate these challenges effectively, emphasizing the importance of strategic alignment, collaboration, and continuous innovation. By addressing these challenges and leveraging digital technologies effectively, the power sector in India can unlock new opportunities for efficiency, reliability, and sustainability, ultimately benefiting consumers and society as a whole.

5.2 Discussion of Research Question One

The findings from Research Question 1 shed light on the multitude of reasons contributing to the slow adoption of digitization in the power sector, as categorized within the SORTIE framework. The analysis revealed a total of 90 reasons distributed across the six focus areas: Strategy, Operational Excellence (OE), Regulations, Technology, Innovations, and Economic Considerations. This comprehensive inventory of reasons provides valuable insights into the complex challenges faced by stakeholders in digitizing the power sector.

Within the Strategy focus area, reasons primarily revolved around the need to realign business processes for product/service delivery. Issues such as lack of clear strategic direction, resistance to change, and inadequate leadership support emerged as prominent barriers to digitalization efforts. These findings underscore the importance of developing a cohesive digitalization strategy that aligns with organizational goals and fosters a culture of innovation and agility.

In the Operational Excellence focus area, challenges related to people, processes, and tools were identified as key barriers to digital transformation. Factors such as workforce skill gaps, inefficient workflows, and legacy systems were cited as impediments to achieving operational excellence through digitization. Addressing these challenges will require targeted investments in workforce development, process optimization, and technology infrastructure to enhance operational efficiency and drive sustainable growth.

Regulatory constraints emerged as a significant barrier to digitalization within the Regulations focus area. Issues such as outdated regulations, compliance burdens, and bureaucratic red tape were cited as obstacles to innovation and investment in digital technologies. To overcome these challenges, stakeholders must advocate for regulatory reforms that promote innovation, remove barriers to entry, and create a supportive policy environment for digital transformation.

In the Technology focus area, challenges related to IT-OT-ET convergence and technology infrastructure were highlighted as key barriers to digitalization. Factors such as interoperability issues, cybersecurity risks, and legacy IT systems posed significant challenges to the adoption of digital technologies in the power sector. Addressing these challenges will require investments in robust and scalable technology infrastructure, as well as the adoption of emerging technologies such as artificial intelligence, Internet of Things, and big data analytics.

Innovations that align with the needs of the power sector were identified as critical enablers of digitalization within the Innovations focus area. However, challenges such as limited R&D funding, slow pace of technology adoption, and resistance to change were cited as barriers to innovation in the power sector. To foster innovation, stakeholders must prioritize investments in R&D, foster collaboration and partnerships, and create a supportive ecosystem for technology startups and entrepreneurs.

Finally, Economic Considerations such as investment, short-term and long-term benefits, and return on investment emerged as key drivers of digitalization within the power sector. However, challenges such as limited funding, high upfront costs, and uncertain ROI were cited as barriers to investment in digital technologies. To overcome these challenges, stakeholders must develop robust business cases, prioritize investments based on strategic objectives, and explore innovative financing mechanisms such as public-private partnerships and incentive programs.

In conclusion, the findings from Research Question 1 underscore the multifaceted nature of the challenges facing digitalization in the power sector. By addressing these challenges within the context of the SORTIE framework, stakeholders can develop targeted strategies and interventions to accelerate the adoption of digital technologies, drive operational excellence, and unlock the full potential of the power sector in the digital age.

5.3 Discussion of Research Question Two

The development of the SORTIE framework represents a significant step towards fostering faster, better, and more robust digitalization in the power sector. By synthesizing the findings from Research Question 1 and leveraging insights from subject matter experts, the framework provides a structured approach to addressing the key challenges identified within the six focus areas: Strategy, Operational Excellence (OE), Regulations, Technology, Innovations, and Economic Considerations.

The SORTIE framework offers a systematic way to organize and prioritize the reasons for the slow adoption of digitalization in the power sector. By categorizing these reasons into distinct focus areas, the framework enables stakeholders to identify and address the root causes of digitalization challenges more effectively. Moreover, the framework serves as a common language for stakeholders to communicate and collaborate on digitalization initiatives, facilitating alignment and coordination across diverse stakeholder groups.

Within the Strategy focus area, the SORTIE framework emphasizes the importance of realigning business processes for product/service delivery to drive digital transformation. By prioritizing strategic initiatives that support innovation, agility, and customer-centricity, organizations can create a solid foundation for successful digitalization efforts. The framework encourages stakeholders to develop clear and actionable strategies that align with organizational goals and foster a culture of continuous improvement and innovation.

In the Operational Excellence focus area, the SORTIE framework highlights the critical role of people, processes, and tools in driving digital transformation. By investing in workforce development, process optimization, and technology infrastructure, organizations can enhance operational efficiency and drive sustainable growth. The framework encourages stakeholders to adopt best practices and standards for digitalization, leverage emerging technologies, and streamline workflows to improve productivity and performance.

Regulatory constraints are addressed within the Regulations focus area of the SORTIE framework. By advocating for regulatory reforms that promote innovation, remove barriers to entry, and create a supportive policy environment for digital transformation, stakeholders can unlock new opportunities for growth and innovation. The framework encourages stakeholders to engage with policymakers, industry associations, and regulatory bodies to shape policies that support digitalization and drive economic development.

In the Technology focus area, the SORTIE framework emphasizes the importance of IT-OT-ET convergence and technology infrastructure in driving digital transformation. By addressing interoperability issues, cybersecurity risks, and legacy IT systems, organizations can create a secure and resilient digital ecosystem. The framework encourages stakeholders to invest in robust and scalable technology infrastructure, embrace emerging technologies, and adopt industry best practices to drive innovation and competitiveness.

Innovations that align with the needs of the power sector are highlighted within the Innovations focus area of the SORTIE framework. By fostering a culture of innovation, collaboration, and entrepreneurship, stakeholders can drive technological advancements and create new opportunities for growth and development. The framework encourages stakeholders to invest in R&D, foster partnerships with startups and technology providers, and leverage emerging technologies to address industry challenges and drive sustainable innovation.

Finally, Economic Considerations such as investment, short-term and long-term benefits, and return on investment are addressed within the Economic Considerations focus area of the SORTIE framework. By developing robust business cases, prioritizing investments based on strategic objectives, and exploring innovative financing mechanisms, stakeholders can unlock new sources of capital and drive investment in digital technologies. The framework encourages stakeholders to adopt a holistic approach to economic planning, considering both financial and non-financial factors to maximize the value of digitalization initiatives.

5.4 Discussion Framework Utility

Both internal and external Challenges, in each six pillars SORTIE are to be taken up with respective area leaders.After issues are sorted out POG will select a solution which will be verified for usability, authenticity, features, and benefits and meeting minimum functional specifications along with alternative options. A cost benefit analysis is carried out.

Upon finalizing the solution, a commitment for budget and schedule is to be signed off by the POG team and kick start the kick-off meetings with the vendor. The implementation progress is reviewed, and periodic reports are generated to flag barriers if any are arising. A closed feedback loop to the six SORTIE teams is to be provided by the POG team both during implementation and post-implementation to validate whether the value for money is realized, functionalities promised are delivered. After establishing the effective functioning of the solution, and closing any punch points that arose during commissioning, the solution is handed over to the user and IT department to take care of operation and maintenance aspects. POG shall take care of change management, process and standards updating, training needs, hand holding if required etc till the team becomes familiar and comfortable with the solution. Monitoring is based both qualitative parameters like user satisfaction, efficiency of usage, ease of utility etc and quantitative parameters cost and time metrics etc. POG flow process in framework uitlity is shown in Figure 17

POG flow process.

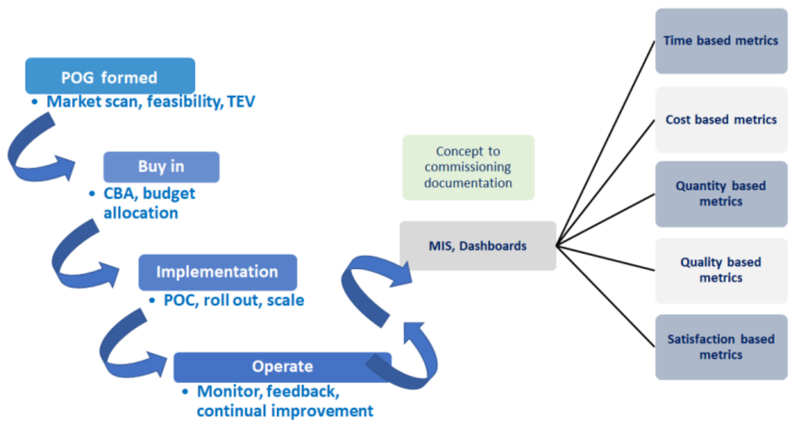


Figure 17
POG flow process

The SORTIE framework assures effective IT-OT marriage. The SORTIE framework indeed plays a crucial role in ensuring the effective integration of IT (Information Technology) and OT (Operational Technology), fostering collaboration among various roles involved in managing data. Let's break down the components of the SORTIE framework and how they contribute to this synergy:

1. Seamless Integration of IT-OT: This is the core objective of the SORTIE framework. It aims to seamlessly merge IT systems (which deal with data processing, storage, networking, etc.) with OT systems (which control physical processes like

manufacturing, energy production, etc.). This integration is essential for optimizing operations, enhancing efficiency, and enabling better decision-making.

2. Collaboration Among Data Roles:

Data Architect: Responsible for designing the overall structure and architecture of the data systems, ensuring that IT and OT systems can effectively communicate and share data.

Data Engineer: Builds and maintains the data pipelines, ensuring that data flows smoothly between IT and OT systems, and is properly processed and stored.

Data Administrator: Manages the day-to-day operations of the data systems, including security, access control, and performance optimization.

Data Scientist: Utilizes advanced analytical techniques to extract insights from the data generated by IT and OT systems, helping to improve operations and decision-making.

Data Analyst: Conducts exploratory data analysis and generates reports to provide actionable insights to stakeholders.

Data Owner: Typically a business stakeholder who is responsible for the overall governance and strategy of the data within the organization.

By fostering collaboration among these roles, the SORTIE framework ensures that the needs and requirements of both IT and OT are effectively addressed, leading to more successful integration and utilization of data for business objectives.

Overall, the SORTIE framework serves as a comprehensive approach to facilitate the effective marriage of IT and OT, recognizing the importance of collaboration among various data-related roles to achieve this goal.
Pease refer Figure 18
IT-OT marriage platform.

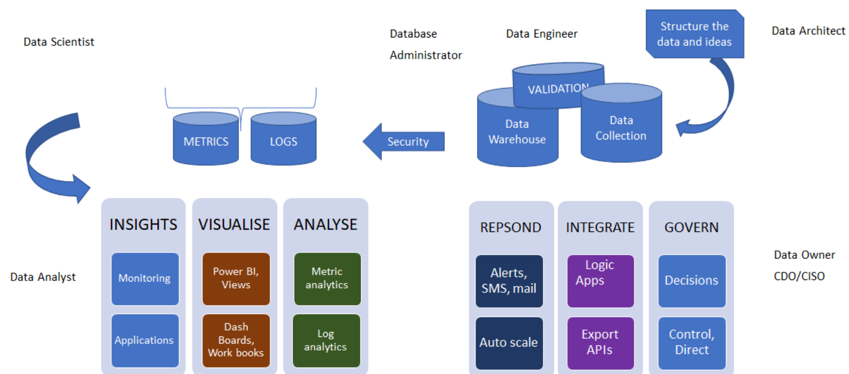


Figure 18
IT-OT marriage platform

Absolutely, true leadership requires a deep connection to the ground reality combined with analytical acumen. In today's fast-paced business environment, C-suite officers need to have a clear understanding of what's happening at the operational level and access to relevant information to make informed decisions. The SORTIE framework indeed facilitates the integration of information from the field to the boardroom, enabling seamless communication and decision-making processes.

Digitalization plays a significant role in achieving this goal, particularly through the integration of IT and OT systems. This integration, allows for the real-time flow of data and insights from operational processes (the "field") to executive levels (the "boardroom"). Here's how the integration helps:

1. Real-Time Insights: By integrating IT and OT systems, leaders gain access to real-time data and insights about operational performance, enabling them to make timely and informed decisions.

2. Efficiency and Optimization: IT-OT integration enables the automation of processes and the optimization of resources, leading to improved efficiency and cost savings.

3. Risk Management: With access to real-time data from the field, C-suite officers can better assess risks and take proactive measures to mitigate them, enhancing overall resilience and business continuity.

4. Innovation and Agility: By leveraging digital technologies and data-driven insights, leaders can identify opportunities for innovation and adapt quickly to changing market conditions.

5. Strategic Alignment: IT-OT integration helps ensure that operational objectives are aligned with broader strategic goals, facilitating better decision-making at all levels of the organization.

Overall, the SORTIE framework, combined with digitalization and IT-OT integration, empowers C-suite officers to stay connected to the ground reality, make data-driven decisions, and drive organizational success.Please refer Figure 19 Field to board room IT-OT integration.

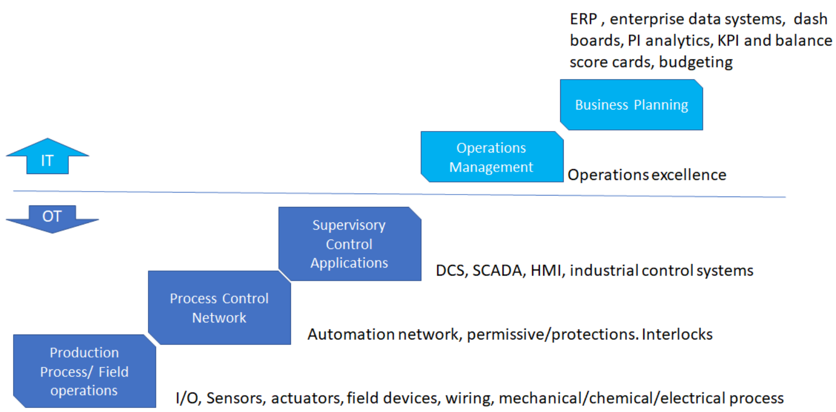


Figure 19
Field to board room IT-OT integration

5.5 Conclusion

Deploying the SORTIE framework has yielded promising results, with projects demonstrating significantly accelerated timelines compared to traditional digitalization efforts. Typically, projects in the power sector undergo a lengthy cycle of 10-18 months, but with SORTIE, these timelines have been condensed to a window of 3-6 months. This expedited pace has not only reduced project latency but also mitigated technology lag, allowing organizations to stay ahead in the rapidly evolving digital landscape.

Furthermore, the adoption of SORTIE has led to notable cost and effort reductions by eliminating unnecessary iterations and minimizing mistakes. The collaborative nature of the framework has facilitated seamless integration between IT and OT experts, enabling them to converge on viable solutions with mutual buy-in, thereby enhancing operational efficiency and driving innovation within the sector.

CHAPTER VI:
USE CASES DEPLOYING THE SORTIE FRAMEWORK

6.1 Use Cases –in power plant

The SORTIE framework has been instrumental in driving digital transformation initiatives across various utilities, resulting in significant benefits and improvements in operations, maintenance, quality, and technical services. Several utilities, such as OPTCL, CLP, and Noida Power Company Limited, have successfully leveraged digital technologies to enhance their efficiency, reliability, and overall performance.

For instance, OPTCL established a robust optical ground wire (OPGW) communication backbone to support various IT and OT applications, including unified load dispatch, SCADA, EMS, PMU, GIS, substation automation, and remote surveillance. Similarly, CLP implemented virtual desktops, cloud security solutions (Assente D et al, 2016), and advanced security technologies to improve its operational resilience and data protection. Noida Power Company Limited adopted advanced distribution management systems, outage management systems, and customer relationship management tools to streamline its operations and enhance customer satisfaction.

The deployment of digitalization in power plants encompasses a wide range of applications, including asset monitoring, process optimization, and condition monitoring. Advanced tools such as advanced process control (APC) software, pattern recognition software, and fatigue monitoring systems are being used to optimize plant performance, improve safety, and reduce operational costs. These tools enable utilities to optimize their operations, minimize downtime, and enhance overall efficiency.

Moreover, digitalization is not limited to core operational functions but is also extending to peripheral areas such as environmental health and safety (EHS), procurement, logistics, finance, and human resources. This comprehensive approach to digitalization allows utilities to transform their entire value chain and achieve greater agility, transparency, and cost-effectiveness.

Overall, the deployment of digitalization in the power sector is driven by various factors, including the need for operational efficiency, compliance with regulatory requirements, and the desire to improve customer experience. By embracing digital technologies and leveraging frameworks like SORTIE, utilities can unlock new opportunities for innovation, growth, and sustainability in the rapidly evolving energy landscape.

For example OPTCL-Odisha Power Transmission Corporation Limited, a transmission network company in Eastern India established a robust optical ground wire (OPGW) communication backbone to support its IT and OT applications like unified load dispatch and communication, SCADA, supervisory control and data acquisition, EMS-energy management system, PMU-phasor measurement units, GIS-geographic information system, DTPC-digital tile-protection coupler, substation automation, AMI-advanced metering infrastructure, remote surveillance and videoconferencing projects etc.

CLP-China Light and Power undertook initiatives like introduction of virtual desktops, conditional access for personal devices and adoption of Zscaler for cloud security, adoption of OPSWAT (Omni-platform security with access technologies), MetaDefender kiosk for scanning external dicks, etc.

Noida Power company Limited brought oracle outage management system, integrated advanced distribution management system (ADMS), SCADA-supervisory control and data acquisition system, CRM-customer relationship management, tab-based apps for maintenance management, paperless logging of operational shift reports, DC-DR-data center disaster recovery, HCI hyper converged infrastructure as part of business continuity aspect.

O&M Strategies for cost management by FLUENT FRID, Digital Transformation of Lube oil management system (LOMS) and Value creation by Lube oil consumption Optimization by NTPC, Digitalization of periodic ash dyke inspection by cross functional team through mobile app by NTPC, Data Analytics to boost availability of Dry Ash Conveying System at APL-Tirora by Adani Power, Digitalizing operations: best practices in GWEL thermal power plant for logbook management by GMR Power, Leveraging AVEVA PI System for Advanced Enterprise Asset Management , Digital Block driven transformation for fast-track or shutdown and turnarounds projects, Project Drishti for safety culture by Tata Power, Reduction of the Carbon Footprint in the existing Plant by Blending Steam with Solar Tower Technology using data analytics, Asset Fault Prediction through Machine Learning Models by NTPC, Use of EPRI developed knowledge-based fault signature with Advanced Pattern recognition (APR), Advanced Process Control Demonstrations for Improving Steam Temperature Control etc. are some more examples on digitalization.

IOT based condition monitoring of distribution, transmission, generation assets, analytics-based decision making, VR based training to employees, dash boards to improve visibility of organizational performance, customer experience software, smart metering solutions.

It’s also important to incentivize technological development through institutional reforms, including the easing of existing systems, such as realizing six-year periodic inspections of thermal power generation facilities by AI and IoT technologies.

Using this framework, digital solutions are deployed in operations, maintenance, efficiency, planning, and HSE departments in power plants. There are four broad functional areas of use cases viz., control, optimization, visualization, and automation. Please refer Figure 20

Functional uses of digitalization.

Optimization in three areas viz., outcome, resource utilization, and risk management. Visualization is mainly having two areas MIS and dash boards.

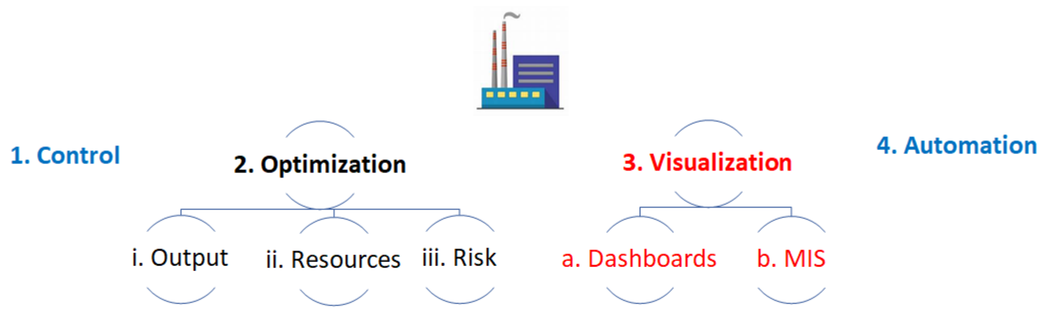


Figure 20
Functional uses of digitalization

6.2 Wheel of Use Cases

The wheel of use cases depicted in Figure 21 SORTIE framework use cases in power plant, showcase numerous examples encompassing maintenance management-OLSM, Maximo , Operational intelligence-PADO, ABT, digital worker, Auto start up and shut down curves, Logistics, warehouse management, ash management, coal management, sourcing and procurement , time management, etc.

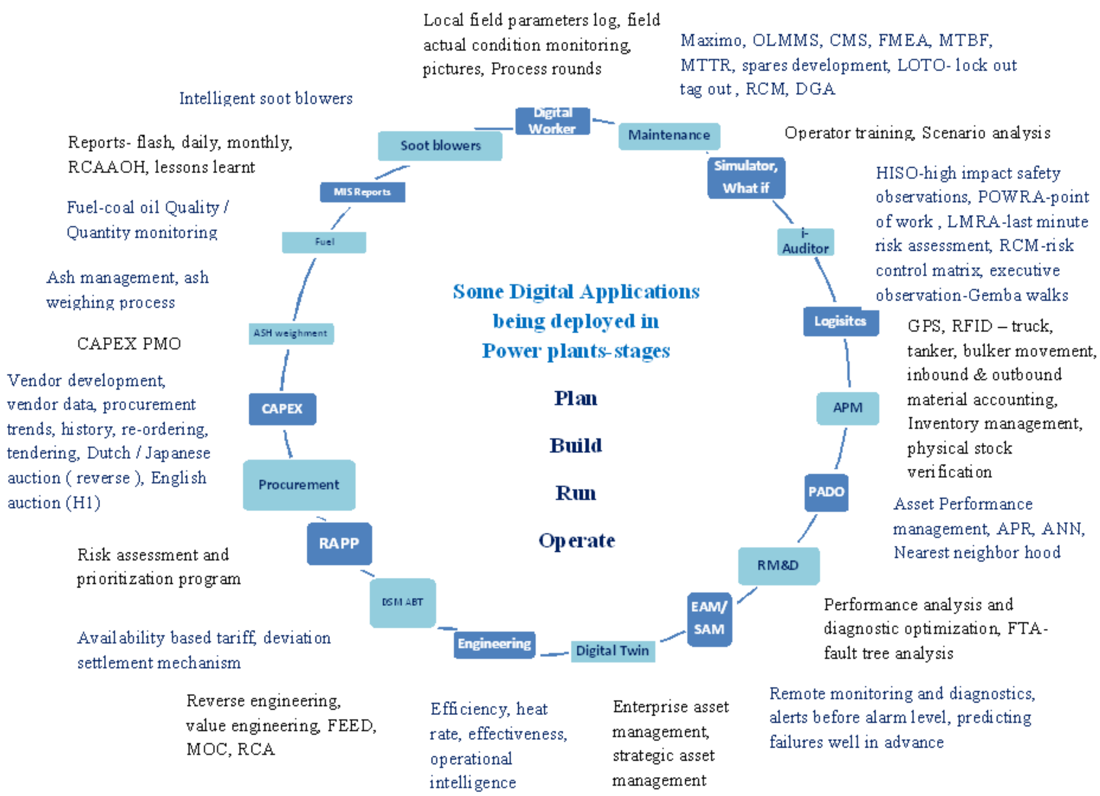


Figure 21
SORTIE framework use cases in power plant

Digitalization is being deployed in various applications such as below in power plants, though the degree and extent of number of applications vary from plant to plant depending on the maturity and level of digitalization (Kane et al, 2017) undertaken.

Present day employees expect to work in an environment that supports their creativity and personal growth. The workplace digitalization is hailed by the employees as it enhanced their productivity, wellbeing and resulted in better stake holder management contrary to initial apprehensions of threat to their jobs. Further the changing and aging workforce need for easy access to data, mistakes reduction goals, accountability, transparency, safety compliance goals act as drivers. It balances authority and workflow breaking siloes. Some advanced digital tools that may be deployed alongside the existing control system.

6.3 Salient examples of use cases

Deploying the SORTIE framework through several use cases, each highlighting different aspects of the framework's application has been a good expereince accopmlihsed through this reearch. Here are a few examples in strategic planning, regulatory reform, technology infratructure and capacity buidling:

1. Strategic Planning Use Case:

A leading utility company in India decides to embark on a digital transformation journey to improve operational efficiency and customer satisfaction. Using the SORTIE framework, the company conducts a comprehensive assessment of its current digital maturity level and identifies key areas for improvement. Leveraging strategic planning principles outlined in the framework, the company develops a cohesive digitalization strategy aligned with its organizational goals and industry best practices.

This strategy includes defining clear objectives, prioritizing investments, and establishing governance structures to oversee implementation. The power value chain has numeraous use cases as depicted in Figure 22

Backward and Forward Integration of Power Value Chain . It begins with inbound opeartions like coal imports entailing mine to load port to discharge port to receipt at plant.It covers all the energy conversion processes. Measurements , weighments, monitoring paratmers, contolling paramters, autmation of equipment, protections, interlocks, permissives, ESG, sourcing procurement, security, surveillance, performance optimisation etc.

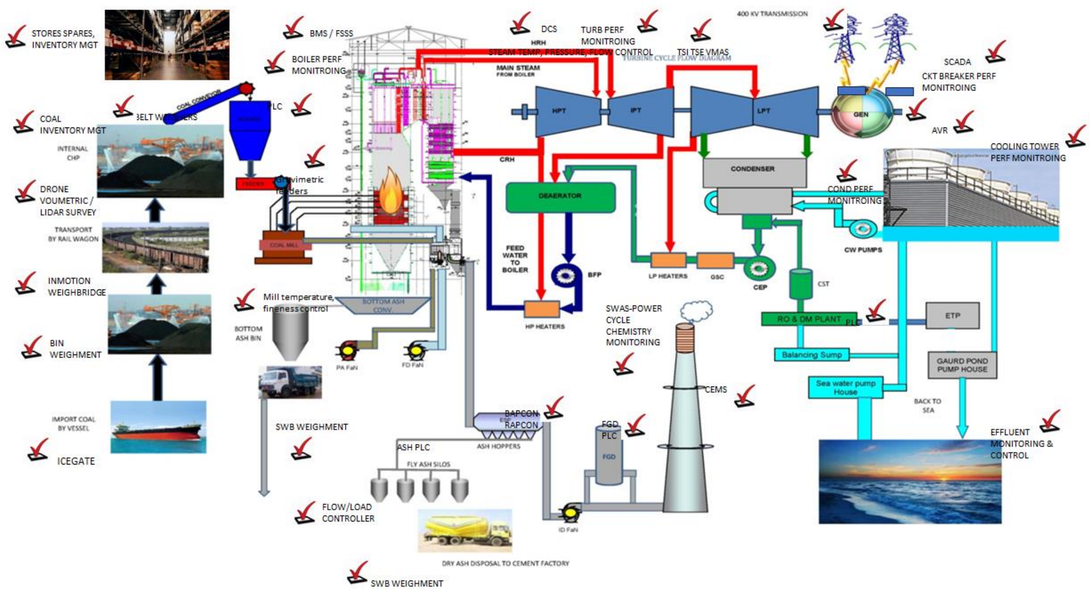


Figure 22
Backward and Forward Integration of Power Value Chain

2. Regulatory Reform Use Case:

In response to regulatory challenges hindering digitization efforts, a consortium of power sector stakeholders collaborates to advocate for reforms that promote innovation and remove barriers to entry. Drawing upon the regulatory bucket of the SORTIE framework, the consortium engages with policymakers and regulatory authorities to advocate for streamlined approval processes, updated regulations, and a supportive policy environment for digital transformation. By leveraging collective expertise and influence, the consortium successfully influences regulatory reforms that create an enabling environment for digitization adoption.

Enviromnatal complaince with respect to air , water and land pollution control requirements , safety anf factory rules compliance necesaties, meeting ESG mandates are some examples.

Some example are shwon at Figure 23

Drone deployment using sortie framework. From left to right , row wise, first picture shows eia study being carried out by a drone, transmission towers and lines online isnpection, cross country conveyor inspection, coal physical stock verification, fire fighting, boiler internal inspection using a shperical cage mounted drone, warehouse auditing, tall structures like chimneys and natural draft cooling towers inspection, surveillance and security usage.

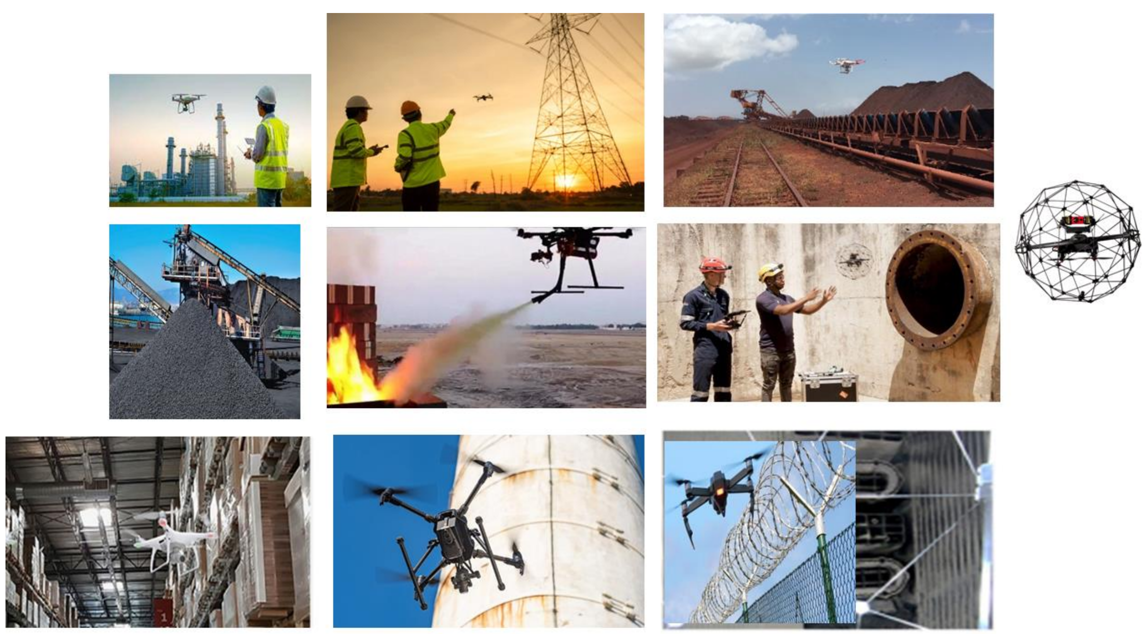


Figure 23
Drone deployment using sortie framework

The ESG Compliance Calendar Tool presents a robust solution for organizations seeking to streamline and enhance their compliance management processes. By offering features such as task assignment and management, responsibility determination, performance monitoring, and automated notifications, this tool enables efficient management of compliance obligations. Particularly noteworthy is its ability to facilitate proactive compliance management through automated notifications and comprehensive reporting capabilities. Overall, the tool serves as a comprehensive solution for managing compliance obligations efficiently, enhancing accountability, and ensuring proactive compliance management.

In environmental monitoring, drones equipped with integrated GPS technology have emerged as invaluable assets for efficient monitoring and response to incidents such as fire ignition, pollutant spills, and illegal dumping. These drones provide real-time high-resolution video footage, enabling timely decision-making and response efforts while remaining cost-effective. Moreover, their ability to conduct faster and more reliable 3D mapping and topographical surveys compared to traditional methods enhances accuracy in assessing terrain and environmental conditions. Additionally, drones equipped with Light Detection and Ranging (LiDAR) technology excel in applications like forestry management and coastal zone monitoring, providing highly detailed 3D maps for comprehensive analysis of ecosystem health and potential risks.

In the health sector, drones are increasingly being deployed to minimize human exposure to hazardous conditions and access remote or dangerous locations where traditional methods may be impractical. Particularly significant is their role in conducting effective sanitization efforts, delivering essential supplies to remote areas, and providing aerial surveillance during emergency response operations. By leveraging advanced imaging and sensing technologies, drones contribute to real-time situational awareness, improving safety and efficiency in emergency preparedness and response efforts.

In terms of industrial safety, drones play a critical role in conducting inspections, security surveillance, and emergency response operations in challenging environments. Equipped with advanced imaging technologies and autonomous capabilities, drones provide reliable and persistent surveillance solutions, enhancing situational awareness, and response effectiveness for law enforcement agencies and industrial facilities alike. Their versatility and agility make them indispensable assets in modern security operations, enabling authorities to safeguard communities and protect critical infrastructure with greater efficiency and effectiveness. Overall, drones offer significant advantages in video surveillance, providing cost-effective and rapid response solutions for incident detection and prevention in industrial settings.

3. Capacity Building Use Case:

A state-owned utility in India recognizes the importance of investing in workforce development to build digital literacy and technical skills among its employees. Using the capacity building principles outlined in the SORTIE framework, the utility designs and implements training programs, knowledge-sharing platforms, and mentorship opportunities to empower its workforce to embrace digital technologies and drive organizational change. By investing in employee development, the utility strengthens its internal capabilities and accelerates the adoption of digital solutions across its operations.

Other asset motoring and optimization use cases include performance analysis and diagnostic optimization (PADO), generator health monitoring (GHM), energy management system (EMS), online dissolved gas analysis (DGA) for transformers, intelligent soot blowers, digital worker (log), turbo supervisory instrumentation (TSI),

turbine stress evaluator (TSE), availability-based tariff (ABT), Boiler tube leakage detection system (BTLDs).Please refer to Figure 24
Author Inspecting the Boiler Tube Leak Detection System.

Recently, some researchers used genetic algorithms that can provide holistic solutions for complex problems to optimize the steam temperature and boiler operations after accounting for the coal flow, steam flow, heat reduction spray flow, etc. Using these algorithms led to coal saving of 1.9 grams per kWh.

Figure 24
Author Inspecting the Boiler Tube Leak Detection System

Another use case is the digital worker initiative aims to streamline equipment inspection, performance observation, and issue detection through a mobile applet accessible to control-room operators. This applet enables operators to record field data in real-time, comparing it with data from the Distributed Control System (DCS) for discrepancies and issuing notifications to relevant departments for recalibration or corrective action. It features functionalities such as capturing pictures, capturing locational data via GPS or NFC technology, and facilitating two-way communication.

Additionally, it provides input options like radio buttons or punch-in cells for data entry, populating information from SAP's PM module or asset hierarchy, as well as OSI-PI values. While SAP accepts only transactional values like work orders and permits to work, supplementary systems such as online maintenance management systems and paperless office solutions support functions like note-taking, safety reporting, inventory management, and budget utilization tracking.

Workflow Automation The system ensures the flow of tasks, documents, and information is executed independently according to predefined business rules. This includes implementing automated emails, alerts, escalations, and approval hierarchies through Business Process Management (BPM) or Robotic Process Automation (RPA).

5. **Technology Infrastructure Use Case:**

A renewable energy developer in India aims to optimize the performance of its solar power plants through digitalization. Leveraging the technology bucket of the SORTIE framework, the developer invests in robust and scalable technology infrastructure, including cloud-based platforms, IoT sensors, and big data analytics tools. By upgrading its technology infrastructure, the developer gains real-time visibility into plant performance, identifies optimization opportunities, and improves overall operational efficiency.

Logistics control:

Real-time monitoring of vehicle movement, including coal trucks, lignite trucks, oil tankers, and raw material containers, offers opportunities to optimize logistics, reduce turnaround time, and prevent pilferage losses. RFID technology, operating at 125 kHz and allowing one-way communication, can facilitate such monitoring, especially for short distances fewer than 10 cm. RFID systems can be deployed for coal and lignite accounting, tracking material movement from loading to unloading points, and managing inbound and outbound material flows. By automating processes at the unloading, storage, and transfer stages, utilities can generate reports automatically, reducing errors associated with manual data entry or omissions. This automation fosters continuous improvement in performance and operational procedures, enhancing efficiency and reliability.

Ash management

The implementation of an ash management solution involves automating end-to-end functions, including managing truck entrances and exits with a single remote operator. This automation includes verifying and recording truck information such as weight, type of ashes, vehicle registration, and driver identity through photos taken by cameras. Weigh tickets for drivers are printed through kiosks, and trucks' destinations are displayed according to categories like quarry, cement factory, or road filling. Data is backed up on a centralized SQL database, enabling the printing of reports and instant extraction of unloading reports. Additional functionalities include ash weighment using static weigh bridges, material balancing, and monitoring stack emissions through Continuous Emissions Monitoring Systems (CEMS).

Turbo vibration monitoring

All TSI –turbo supervisory indicators are captured as depicted in Figure 25 Turbo Supervisory Instrumentation-TSI. The implementation involves permanent monitoring of shaft vibration and torsion, aimed at determining the torsional natural frequencies of the turbo generator set shaft assembly and supervising the response to the amplitudes of the most critical modes. This allows for turbine shaft line monitoring facilitating targeted outage planning. Real-time measurement of stresses and vibration amplitudes is conducted at all critical locations along the rotor, including couplings, with the objective of defining vibration amplitudes and permissible air gaps.

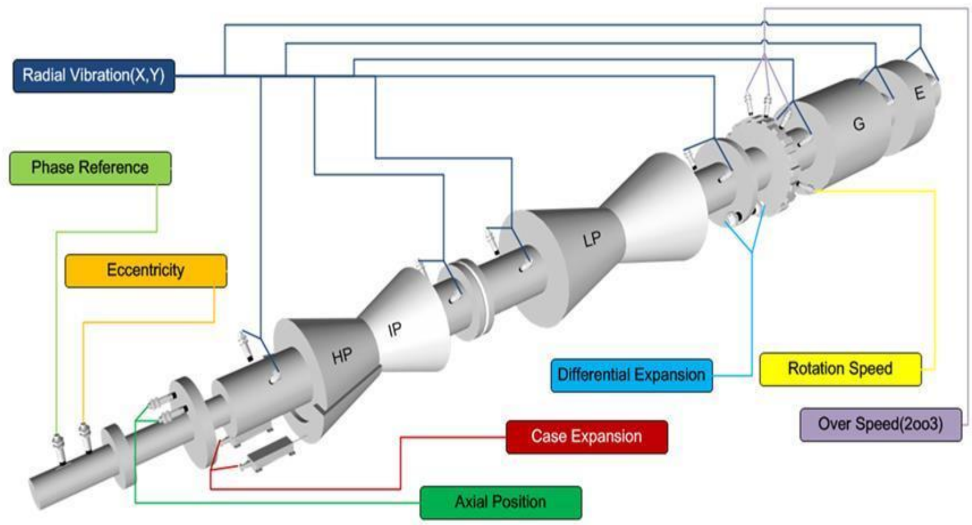


Figure 25
Turbo Supervisory Instrumentation-TSI

Collector Health Monitoring

Detection of sparking at exciter collector and brush assemblies to provide early warning to avoid a collector flashover.

Intelligent Soot blowing system.

The implementation involves intelligent soot blowing automation, which includes adjusting blowing to actual operating conditions to maximize overall boiler efficiency.

This entails determining the cleanliness of different sections of the boiler and visualizing the results on supervisors' screens. Additionally, the system calculates the heat transfer rates of each heat exchanger in the boiler, providing the operator with a clear basis for decision-making regarding the initiation of a blowing procedure. If necessary, the system can automatically start blowing without operator intervention through the Distributed Control System (DCS).

Vibration monitoring and analysis system-VMAS

All critical rotating equipment is monitored and controlled for reliability and adaptive planning. This is one of the best condition monitoring applications.

NFC based equipment local visits/inspections:

This feature requires the operator to approach the equipment and scan its 'near frequency code' (NFC) Figure 26

Near Frequency Control Devices. This action triggers the opening of the relevant form associated with that equipment, allowing the operator to log in parameters. This ensures that local visits are properly documented and recorded. Avoids proxy reading entry.

Figure 26
Near Frequency Control Devices

Industry 4.0:

In the context of Industry 4.0, plant components and machines are equipped with the capability to think and communicate with each other. This is facilitated by advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML).

One application of these technologies is the development of AI-powered heat balance diagrams with simulation capabilities, allowing for enhanced understanding and optimization of thermal processes within industrial plants. Additionally, Industry 4.0 involves the adoption of data-driven (Leyh C, 2017), cloud-enabled enterprise systems that leverage AI and ML for various purposes, including descriptive, diagnostic, predictive, and prescriptive analytics. Furthermore, AI and ML technologies are utilized in communications, protections, and interlocks within industrial settings, enabling more efficient and adaptive operation. Unit start-up curves are also enhanced through the application of these technologies, leading to improved performance and operational outcomes.

Coal fired plant Flexibilization.

The shift in coal plants from a base load regime to a peaking load regime, similar to gas turbines, presents challenges such as reduced plant efficiency and increased risk of failures due to cyclic load changes. This shift also leads to higher operation and maintenance costs and decreased revenue accrual, especially with the growing competitiveness of renewable energy sources. However, by leveraging monitoring, digitalization, Internet of Things (IoT), analytics, and automation technologies, these challenges can be addressed to some extent by optimizing processes. Automation and Advanced Process Control (APC) solutions are particularly effective and cost-efficient measures for enabling flexible operations, especially during part-load operations, thus ensuring commercial viability. It is anticipated that there will be significant net load swings of 80 GW or more in the near future, highlighting the importance of digitalization in enhancing the effectiveness of flexible operations in conventional power plants. Advanced digital tools such as tuning of existing control loops, APC software, asset monitoring systems, pattern recognition software, fatigue monitoring systems, and combustion control techniques can be deployed alongside existing control systems to facilitate flexible operations and improve overall performance.

Some advanced digital tools that may be deployed alongside the existing control system.

- Tuning of existing control loops,
- advanced process control (APC) software
- asset monitoring system,
- pattern recognition software,
- fatigue monitoring system and combustion control techniques

Boiler Fatigue monitoring system

The Boiler Fatigue Monitoring System (BFMS) employs remote devices to calculate the fatigue of individual boiler components, specifically targeting thick wall pressure parts. By analyzing data remotely, BFMS can determine the extent of creep and low-cycle fatigue in critical components, providing valuable insights into the condition and performance of the boiler. This proactive monitoring approach enables operators to identify potential issues early on, allowing for timely maintenance and intervention to prevent failures and optimize the reliability and lifespan of the boiler system.

Equivalent operation hour's calculator for cyclic loads of turbine

The system calculates the lifetime and number of cycles required for crack initiation in components, storing this data for trend analysis and comparison purposes. By detecting and preventing high-wear operating modes, it optimizes the selection of overhaul and inspection windows, thereby enhancing the overall safety and reliability of the power plant. Additionally, the system facilitates the optimization of spare component material utilization and promotes cost-effective in-service monitoring and analysis, contributing to the efficient and sustainable operation of the power plant.

In turbines, part-load operations can cause fluctuations in steam temperatures, particularly in hot reheat temperature, resulting in stress on the equipment. To address this issue, solutions for calculating equivalent operating hours are being explored to facilitate flexible operation and mitigate the impact of temperature changes on turbine components.

Coal stockpile temperature monitoring

Monitoring the temperature of coal stockpiles is crucial for ensuring safety and preventing potential hazards such as spontaneous combustion. Advanced monitoring techniques, including hotspot detection and 3D profiling of stockpiles, offer enhanced capabilities for identifying potential issues and optimizing stockyard management. These technologies enable real-time monitoring of temperature variations across the stockpile, allowing for early detection of hotspots and proactive measures to mitigate risks associated with coal storage.

6. Collaboration and Partnerships Use Case: A consortium of power sector stakeholders, including utilities, technology providers, academia, and government agencies, forms a collaborative platform to drive innovation and share best practices. Using the collaboration principles outlined in the SORTIE framework, the consortium establishes public-private partnerships, industry consortia, and research collaborations to pool resources, leverage expertise, and drive collective action towards common goals.
7. By fostering collaboration and partnerships, the consortium accelerates the pace of digitization adoption and unlocks new opportunities for innovation and growth.

These use cases demonstrate how the SORTIE framework can be applied across different facets of the power sector in India to accelerate digitization adoption and drive sustainable growth and efficiency. By embracing a strategic, collaborative, and multi-stakeholder approach, stakeholders can unlock the full potential of digital technologies to address the complex challenges facing the power sector and deliver value to consumers and society.

6.4 Conclusion

The research analysis and findings presented in this study highlight the significant role of drones in power plant operations, emphasizing their versatility and effectiveness in various functions aimed at ensuring safety, efficiency, and environmental compliance.

The research analysis and findings presented in this study highlight the significant role of drones in power plant operations, emphasizing their versatility and effectiveness in various functions aimed at ensuring safety, efficiency, and environmental compliance. Through the examination of numerous use cases, it becomes evident that drones are increasingly becoming indispensable tools in power plant management, offering a wide range of benefits. From conducting inspections of critical infrastructure and monitoring environmental risks to facilitating inventory management and surveillance, drones offer a comprehensive solution to various challenges faced by power plants.

One key advantage highlighted in the findings is the real-time feedback provided by drones, enabled by their ability to transmit live video footage via secure digital channels. This feature not only enhances the safety and efficiency of drone operations but also allows for immediate analysis and decision-making by operators, teams, and specialists.

Furthermore, the research underscores the potential of drones to revolutionize traditional inspection and maintenance practices in power plants. By offering a cost-effective, efficient, and safe alternative to manual inspections, drones enable power plant operators to conduct thorough assessments of equipment and infrastructure, identify potential issues, and implement timely corrective actions.

In conclusion, the findings of this study underscore the transformative impact of drones on power plant operations and management. By leveraging advanced technology and innovative solutions, drones empower power plant operators to enhance safety, optimize efficiency, and ensure environmental compliance, ultimately contributing to the sustainable and reliable generation of electricity. As drone technology continues to evolve, its potential to revolutionize the power sector will only continue to grow, opening up new opportunities for innovation and improvement in power plant operations.

CHAPTER VII:
SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

7.1 Summary

The research conducted in this study aimed to identify and analyze the reasons for the lower penetration of digitalization in the power sector and develop a framework to address these challenges. Through structured interviews, surveys using questionnaires, and focused interviews using the Delphi method, insights were gathered from users, clients, and subject matter experts (SMEs).

Based on the collected data, an exhaustive list of reasons hindering digitalization in power plants was compiled. Building on these reasons, a framework was developed to guide the digitalization process in the power sector. The framework outlines the phases of power plant digitalization, including real-time SCADA implementation, asset performance management (APM), and predictive analytics integration.

The research identified several benefits and features of digitalization in power plants, including cost optimization through activity-based budgeting and optimal fuel mixing, workforce transformation through virtualization, increased commercial viability of digital technology, and improved regulatory compliance and decision-making through data-driven insights.

Furthermore, the study highlighted the importance of operational intelligence and adaptive planning in power plant digitalization, utilizing probes, sensors, smart devices, and real-time data processing to enhance control and efficiency. The deployment of digitalization in process control was categorized into three phases: offline open-loop control, online open-loop control, and online closed-loop control, each representing different levels of automation and algorithm-based control.

Overall, the research findings underscored the significance of embracing digitalization in the power sector to improve efficiency, reduce costs, and adapt to changing regulatory and market conditions. The developed framework provides a structured approach for power plants to navigate the complexities of digital transformation and realize the full potential of advanced analytics and technologies.

The power industry has witnessed significant strides in digitalization, with numerous examples showcasing its adoption across various functions. These examples include: Implementation of digital worker initiatives, cloud platforms, central monitoring systems, and asset performance management (APM) tools in power plants. Adoption of predictive analytics software and advanced pattern recognition for improved performance monitoring and fault detection, condenser performance monitoring, (Hanumanth J et al, 2019). Deployment of drones and robots for inventory management, inspection of critical infrastructure, and cleaning activities in solar plants. Utilization of digital twins and virtual power plants for predictive maintenance and optimization of energy generation (Negri et al, 2017).- Integration of advanced management systems for coal stockyards and remote monitoring solutions for fault prediction and rectification.- Implementation of lone worker management platforms, access control systems, and enterprise resource planning (ERP) tools for enhanced safety and efficiency.- Leveraging of digital solutions such as supervisory control and data acquisition (SCADA) systems, computational fluid dynamics (CFD), and distributed control systems (DCS) for improved operational control and asset management.

These digital initiatives offer various benefits, including cost optimization, enhanced reliability, and improved decision-making. They also enable proactive maintenance strategies, real-time monitoring, and predictive analytics-driven optimizations. Furthermore, digitalization plays a crucial role in supporting flexible power plant operations, facilitating fault detection and rectification, and ensuring regulatory compliance.

Overall, digitalization has become essential for modern power plants, enabling them to achieve higher efficiency, reliability, and safety standards while adapting to changing market dynamics and regulatory requirements.

7.2 Implications

Theoretical Implications

The theoretical implications of this research are significant in several ways. Firstly, by addressing current challenges in the power sector and proposing novel business models, the research contributes to the advancement of theoretical understanding in the field of energy management and digitalization. The development of these innovative models provides valuable insights into how traditional industries can adapt and thrive in the digital age.

Secondly, the research lays the groundwork for further exploration and investigation in this area. By identifying key factors and developing a framework for accelerating digital deployment in the power sector, it opens up avenues for future research to delve deeper into specific aspects of digital transformation and its impact on energy systems.

Additionally, the proposed framework serves as a practical tool for industry practitioners and policymakers. By providing a structured approach to digital deployment, it offers guidance on how organizations can navigate the complexities of digital transformation and achieve their objectives more effectively.

Overall, the theoretical implications of this research extend beyond the immediate scope of the study, offering valuable insights and paving the way for future advancements in the field of energy management and digitalization.

Practical Implications

The practical implications of this research are manifold and aimed at bridging the gap between theory and practice in the power sector. By actively involving subject matter experts, industry specialists, and professionals from various domains, the research ensures that real-world perspectives and insights are integrated into the framework development process. This inclusive approach helps to ground the research in practical realities and ensures that the proposed framework is actionable and relevant to industry needs.

Furthermore, by engaging with original equipment manufacturers (OEMs), power plant professionals, and academicians, the research leverages a diverse range of expertise and knowledge. This collaboration facilitates the identification of key challenges and opportunities in digital deployment within the power sector and enables the development of tailored solutions that address specific industry requirements.

Practically, the research outcomes provide valuable guidance and direction for stakeholders in the power sector, including utility companies, policymakers, and technology providers. The pragmatic framework generated through this research offers actionable insights and recommendations for accelerating digital transformation initiatives, thereby enhancing operational efficiency, reliability, and sustainability across the industry.

Overall, the practical implications of this research extend to the implementation and execution of digitalization strategies within the power sector, ultimately contributing to improved performance, competitiveness, and resilience in the face of evolving energy landscapes and technological advancements.

7.3 Author's role as researcher and implementer of SORTIE frame work

As a researcher and implementer of SORTIE framework in deploying the use cases, my contributions are summarized as below with multifaceted actions to ensure crucial and successful integration of IT and OT systems within my organization.

1. Research and Development:

Conducted thorough research on existing IT and OT systems in my organization, as well as emerging technologies relevant to the SORTIE framework. Explored case studies and best practices in IT-OT integration across various peer plants and other industries to identify successful use cases and implementation strategies.

2. Use Case Identification:

Identified potential use cases within organization and other industry where IT-OT integration can drive significant value, such as improving operational efficiency, reducing downtime, enhancing decision-making processes, or enabling predictive maintenance.

3. Solution Design and Implementation:

Need based solutions are evaluated basis feedback from the field and shop floor end users in the plant. Strategic aspects are taken care taking cue from strategic goals and organizational digital road map; Solutions are conceptualized and designed comprehensively taking considerations that encompass the integration of IT and OT systems, considering factors such as data interoperability, security, scalability, and usability.

4. Testing and Validation:

I have collaborated with end-users and subject matter experts to validate the effectiveness of the solutions in addressing the identified use cases along with key performance indicators (KPIs) to measure the impact of IT-OT integration on operational outcomes and business objectives.

5. Documentation and Knowledge Sharing

Documented the entire process of researching, designing, and implementing SORTIE framework use cases, including lessons learned, challenges faced, and best practices.

By effectively fulfilling your role as a researcher and implementer of SORTIE framework use cases, I have contributed to the successful integration of IT and OT systems, driving operational excellence and innovation within my organization.

7.4 Recommendations for Future Research

For future research endeavors, several avenues present themselves based on the findings and implications of this study. Firstly, integrating the developed framework with a public-private partnership (PPP) model could be a promising area of investigation. Exploring how PPPs can facilitate the implementation of digital deployment initiatives in the power sector, while balancing the interests of both public and private stakeholders, would be valuable.

Additionally, further research could delve into the dynamics of collaboration between industry and academia in developing innovative solutions for the power sector. Investigating the mechanisms and best practices for fostering effective collaboration, including funding models and ownership structures, would provide insights into how academia-industry partnerships can drive innovation and accelerate solution implementations.

Moreover, considering the rapid pace of technological advancements, ongoing research could focus on continuously refining and updating the developed framework to keep pace with evolving digital trends and emerging challenges in the power sector. This iterative approach to framework development would ensure its relevance and applicability in an ever-changing landscape.

Furthermore, exploring the potential of emerging technologies such as artificial intelligence, block chain, and Internet of Things (IoT) (Somayya M et al, 2015)in enhancing digital deployment in the power sector could be a fruitful area for future research. Investigating how these technologies can be integrated into existing frameworks to further optimize operations, improve efficiency, and drive innovation would be beneficial.

Overall, future research endeavors should aim to build upon the foundation laid by this study, exploring new avenues for collaboration, innovation, and technological integration to accelerate the digital transformation of the power sector and address its evolving needs and challenges.

7.5 Conclusion

In conclusion, this research has shed light on the reasons behind the lower penetration of digitalization in the power sector and has provided a comprehensive framework to address these challenges. Through structured interviews, surveys, and focused discussions using the Delphi method, valuable insights were gathered from users, clients, and subject matter experts, leading to the compilation of an exhaustive list of barriers hindering digitalization in power plants. Building upon these findings, the framework delineates the phases of power plant digitalization, offering a structured approach encompassing real-time SCADA implementation, asset performance management (APM), and predictive analytics integration.

Moreover, the study has highlighted numerous benefits and features associated with digitalization in power plants, including cost optimization, workforce transformation, increased commercial viability, and improved regulatory compliance. The importance of operational intelligence and adaptive planning in enhancing control and efficiency was emphasized, with deployment categorized into three phases of process control: offline open-loop control, online open-loop control, and online closed-loop control.

Furthermore, the research showcased various examples of digital initiatives adopted in the power industry, ranging from the implementation of digital worker initiatives and cloud platforms to the utilization of drones for inventory management and inspection activities. These initiatives offer benefits such as cost optimization, enhanced reliability, improved decision-making, and proactive maintenance strategies.

The theoretical implications of this research contribute to the advancement of understanding in energy management and digitalization, while its practical implications offer valuable guidance for stakeholders in the power sector. By bridging the gap between theory and practice, the research provides actionable insights and recommendations for accelerating digital transformation initiatives, ultimately enhancing operational efficiency, reliability, and sustainability across the industry.

Moving forward, future research endeavors should focus on integrating the developed framework with public-private partnership models, exploring academia-industry collaboration dynamics, continuously refining the framework to keep pace with technological advancements, and investigating the potential of emerging technologies in enhancing digital deployment in the power sector. By building upon the foundation laid by this study, future research can further accelerate the digital transformation of the power sector and address its evolving needs and challenges..

APPENDIX A
ANSWER TO RQ1: THE 90 'SORTIE' reasons

Reason for digitalization not percolating in the power sector	Description
1) Context and relevance not clear	1. The context and relevance are unclear, leading to uncertainty in digitalization initiatives.
2) Not willing to be the first movers.	2. There is a reluctance to be pioneers in adopting digital technologies.
3) Notion that digitation is for services and not for plants.	3. The misconception persists that digitization is more suited for services rather than power plant operations.
4) Decision maker's dilemma	4. Decision-makers face dilemmas in choosing the right digitalization strategies.
5) Disconnect between management, business processes, and user.	5. There is a disconnect between management, business processes, and end-users.
6) Consumer and other stakeholder's interface	6. Effective interfaces with consumers and other stakeholders are lacking.
7) Transformative leadership	7. Transformative leadership is needed to drive successful digital transformation.
8) Company culture	8. Company culture plays a crucial role in embracing digitalization efforts.
9) Work environment	9. The work environment may not be conducive to digital innovation and adaptation.
10) Resilience (enterprise risk resilience)	10. Resilience, particularly in terms of enterprise risk, is essential for sustainable digitalization.
11) Customer expectations	11. Meeting customer expectations is a critical aspect of successful digital initiatives.
12) Lack of effective strategy	12. Many organizations struggle with formulating effective digitalization strategies.
13) Absence of strategic alignment	13. Strategic alignment is often absent, hindering the implementation of digital initiatives.
14) Missing top management engagement	14. Top management engagement is often lacking, impeding progress in digitalization efforts.
15) Improper knowledge management strategies	15. Inadequate knowledge management strategies hinder the effective use of digital technologies.

16) Absence of change management culture	16. A lack of change management culture can lead to resistance and inefficiencies in digital transformation.
17) Lack of common thread among strategy, vision, leadership, culture, and staff	17. The absence of a common thread among strategy, vision, leadership, culture, and staff complicates digitalization efforts.
18) Business model alignment	18. Ensuring alignment with the business model is crucial for successful digitalization.
19) Managerial and organizational capabilities	19. Managerial and organizational capabilities may be insufficient to drive digitalization initiatives forward.
20) Collaboration between departments to seamless implementation	20. Collaboration between departments is crucial for the seamless implementation of digital solutions.
21) Lack of Conviction- that digitization supports efficiency and sustainability.	21. Many stakeholders lack conviction that digitization can improve efficiency and sustainability.
22) Effort expectancy	22. Effort expectancy may hinder the adoption of digital technologies.
23) Dearth of capabilities and skills in-house	23. In-house capabilities and skills may be lacking for successful digitalization.
24) Lack of historic data for making the machine learning faster	24. Historical data scarcity may impede the effectiveness of machine learning applications.
25) Mindset of experience silos, lack of KT	25. Siloed mindsets and lack of knowledge transfer hinder digitalization efforts.
26) Perceived complexity of use	26. Perceived complexity of use may discourage adoption of digital technologies.
27) Perceived loss of power/authority	27. Perceived loss of power or authority may lead to resistance to digitalization.
28) Privacy breach qualms	28. Concerns about privacy breaches can hinder the implementation of digital solutions.
29) Siloes and legacy systems.	29. Siloed and legacy systems pose challenges for digital integration.
30) Standardization issues affecting custom-tailored needs.	30. Standardization issues may impede customization of digital solutions.
31) Threat to job security	31. Job security concerns may discourage workforce buy-in for digital initiatives.
32) Trust in data by the company	32. Trust in data quality is essential for successful digitalization.

33) Inflated internal capabilities to undertake the digital transformation.	33. Internal capabilities may be overestimated, leading to unrealistic expectations for digital transformation.
34) Lacking sense of urgency, POC delays	34. Lack of urgency and delays in proof of concept can slow digitalization efforts.
35) Skills mismatch	35. Skills mismatches may hinder the effective implementation of digital technologies.
36) Lack of talent	36. Talent shortages pose challenges for recruiting skilled personnel for digital initiatives.
37) Dearth of practical problem-solving	37. Practical problem-solving skills may be lacking in the workforce.
38) Low qualified and elderly employees	38. Low-qualified and elderly employees may struggle to adapt to digital technologies.
39) The dearth of regulations;	39. Regulatory dearth creates uncertainty and obstacles for digitalization.
40) Misaligned financial incentive especially in regulated markets;	40. Misaligned financial incentives in regulated markets can impede digitalization efforts.
41) Absence of policies that encourage;	41. Absence of policies that encourage digital innovation hampers progress.
42) Central (federal) vs. state concurrencies;	42. Competing central and state regulations complicate digitalization efforts.
43) Infrastructure, eco system from government;	43. Government support in infrastructure and ecosystem development is lacking.
44) Single window approvals;	44. Simplified approval processes can expedite digitalization initiatives.
45) Tax benefits;	45. Tax benefits can incentivize investment in digital technologies.
46) Deficiency of data governance;	46. Deficiencies in data governance hinder effective data management.
47) Subsidies and incentives for startups;	47. Subsidies and incentives can encourage adoption of digital solutions.
48) Not addressing the customers' security and privacy concerns;	48. Addressing customer security and privacy concerns is essential for successful digitalization.
49) Data ownership and IP rights;	49. Clarifying data ownership and IP rights is crucial for digital initiatives.
50) Privacy of individuals vs. understanding of an individual;	50. Balancing individual privacy with data understanding is a regulatory challenge.

51) Market rules of competition.	51. Market competition rules impact digitalization strategies and investments.
52) Adequacy of existing IT infrastructure;	52. The adequacy of existing IT infrastructure can affect digitalization readiness.
53) Compatibility among existing and proposed technologies/devices;	53. Compatibility among technologies affects the integration of digital solutions.
54) Cyber security apprehensions;	54. Cyber security concerns pose risks to digitalization efforts.
55) Domain expertise gaps between IT and OT experts;	55. Domain expertise gaps between IT and operational technology experts create challenges.
56) Edge vs. Fog vs. cloud deployment dilemma;	56. Choosing between edge, fog, and cloud deployment presents dilemmas.
57) Technology diffusion tardiness;	57. Delayed technology diffusion slows digitalization progress.
58) Inadequate digital infrastructure;	58. Inadequate digital infrastructure constrains digitalization initiatives.
59) Technology capability and integration;	59. Technology capability and integration challenges affect digitalization projects.
60) Architecture design;	60. Architecture design considerations impact digital solution implementation.
61) Lack of situational sensor intelligence;	61. Situational sensor intelligence may be lacking for effective decision-making.
62) Compatibility and co-existence issue the connectivity layer;	62. Compatibility and co-existence issues at the connectivity layer hinder integration.
63) Security vs. accessibility;	63. Balancing security with accessibility is a technological challenge.
64) Lack of collaboration in IT, ET, and OT.	64. Collaboration between IT, operational technology, and engineering teams is essential.
65) ML/AI based use cases to enhance reliability and efficiency;	65. ML/AI use cases can enhance reliability and efficiency in power plants.
66) Products to support flexibility in operations;	66. Flexibility-supporting products drive innovation in power plant operations.
67) Demonstrability of results;	67. Demonstrating results is crucial for gaining buy-in for digital initiatives.
68) Latency in technology adoption;	68. Latency in technology adoption hampers digitalization progress.

69) Energy efficient apparatus/ products;	69. Energy-efficient apparatus and products contribute to sustainability goals.
70) Intelligent sensors;	70. Intelligent sensors enable data-driven decision-making in power plants.
71) Waiting for use cases, proofs, and references;	71. Waiting for use cases and proofs delays digitalization efforts.
72) Ignoring or not heeding to the superior functionalities of competitors;	72. Ignoring competitor functionalities can hinder competitiveness.
73) Work performed by people vs. computing machines;	73. Balancing work between people and machines is a challenge for digitalization.
74) Providing more resources to IT staff vs. more self-service analytics;	74. Allocating resources between IT staff and self-service analytics impacts digital strategies.
75) Technology impact lags;	75. Technology impact lags hinder digitalization benefits realization.
76) Pace of change and time to market.	76. The pace of change and time-to-market pressures affects digitalization initiatives.
77) Balance sheet not supporting (financial constraints);	77. Financial constraints on the balance sheet hinder digitalization investments.
78) Disincentives for investment due to policy paralysis by the governments;	78. Policy paralysis by government's disincentives investment in digital technologies.
79) Low load factors due to onslaught of renewables resulting low revenues;	79. Low load factors due to renewables impact revenue streams in power plants.
80) Huge dues remain to be realized constraining working capital;	80. Outstanding dues constrain working capital for digitalization investments.
81) Tangibility of benefits is difficult to demonstrate;	81. Demonstrating tangible benefits of digitalization can be challenging.
82) Features with no benefits to customers. Reluctance to pay for that;	82. Features without customer benefits may hinder adoption of digital solutions.
83) Aggregate data or personalize (centralization vs. decentralization);	83. Centralization versus decentralization impacts data management strategies.
84) Storing all data vs. selecting data to store that serves a specific purpose;	84. Selective data storage for specific purposes is essential for efficient digitalization.

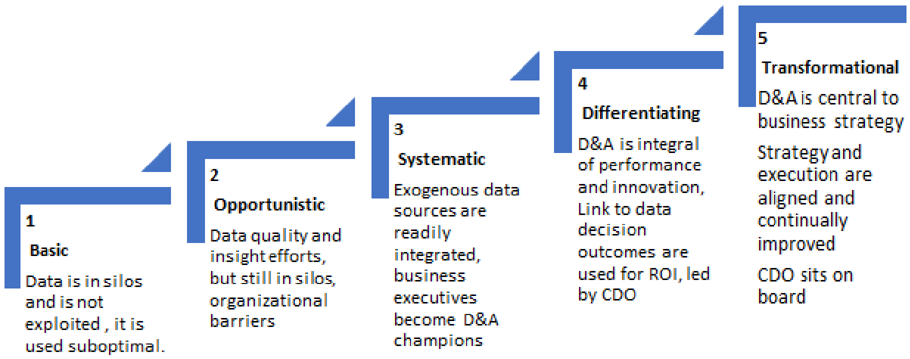
85) Distributed value creation and capture;	85. Distributed value creation and capture pose challenges for digitalization strategies.
86) Investments friendly POCs;	86. Investments-friendly proof of concepts facilitates digitalization initiatives.
87) Insufficient funds for digitization of the process;	87. Insufficient funds constrain digital process digitization efforts.
88) Digital technologies enable a circular economy;	88. Digital technologies enable circular economy initiatives in the power sector.
89) Priorities (competing and conflicting);	89. Competing and conflicting priorities impact digitalization strategies.
90) Payments from savings-based investments.	90. Payments from savings-based investments drive digitalization funding.

APPENDIX B
Selected participants list

S. N	Name with designation and organization	Domain
1	Mr. Sarangapani ED- NTPC,	OT Expert
2	Mr. Ankur Seth AVP Data analytics- Adani,	OT Expert
3	Mr. Sibir Roy GM- CESC,	OT Expert
4	Mr. Thyagaran, head IT-KSK,	OT Expert
5	Mr. Bipin Mishra, GM- KSK,	OT Expert
6	Mr. Girish Raghuvamshi GM-Adani,	OT Expert
7	Dr. Tapan Kumar Ray, AGM- NTPC,	OT Expert
8	Ms. Sushma, GM-NTPC,	OT Expert
9	Mr. Elangovan GM-ITPCL,	OT Expert
10	Mr. MS Murali, SM-ITPCL,	OT Expert
11	Mr. Bharani CM-Taqa,	OT Expert
12	Mr. Kathiravan, IT-Taqa,	OT Expert
13	Mr. CS Srinivas CGM OS NTPC	OT Expert
14	Mr. Raghavendra , IT , ITPCL	OT Expert
31	Mr. Vinit Priyadarshi, Asset management- Black & Veatch	IOT Expert
15	Mr. Vimal -Delivirien,	IT Expert
16	Mr. Amit Priye, GM-GE,	IT Expert
17	Mr. Saptiman , Ams-GE,	IT Expert
18	Mr. D Souja, RM-Bentley,	IT Expert
19	Mr. Sekhar, Altizon,	IT Expert
20	Mr. Pradeep Jeswani, Director OSI PI,	IT Expert
21	Mrs. Komal Mahajan, Fuel software specialist-Black & Veatch,	IT Expert
22	Mr. Praveen Jhadav, OSIsoft,	IT Expert
23	Dr. Uppala Sunil, Director Analytics, Siemens,	IT Expert
24	Mr. Venkataraman, Siemens,	IT Expert
25	Mr. Pakaj Dua, SME-Shneider,	IT Expert
26	Mr. Scotty, Bentley AssetWise,	IT Expert
27	Mr. Ashutosh Vidona Sanil, Data Analytics,	IT Expert
28	Mr. Debasmit Mohanty, Data Analytics	IT Expert
29	Dr. SD Sharma, DBA scholar,	IT Expert
30	Mr. Ramana Tummabathula, Dir. Accenture,	IT Expert

APPENDIX C
SURVEY-1 QUESTION & RESULTS

Survey-1 to find the maturity level of digitalization in originations, Out of 86 approached 65 (76%) responded with below responses on ‘at what level your organization is at present’.



Level-1 Basic	Level-2 Opportunistic	Level-3 Systematic	Level-4 Differentiating	Level-5 Transformational
31	23	8	2	1
47.7%	35.4%	12.3%	3.1%	1.5%

Source-Gartner D&A maturity level

APPENDIX D
SURVEY-2 QUESTION & RESULTS

I. Survey-2 to rank SORTIE buckets

Structured interview with focused group: Ranking of SORTIE buckets though WhatsApp calls among focused group:

Task was to rank Strategy, OE, Regulations, Technology, Innovation, and economic considerations (SORTIE) from 1 to 6.

Nine (9) professionals were part of the focus group and took part in the discussion based on their availability from time to time. (Mr. Sarangapanim CGM, NTPC, Mr. Ankur Seth, AVP, Data analytics, Adani, Mr. Sibir Roy, GM, CESC, Thyagaran, head IT, KSK, Mr. Bipin Mishra, DGM, C&I, KSK, Mr. Girish Raghuvamshi GM Adani, Mr. Vinit Priyadarshi, head asset management, Black & Veatch, Dr. Tapan Kumar Ray, AGM, NTPC, M/s Sushma, AGM, NTPC)

Focused group Scoring (10 respondents)								Weightage	Rank
(cause least-1 most-6)		1	2	3	4	5	6		
S	Lack of strategic intent and clarity	0	1	1	2	5	1	44	1
O	No alignment between people, process, tools	1	1	2	4	0	2	37	4
R	Inadequate regulatory support	0	2	1	3	2	2	41	3
T	No convergence between IT-OT-ET	1	1	5	2	1	0	31	5
I	Lack of innovation in power sector related digital apps	1	2	3	4	0	0	30	6
E	Economic considerations like investment, ROI, etc.	1	1	0	3	3	2	42	2

APPENDIX E1

SURVEY-3 STRATEGY Q & A

Strategy (Realigning business process and delivery of products/services.

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Reasons for the slow digitalisation in power sector- STRATEGY

Lack of strategic intent and clarity- some reasons for this

pothalakrao@gmail.com Switch accounts

Not shared

1. Business model alignment

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Decision maker's dilemma

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Disconnect between management, business processes and user

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Missing top management engagement

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Lack of common thread among strategy ,vision, leadership, culture and staff

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

7. Lack of effective strategy

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Transformative leadership

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Not willing to be the first movers

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Notion that digitation is for services and not for plants

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Resilience (enterprise risk resilience)

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Improper knowldge managment strategies

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX E2
SURVEY-3 OE Q & A

OE (Realigning People, Process, and Plant/tools.

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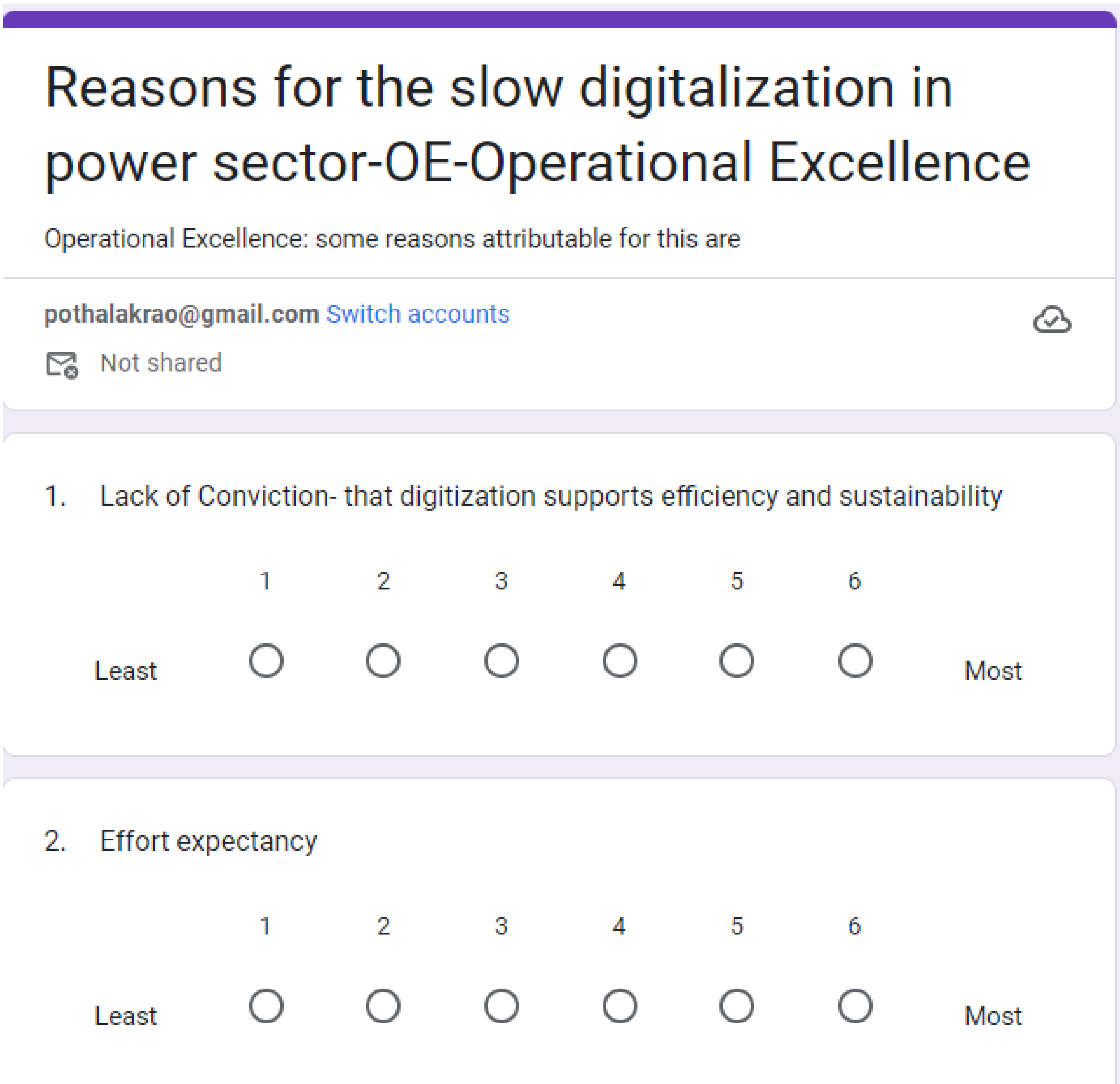

Reasons for the slow digitalization in power sector-OE-Operational Excellence

Operational Excellence: some reasons attributable for this are

pothalakrao@gmail.com Switch accounts

Not shared

1. Lack of Conviction- that digitization supports efficiency and sustainability

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Effort expectancy

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

3. Dearth of capabilities and skills in-house

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Lack of historic data for making the machine learning faster

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Perceived complexity of use

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Perceived loss of power/authority

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

7. Siloes and legacy systems

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Inflated internal capabilities to undertake the digital transformation

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Lacking sense of urgency and delaying the POC

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Privacy breach qualms

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Dearth of practical problem-solving

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Low qualified and elderly employees

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX E3
SURVEY-3 REGULATORY Q & A

Regulations (codes, standards, rules, mandates by government, regulators).

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Reasons for the slow digitalization in power sector-Regulation

Regulation- some reasons attributable for this are

pothalakrao@gmail.com Switch accounts

Not shared

1. Dearth of regulations that promote digitalization

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Misaligned financial incentive especially in regulated markets

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

3. Absence of policies that encourage sustainability

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Central (federal) vs. state concurrencies

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Infrastructure, eco system support from government

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Single window approvals, facilitation by the government

1	2	3	4	5	6
○	○	○	○	○	○

7. Tax benefits

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Deficiency of data governance and interoperability

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Subsidies and incentives for startups

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Not addressing the customers' security and privacy concerns.

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Data ownership and intellectual property rights

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Market environment and rules of competition

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX E4
SURVEY-3 TECHNOLOGY Q & A

Technology (IT-OT-ET convergence).

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Reasons for the slow digitalization in power sector-Technology

Convergence of IT-OT-ET-reasons attributable for this are

pothalakrao@gmail.com Switch accounts

Not shared

1. Adequacy of existing IT infrastructure

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Compatibility among existing and proposed technologies/devices

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

3. Domain expertise gaps between IT and OT experts

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Edge vs Fog vs cloud deployment dilemma

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Technology diffusion tardiness

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Cyber security apprehensions

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

7. Technology capability and integration

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Architecture design

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Lack of situational intelligence in the sensors

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Compatibility and co-existence issues the connectivity layer

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Security vs. accessibility

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Absence of technical collaboration between IT, ET and OT

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX E5
SURVEY-3 INNOVATION Q & A

Innovation (that gel well with the needs of the power sector).

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Reasons for the slow digitalization in power sector-Innovation

Innovation that gels well with the power sector-reasons attributable for this are

pothalakrao@gmail.com Switch accounts

Not shared

1. ML/AI based use cases to enhance reliability and efficiency

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Products to support flexibility in operations

	1	2	3	4	5	
Least	○	○	○	○	○	Most

3. Demonstrability of results

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Latency in technology adoption

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Energy efficient apparatus/ products

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Intelligent sensors

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

7. Waiting for use cases, proofs and references

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Ignoring or not heeding to the superior functionalities of competitors

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Work performed by people vs. computing machines

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Providing more resources to IT staff vs. more self-service analytics

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Technology impact lags

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Pace of change and time to market

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX E6
SURVEY-3 EC Q & A

Economic considerations (investment, short term and long term benefits, ROI).

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Reasons for the slow digitalization in power sector-Economic Considerations

Financial considerations like ROI, investment etc.,-reasons attributable for this are

pothalakrao@gmail.com Switch accounts

Not shared

1. Balance sheet not supporting (financial constraints)

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

2. Disincentives for investment due to policy paralysis by the governments.

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

3. Lower load factors due to onslaught of renewables resulting low revenues

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

4. Huge dues remain to be realized constraining working capital

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

5. Tangibility of digitization benefits is difficult to demonstrate

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

6. Features with no benefits to customers. Their reluctance to pay for that.

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

7. Aggregate data or personalize (centralization vs. decentralization)

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

8. Storing all data vs. selecting data to store that serves a specific purpose

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

9. Distributed value creation and capture

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

10. Investments friendly POCs.

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

11. Insufficient funds/ budget for digitization of the process

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

12. Digital technologies enable the circular economy

	1	2	3	4	5	6	
Least	○	○	○	○	○	○	Most

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APPENDIX F
Abbreviations

ABT meter-Availability Based Tariff meter.
ACES -Automated, connected, electric, and shared.
AHP- Ash Handling Plant
APH- Air Pre Heater
AI- Artificial Intelligence
AIP- Asset investment planning
APC- Advanced Process Control
APC- Auxiliary Power Consumption
APM- Asset performance management
APR-Advanced Pattern Recognition
AR - Augmented reality
API-Application program interface
APM-Asset Performance Management
BCAR-Bureau of Communications and Arts Research
BFO- Bacterial Foraging Optimization e
BFPSO- Bacterial Foraging Particle Swarm Optimization,
BBS- Behavioral bases safety
BI- Business Intelligence
BEV-battery electric vehicle
BpaaS- Business process as a service
BPO- business process outsourcing
BU-Billion Units
BYOD -Bring your own device.
BYOT-Bring your own technology.
CAPA- Corrective and preventive actions
CMMS-Computerized maintenance management system
CAGR: Compound Annual Growth Rate
CEA-Central electricity Authority
CERC- Central Electricity Regulation commission
CERT- Computer emergency response team
CFL- compact florescent lamp
CHP-Coal Handling Plant
CI-customer intelligence
CPS-Cyber Physical Systems
CPPC-Cyber Physical Production System
CPU-Condensate Polishing Unit
COD- Commercial operation date
COH- Capital Overhaul
CST- Condensate Storage Tank
CT-Cooling Tower
CX-customer experience
CW- Circulating Water

DAS- Data acquisition system
DCS- Digital control system
DER- Distributed energy resources
DSM-Demand side management
DSM-Deviation Settlement Mechanism
DSS- Decision support system
DC- Declared Capability
DC- Demurrage Charges
DER-Distributed energy resources
DGR- Daily Generation Report
DMS- Disc Magnetic Separator
DMS-Document Management System
DMST-DM water storage tank
DMZ-De-military zone
DO- Delivery order.
DPM- Daily Planning Meeting
DSM- Deviation Settlement Mechanism (Erstwhile UI)
EAM-Enterprise asset management.
ERP-Enterprise resource planning
ESG-Environment, Society, Governance
ET-Engineering technology
EA-Energy Auditor
EC-Environmental Clearance
EM-Energy Manager
EMS-Energy Management systems
FCEV- Fuel cell electric vehicle
FGD-Flue Gas Desulphurization
FMEA- Failure Modes and Effects Analysis
FRP- Fiber Reinforced Plastic
FTA- Fault Tree Analysis
FTP-File transfer protocol
FDI: Foreign Direct Investment
FY: Indian Financial Year (April to March)
GA- Genetic Algorithm,
GACCA-Gaps, Anomalies, Causes, Consequences, Actions to fix them.
GCV- Gross Calorific Value
GHR-Gross Heat Rate
GOMTI- Goal Objective Measures Targets Initiatives
GPS-Global positioning system
GRP- Glass Reinforced Plastic
GUI- Graphical User Interface
GW-giga Watt
H2-Hydrogen
HCSD- High Concentration Slurry Discharge

HFO- Heavy Fuel Oil
HVAC- Heating, Ventilation, and Air Conditioning
HR-Heat rate
IAB- Internet Architecture Board
ICANN- Internet Corporation for Assigned Names and Numbers
IEA-International energy agency
IOS-Interoperability Standards like OPC
ILMS- Inline Magnetic Separator
IEA-International energy agency
IP- Internet protocol
ITS- intelligent transport systems
ITU_ International Telecommunications Union
IaaS- Infrastructure as service
ICT-Information and communication technology
IoT-Internet of Things
IIoT-Industrial Internet of Things
IT- Information technology
Kcal/kWh- kilo Calories per kilo watt hour
KMS-Knowledge Management System
KPI- Key Performance Indicators
LAN-local area network
LDO – Light Diesel Oil
LED-light emitting diode
LOS-Level of service
LR- Literature review
LPWA- Low power wide area
LTSH- Low temperature super heater
M2M- Machine to Machine
MaaS- Mobility as a Service
MAS- Modify, Achieve, Sustain
MIS-Management Information System
ML-Machine Learning
MOD- Merit order dispatch
MDBFP- Motor Driven Boiler Feed Pump
MES- Manufacturing Execution System
MS- Main Steam
MTI- Measures, Targets, Initiatives
MU- Million Units
MW- Mega Watt
M&A: Merger and Acquisition
NFC-Near Frequency Control
NBFC: Non-Banking Financial Company
OE- Operational excellence
O&G- Oil & gas

OT- Operation technology
O2- Oxygen
OHS- Occupational Health and Safety
OFI- Opportunities for Improvement
O&M-Operation and maintenance
OPC-Open Platform Communication
OSI- Open Systems Interconnection Model
P2P- peer to peer
PA -Primary Air
PaaS-Platform as service
PADO-performance analysis and diagnostic optimization
PdM-Predictive maintenance
PE: Private Equity
PGCIL- Power Grid Corporation of India Limited
PHEV- plug-in hybrid electric vehicle
PIP- Performance Improvement Project
PI-Process Improvement
PLF- Plant Load Factor
PLC- Programmable Logic Control
PLC- Programmable logic control
POG- Performance Optimization Group
POSOCO-Power system Operation Corporation
PPA- Power purchase agreement
PR- Purchase Requisition
PSO- Particle Swarm Optimization,
PV-Photo voltaic
PUE- Power usage effectiveness
QFT- Question Formulation Technique
QMS-Quality Management System
RAMI- Reference Architecture Model Industry 4.0
RCA- Root Cause Analysis
RFID- Radio Frequency Identification
RTM- Real Time Market
RSD- Reserve shut down.
RBD- Reliability block diagram,
ROI- Return on investment
RPA- Robotic process automation
RQ- Research question
R & D: Research and Development
R-APDRP: Restructured Accelerated Power Development and Reform Program
RGGVY: Rajiv Gandhi Grameen Vidyutikaran Yojana
Rs. Indian Rupee
SaaS- Software as service
SAP-Systems Applications and Products in Data processing

SAN-Storage Area Network
SCADA- Supervisory control and data acquisition
SHR-Station Heat Rate
SQ-Sub question
SC-super critical
SCBA- Self-contained breathing apparatus
SCC   Specific coal consumption
SPE-Station Performance Enhancement
TCO- Total cost of ownership
TDBFP-Turbine Driven Boiler Feed Pump
TH- Track Hopper
TNC- transportation network companies
TFC- Total final consumption
T & D: Transmission and Distribution
TWh: Terawatt-Hour
UAV- Unmanned aerial vehicle
UHR-Unit Heat Rate
UI- Unscheduled Interchange
UPS-Uninterrupted power supply
USC-ultra super critical
US$: US Dollar
VAM-Vapor Absorption Machine
V2G- Vehicle-to-grid
V2I- vehicle-to-infrastructure
V2V- Vehicle-to-vehicle
VFD-Variable Frequency Drive
VoD-video on demand
VR-Virtual reality
VRE- variable renewable energy
WAN- Wide Area Network
WT-Wagon tippler

APPENDIX G
GLOSSARY

3D printing (also known as additive manufacturing)

3D (three dimensional) printing, or additive manufacturing, is a computer-controlled technology that builds objects by depositing consecutive layers of material.

4G

The International Telecommunications Union (ITU) defines a speed of 100 Mbps for high-mobility communication (such as from trains and cars) and 1 Gbps for low-mobility communication (such as pedestrians and stationary users).

5G

New networks have higher speeds up to 10 Gbps with more bandwidth.

5S

A place for everything and everything in its place.

ACES Automated, connected, electric and shared.

Processes and real-time sensors, which can be automated or managed from a single front-end dashboard (e.g., a smart phone app or building energy management system).

Advanced connectivity

Wireless low-power networks, 5G/6G cellular, Wi-Fi 6 and 7, low-Earth-orbit satellites, and other technologies support a host of digital solutions that can drive growth and productivity across industries today and tomorrow. (Digital productivity: key issues from the literature BCAR occasional paper Bureau of Communications and Arts Research, n.d.)

Advanced Pattern Recognition (APR)

Software which investigates correlations between different parameters of an equipment or process monitors the correlations & gives an alert when a parameter trends outside the normal band.

Aggregator (also known as demand response providers)

Gather consumer demand of any type, as well as energy supply from distributed producers such as renewables-based power plants, in order to provide balancing services to the grid by adjusting power demand and/or shifting loads at short notice. The aggregator provides an interface between large numbers of individual consumers/ producers and power markets/grid operators.

AI- Artificial Intelligence

AI is the area of computer science that focuses on simulating human intelligence combining rational, emotional, and cognitive levels of intelligence across a larger process including learning, reasoning, and self-correction.

Alert or Anomaly

Warnings or alarm signals generated when the expected value from APR model differs from the actual value by a configurable threshold.

Analytics

The use of data to produce useful information and insights.

Application program interface (API)

An API is a list of commands that allows software programs to communicate with each other and use each other's functions.

Applied AI

Models trained in machine learning can be used to solve classification, prediction, and control problems to automate activities, add or augment capabilities and offerings, and make better decisions.

App-based ride hailing

Prearranged transport services provided by transportation network companies (TNCs), such as Uber, Lyft, Didi Chuxing and Grab, use an online-enabled application or platform (such as smart phone apps) to connect drivers using their personal vehicles with passengers.

Asset

Asset is one that adds value to the business.

Asset (APR)

Each equipment/system for which APR models are built.

Asset Performance Management (APM)

Asset performance management is the analysis of operational data from connected devices to improve their efficiency and productivity of the workforce, while minimizing operating costs

Augmented Reality

The term relates to a computer-based extension of human perception.

Automation

The use of various control systems to allow equipment, a process, or a system to operate automatically, with minimal or no need for human input.

Autonomous vehicle

Often referred to as “driverless” or “self-driving”, it can sense its environment and navigating safely and effectively with no or minimal human intervention. Complying with the Society for Automotive Engineers International Standard J3016.

Autonomous closed-loop industrial control

Where digital meters and sensors collect data on system performance, with Optimisation actions determined by control algorithms and automatically implemented by digital systems.

Bandwidth

The volume of data that can be sent through a network connection, typically measured in bits per second (bps). Greater bandwidth supports faster transfer of data. Example 4G-1Gbps, 5G-10 Gbps.

Behind the meter

On the customer’s side of the utility meter.

Big data

Large amounts of data structured/ unstructured gathered from a range of diverse sources, often in near real time.

Bits and bytes

Bit and byte are units of measurement for data volume (8 bits = 1 byte).

Bitcoin.

Cryptography is used to secure the transactions and to control the creation of additional units of the currency.

Blockchain

Decentralized data structure, administration, and processing for financial transactions. Literally it is a chain of data blocks in which transactions are linked and examined.

Botnet

Automated programs that run over the internet, short for (ro)botnet(work). Some botnets run automatically; others only execute commands when they receive specific input. Often used to launch spam email campaigns, denial-of-service attacks, or online fraud schemes. Not all botnets are malicious.

Bring your own device-BYOD.

It refers to the practice of allowing the employees of an organization to use their own personal computers, laptops, tablets, smartphones, and other devices in the workplace for work-related activities.

Bring your own technology, BYOT.

Same as BYOD

Broadband

A term applied to high-speed telecommunications systems (i.e., those capable of simultaneously supporting multiple information formats such as voice, high-speed data services and video services on demand).

Business analytics

Business analytics is a set of skills, statistical analysis and iterative methods enabling data-driven decision-making using past and present data to gain insight and drive business in future.

Business Intelligence (BI) (data-based business process analysis)

BI encompasses technologies and analytical processes that examine data and present actionable insights in taking strategic and operational business decisions.

Business process as a service, or BPaaS

It is a type of business process outsourcing (BPO) delivered based on a cloud services model. BPaaS is connected to other services, including SaaS, PaaS, and IaaS, and is fully configurable.

Business rules extraction

It refers to the process of harvesting, and in some instances reverse-engineering, legacy code to understand underlying business methods.

Catch (APR)

An event that has started as an alert or anomaly by the System, upon which action if taken, avoids failure or losses. (Based on the diagnostics/ prognostics from the System)

Central Scenario

The IEA Central Scenario, in line with the New Policies Scenario of the IEA World Energy, describes the pathway for energy markets and technological progress based on the continuation of existing energy and climate policies and measures.

ChatGPT

It is Chat Generative Pre-Trained Transformer, a large language model-based chatbot developed by OpenAI and launched on November 30, 2022, which enables users to refine and steer a conversation towards a desired length, format, style, level of detail, and language.

Climate technologies beyond electrification and renewables

Climate technologies include carbon capture, utilization, and storage (CCUS); carbon removals; natural climate solutions; circular technologies; alternative proteins and agriculture; water and biodiversity solutions and adaptation; and technologies to track net-zero progress.

Cloud/Cloud Computing (outsourced data storage)

An IT infrastructure where data is saved on decentralized computer systems via the internet and in principle to be available at any time at any place so long as there is an internet connection**.**

Cloud and edge computing

In cloud and edge computing, workloads are distributed across locations, such as hyperscale remote data centres, regional centres, and local nodes, to improve latency, data-transfer costs, adherence to data sovereignty regulations, autonomy over data, and security.

Collaborative Work Management (CWM)

CWM enables business users (without technical knowledge) to model, coordinate, manage, and optimize repeatable and reportable common work activities.

Connected device (networked, edge or end device)

Consumer electronics, appliances and other devices that can be connected to networks and interact with the network or other devices like smartphones and tablets, televisions, washing machines, security cameras, industrial equipment, cars, etc.

Connectivity

Exchange of data between humans, devices, and machines through digital communications networks.

Computer emergency response team (CERT)

Used to resist cyber-attacks on networked systems and limit damage ensuring continuity of critical services if attacks, accidents, or failures take place.

Critical infrastructure

An asset, system or part of a system which is essential for the maintenance of vital societal functions, such as the health, safety, security, economic or social well-being of people in a country.

Crypto currency

A digital asset designed to function as a medium of exchange.

Curtailment

The practice of temporarily decreasing electricity supply due to grid constraints or other causes.

Customer experience (CX)

It encompasses every interaction with customers in their lifetime relationship with the service or product.

Customer intelligence

It is the data that organizations use to determine the effective ways to interface and interact with their customers.

Customer Journey Tracking (analysis of user behaviour)

The data-based analysis of buying decision processes.

Cyber-attack

An attack, via cyberspace, for the purpose of disrupting, disabling, destroying, or maliciously controlling a computing environment/infrastructure, or stealing controlled information.

Cyber incident

Actions taken through the use of computer networks that result in an actual or potentially adverse effect on an information system and/or the information residing therein.

Cyber Physical Systems (CPS)

CPS are objects which have embedded software and electronics connected to each other in a system, like robots, drones and other movable machines used in traffic control or for managing intelligent electricity networks for example.

Cyber Physical Production System (CPPS)

An example for deployment is avoiding measurement errors, securing uniform quality, and streamlining the entire process.

Cyberspace

A global domain within the information environment consisting of the interdependent network of information system infrastructures including the internet, telecommunications networks, computer systems and embedded processors and controllers.

Cyber security

The ability to protect or defend the use of cyberspace from cyber-attacks and cyber incidents with proper safeguards in place.

Data

A subset of information in an electronic format that allows it to be retrieved or transmitted.

Data Science (knowledge generation from data)

Data Science is an academic field with several components using methodology from mathematics, statistics and information technology for data analysis and interpretation.

Data and text mining

Automated research in the digital environment for the purpose of discovering and extracting knowledge from unstructured data.

Data centre

Facilities designed to house information technology (IT) equipment.

Data traffic (Also called network traffic)

The amount and characteristics of data being transmitted on a network, e.g., quantity, timing, packet size, content.

Data lakes

A term for aggregating data of different types in one centralized database.

Demand response

Demand response or demand-side response refers to the possibility for consumers to adjust their electricity consumption during periods of peak demand, when power supply is scarce or electricity networks are congested, in response to time-based financial incentives.

Digital Signal transmission

That conveys information through a series of coded pulses representing 0s and 1s (binary code).

Digitization

The conversion of analogue to digital.

Digitalization

Describes the increasing application of digital technologies (i.e., ICT) across the economy, including energy, to achieve desired outcomes such as improved safety, efficiency, and productivity. (Digital productivity: key issues from the literature BCAR occasional paper Bureau of Communications and Arts Research, n.d.)

Digitalization

It refers to enabling or improving processes by leveraging digital technologies and digitized data.

Digital Transformation

It is enabled by changing or transforming the processes.

Digital twins (Negri, Fumagalli and Macchi, 2017)

Digital replicas of physical assets that can be used to simulate and optimize industrial design and plant. Digital twins facilitate testing and experimenting on an aggregated view of an asset.

Distributed energy resources (DER)

Small-scale energy resources, decentralized energy resources, such as solar PV, wind power or batteries, generating or storing power at or near the point of consumption.

Drone

Unmanned aerial vehicle (UAV), a drone can either be piloted remotely by a human or else can be a fully autonomous vehicle.

Diagnostic Advisory

Possible list of faults or root causes for a particular alert or group of alerts.

Diagnostic Rules

A combination of arithmetic, Boolean logic and statistical methods applied to inputs and/or outputs of a model to arrive at a list of probable faults.

Digital Trust

It is defined as customer confidence in an organization to protect their data.

DMZ

De-military zone is a perimeter network that protects and adds an extra layer of security to an organization's internal local -area network from untrusted traffic.

Edge device See connected devices.

Use of ICT tools and systems to provide better public services to citizens and businesses.

Electrification and renewables

Electrification and renewables help drive toward net-zero commitments and include solar-, wind-, and hydro-powered renewables and other renewables; nuclear energy; hydrogen; sustainable fuels; and electric-vehicle charging.

Embedded System

These are computer systems embedded in systems or machines where they fulfil precisely defined functions, e.g., the function of an airbag in a car or its navigation system. This type of system is also being integrated into mobile phones, televisions, household devices and forms the basis for the Internet of Things.

Enterprise Resource Planning System (ERP)

It refers to software solutions with which business processes such as procurement, production, controlling and sales can be managed on a centralized basis.

Energy efficiency

Delivering more services for the same energy input is efficient, for example, light-emitting diode (LED) uses less energy to produce the same amount of light than a compact fluorescent lamp (CFL) or incandescent bulb.

Energy intensity

A comparative measure of total energy consumption relative to a specific indicator e.g. primary energy use per unit of GDP or final energy consumption per square meter.

Energy management system

A computer-based system that defines the practices, methods, and structure for industrial or commercial firms to monitor and control heating, cooling, ventilation, and lighting systems, along with other buildings services such as fire and security systems.

Energy poverty

A lack of access to modern energy services e.g., household access to electricity and clean cooking facilities.

Energy saving

The reduction or avoidance of energy use with respect to demand for energy services.

Energy security

The uninterrupted availability of energy sources at an affordable price.

Electric vehicle (EV)

A vehicle whose powertrain includes both a battery (which can be recharged via an external power source) and an electric motor e.g. Battery (BEVs), plug-in hybrid (PHEVs) and fuel cell (FCEVs).

Firmware

Permanent software programmed into a digital device's read-only memory.

Flexibility (in electricity systems)

The capability of the electricity system to respond to upward or downward changes in the supply/demand balance in a cost-effective manner over a timescale ranging from a few minutes to several hours.

FTP

File transfer protocol built on the TCP/IP protocol allowing transfer of files between two host machines, over the network.

Future of mobility

Mobility technologies aim to improve the efficiency and sustainability of land and air transportation of people and goods using autonomous, connected, electric, and shared solutions.

Future of bioengineering

Converging biological and information technologies improve health and human performance, transform food value chains, and create innovative products and services.

Future of space technologies

Advances and cost reductions across satellites, launchers, and habitation technologies are enabling innovative space operations and services.

Generative AI

Generative AI can automate, augment, and accelerate work by tapping into unstructured mixed-modality data sets to enable the creation of new content in various forms, such as text, video, code, and even protein sequences.

GUI

Graphical User Interface for the System

GW

Gig watt (109 Watts). 1 Watt = 1 joule per second.

Hardware

The physical components of an information system.

Home or building automation.

Refers to systems that integrate diverse electrical devices and energy-consuming equipment in a house or building, allowing control on site or remotely for convenience, energy efficiency and safety benefits.

Hyper-scale (data centre)

Hyper-scale data centres are very efficient, large-scale public cloud data centres operated by companies such as Alibaba, Amazon, and Google.

Horizontal Integration

Denotes networking of companies operating at approximately the same level, for example, manufacturing similar products.

ICT

Information and communications technology, include all types of digital equipment such as sensors, connected devices, network equipment and infrastructure (e.g., data centres and network cables)

Immersive-reality technologies

Immersive-reality technologies use sensing technologies and spatial computing to help users “see the world differently” through mixed or augmented reality or “see a different world” through virtual reality.

Industrializing machine learning

A rapidly evolving ecosystem of software and hardware solutions is enabling practices that accelerate and de-risk the development, deployment, and maintenance of machine learning solutions.

Internet of Things (IoT)

Where everyday objects are connected to networks to provide a range of services or applications in areas such as cars, home automation and smart grids.

Intelligent transport systems (ITS)

Intelligent transport systems include the use of sensors, communications technologies, and advanced analytics to improve system operations, with the aim of improving safety, efficiency, and service, as well as lowering costs. E.g., in-road detectors to control traffic lights, RFID to automatically collect tolls, and the use of GPS and plug-in hybrid telecommunications (Hammoudi S et al, 2018)for roadside assistance.

Internet

The internet is the single, interconnected, worldwide system of commercial, governmental, educational, and other computer networks that share (a) the protocol suite specified by the Internet Architecture Board (IAB), and (b) the name and address spaces managed by the Internet Corporation for Assigned Names and Numbers (ICANN).

Internet Protocol (IP) traffic

IP traffic includes fixed and mobile internet traffic (IP traffic that crosses an internet backbone), corporate IP wide area network (WAN) traffic, and IP transport of TV and video on demand (VoD).

Interoperability

The ability of different computer systems or software to exchange and make use of information.

Industry 4.0

It is a combination of Digital Transformation and Digitalization.

Knowledge Repository

A combinational data historian containing all inputs, computations, outputs and states of the System.

Last mile transport

The "last mile" refers to the stage of a trip or (in supply chains) delivery that is typically the most difficult to address in terms of perceived inconvenience or cost.

Learning algorithm

A process or method used to extract patterns from data collection to identify and adapt appropriate solutions or applications for a device or system. Examples include smart thermostats in buildings energy services, such as lighting, heating, cooling, and ventilation, to reduce total energy consumption while maintaining the energy service and user comfort with safety and efficiency.

Load

The level of network interaction of a network-enabled device, which influences its power consumption.

Low power wide area (LPWA) networks

LPWA networks provide low power draw and wide area coverage and are designed for IoT and M2M applications that provide low data rates, long battery lives, and at low cost.

Markers

An indicator/ signpost used in APR to specify a position/ date and time on all trends, statuses, and reports where an event/ condition has been marked by the system or a user.

Machine learning

Machine learning, a subfield of AI, is the science of getting computers are given access to large data sets and allowed to learn for them to act without being explicitly programmed.

Machine-to-machine (M2M)

M2M connections include energy sector applications such as smart meters and process sensors in power plants, GPS for logistics and vehicles, smart metering, and other IoT technologies.

Manufacturing Execution System (MES)

Production systems which allow production management and control in real time.

Malware

Software (e.g., a virus, worm, rootkit, botnet, or other code-based malicious entity) specifically designed to disrupt, damage, or gain unauthorized access to an ICT system.

Micro grid (sometimes called a mini grid.)

Small electric grid systems linking several households or other consumers.

Mobility as a Service (MaaS)

MaaS identifies mobility solutions that are consumed as a service including bicycles, buses, trains, cars, taxis, and ride-hailing services. MaaS typically comes with a shift away from the conventional vehicle ownership paradigm.

ModBus

IT is a request -response protocol implemented using master-slave relationship.

Network (digital)

A digital structure that allows the transmission of data or information between two or more connected devices; networks can interconnect with other networks and contain sub-networks.

Network (electricity or gas)

Electrical grid or gas pipeline.

Networked device

Same as connected device.

Next-generation software development

New software tools, including those that enable modern code-deployment pipelines and automated code generation, testing, refactoring, and translation, can improve application quality and development processes.

Node

Electronic devices that can send, receive, or forward information; nodes can be network devices (such as a modem) or edge devices (such as a digital telephone handset, a printer, or a computer).

Open data

Free and widely available data for consultation and reuse, including reuse for commercial purposes, with a view to increasing transparency and stimulating economic activity.

Operation and maintenance (O&M)

Refers to monitoring and repair of equipment, utilities, or other property (e.g., buildings and vehicles) to ensure operational performance, functionality, and asset value.

Optical network

Optical networks transmit information in the form of light pulses through thin glass or plastic optical fibre, offering much higher transmission capacity than conventional copper-wire networks.

OSI Model (Open Systems Interconnection Model)

It is a standardized model which describes how different network components communicate with each other.

Patch

An update to an operating system, application or other software, issued specifically to correct particular problems with the software.

Peer-to-peer (P2P)

In energy, connecting system users and market participants with each other to enable direct trading.

Phishing /whaling

Trying to obtain sensitive information such as usernames and passwords by means of an email (or other electronic communication) which is disguised as a trustworthy communication, but which when opened or when a link is clicked on allows the sender a point of access.

Photovoltaic (PV)

One of the main technologies, semiconductor devices, directly converts solar energy into electricity.

Physical internet

An open, modular, and shared global logistics system, inspired by the movement of data on the internet, in contrast to the proprietary logistics systems that are common today.

Platform

A layer of software that combines different kinds of devices, data, and services, on top of which other firms can build their own offerings, e.g., search engines, social media, e-commerce platforms, app stores, and price comparison websites.

Platooning

Platooning refers to the practice of driving vehicles (primarily heavy duty tractor-trailers or rigid trucks) in a single line with small gaps between them to reduce drag and thereby save fuel during highway operations.

Plug-and-play

Software or devices that are intended to work perfectly when first used or connected, without need for installation, reconfiguration, or adjustment by the user.

Plug & Work

Like the more well-known term "plug-and-play", this term denotes solutions from hardware and software that can allow a computer to be combined with other devices without much work in configuration.

Power

In the context of energy, refers to electricity (e.g., power plants).

Power purchase agreement (PPA)

A financial agreement/contract between two parties: one that generates electricity and one that is looking to purchase the electricity.

Power usage effectiveness (PUE)

A measure of how efficiently a data centre uses energy; the best global data centres have PUE values of around 1.1 (meaning 0.1 kWh used for cooling/power provision for every 1 kWh used for IT equipment).

Predictive Analytics/Predictive Maintenance

Predictive Analytics goes one step beyond normal data analysis and uses the results and the knowledge gained from the analysis to make statements about possible events in the future.

Predictive Models

A model which uses pattern recognition methods, calibrated with normal equipment operating data, for estimating the expected values of parameters.

Prosumers Pro(ducer-con)sumers.

Usually refers to small-scale, distributed generation which allows consumers to increasingly have the choice to buy electricity from a retailer or to produce at least part of it themselves.

Quantum technologies

Quantum-based technologies could provide an exponential increase in computational performance for certain problems and transform communication networks by making them more secure.

Radio-frequency identification (RFID)

RFID uses electromagnetic fields to automatically identify, and track tags attached to objects. The tags contain electronically stored information.

Ransomware

A type of malware which encrypts user data, asking victims to pay a ransom to obtain a decryption key.

Real time Information

is available simultaneous with an event, or immediately after collection. There is no delay in the timeliness of available information.

Rebound effect.

The reduction in expected gains from the introduction of new technologies or policies that increase the efficiency of resource use, because of behavioural or other systemic responses, for example the increased consumption of energy following improvement in the efficiency of an energy-consuming product or service.

Ridesharing

Ridesharing refers to multiple passengers sharing a single vehicle to take a trip using “dynamic” and “app-based” ridesharing.

Right-sizing

Improved resource and energy efficiency of service provision can be achieved by optimizing the size of equipment, for example vehicles, to match utilization patterns, for instance to match the number of passengers.

RAMI 4.0 (Reference Architecture Model Industry 4.0)

RAMUS 4.0 is a three-dimensional structural model which presents all levels and participants of Industry 4.0 in a comprehensible manner.

Radio Frequency Identification (RFID) (automatic object identification)

RFID devices are chips which communicate with a reading device using an electromagnet field.

Recovery (recoverable resources)

Remaining recoverable resources of oil and gas are comprised of proven reserves, reserves growth (the projected increase in reserves in known fields) and yet undiscovered resources that are judged likely to be ultimately producible using current technology.

Resources

Can be defined either as technically recoverable (i.e., producible with current technology) or as technically and economically recoverable, meaning that they are exploitable at current oil prices.

Robotics

The science of design, engineering and use of increasingly intelligent machines that sense, act purposefully and perform work autonomously, and their control and information processing systems.

Smart Factory

A Smart Factory is a production facility in which the production processes are optimized automatically and managed via network machines.

Sandbox

A type of "safe house" where pilots of specified types of innovative products, services and market arrangements can take place, with the support of sector regulators.

Self-consumption

When an energy producer, consumes for self-auxiliaries.

Sensor

A device which detects or measures some type of input from the physical environment (e.g., daylight, temperature, motion, or pressure).

Server

A server is a computer that provides functionality and services to other devices through network connections.

Shared mobility

A transport strategy that enables users to gain short-term access to vehicles, bicycles, and other transport modes on an as-needed basis.

Simulation

The use of computing to model the dynamic responses of a system to exogenous events.

Smart charging

A charging strategy for electric vehicles that uses connectivity and other digital technologies to automatically shift battery charging to times when electricity prices are low and/or when overall electricity demand is low.

Smart cities

A city becomes smart by virtue of strategically leveraging ICT infrastructures and applications towards better delivery of benefits to the citizens like Smart controls (including smart lighting, smart thermostats), smart mobility, security, and safety etc.

Smart device /appliance

Network-enabled devices or appliances (e.g., washing machines and televisions) with integrated information and communication functions that allow them to transmit and receive information.

Smart grid

An integrated electricity system that uses advanced software applications and communication network infrastructure, together with sophisticated sensing and monitoring technologies, to optimize the management of energy supply, demand, and transmission, maximizing system reliability, resilience, and stability.

Smart meter

A meter that records electricity consumption in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes, with two-way communication, remote reading, support for advanced tariff and payment systems, and remote disablement and enablement of supply.

Software

The programs and other operating information used by a computer.

Standardization

The process of implementing and developing technical standards based on the consensus of different parties that include firms, users, interest groups, standards organizations, and governments to maximize compatibility, interoperability, safety, and repeatability.

Standby power

The power consumed by an appliance or device when it is not actively in use but is ready to be rapidly put into use.

Subcritical/supercritical

Refers to the efficiency of fuel conversion by coal power plants.

Supercritical (SC)

Refers to those thermal plants in which steam is raised above the critical point of water (221 bar and 374oC).

System operator

The organization is responsible for operating part or all the power system. And is ideally separate(d) from ownership of transmission and generation assets.

Test bed

In engineering, an area equipped with instruments used for testing machinery, engines, etc. under working conditions.

Total final consumption (TFC)

Is the sum of consumption by the different end-use sectors including industry (mining & manufacturing), transport, buildings (residential and services) and other (including agriculture and non-energy use). It excludes international marine and aviation bunkers, except at the world level where it is included in the transport sector.

Trans active energy

The use of a combination of economic and control techniques to improve grid reliability and efficiency, in a world with increasing numbers of independent prosumers.

Trust architectures and digital identity

Digital-trust technologies enable organizations to build, scale, and maintain the trust of stakeholders in the use of their data and digital-enabled products and services.

Ultra supercritical (USC)

Refers to those plants in which steam is raised at temperatures higher than 593oC (1 100oF).

Upstream oil and gas

The upstream sector includes production of oil and gas from all onshore and offshore oil and gas facilities (from either conventional or unconventional reservoirs) and gathering and processing of the produced hydrocarbons.

Unconventional reservoirs

Unconventional reservoirs include a variety of oil and gas resources that cannot easily be accessed using standard drilling technologies, where the hydrocarbons are trapped by the nature of the rock itself rather than by the geometrical arrangement of the rock layers (as in conventional structural or stratigraphic traps).

Unconventional resources

Include extra-heavy oil and bitumen (oil sands), shale gas, and coal-bed methane.

Vertical Integration

Vertical integration is when a business expands by acquiring another company that operates before or after them in the supply chain. (Backward / forward or upstream/downstream integration)

Value chain

The complete range of activities comprises the development of network-enabled devices, which includes device and component manufacturing, software development, network design, network architecture, communication protocol development, technical standardization processes and service providers.

Variable renewable energy (VRE)

Renewable energy technologies – including solar PV, onshore and offshore wind, concentrating solar power without storage and run-of river hydropower – whose maximum output at any time depends on the availability of fluctuating renewable energy resources, such as wind or solar insolation.

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication

Technologies can enable trucks to drive in very close proximity without sacrificing safety or manoeuvrability.

Virtual power plant

A network of decentralized, small, or medium-scale power generating units such as wind farms and solar parks, as well as flexible power consumers and batteries.

Vehicle-to-grid (V2G)

Technologies by which an EV can both draw electricity from the grid and supply it back into the grid.

Vertical Integration

It describes the networking of inter-company departments as against the horizontal integration where it is within the department.

Web3

Web3 includes platforms and applications that aim to enable shifts toward a future, decentralized internet with open standards and protocols while protecting digital-ownership rights. It’s not simply crypto currency investments, but rather a transformative way to design software for specific purposes. This shift potentially provides users with greater ownership of their data and catalyses new business models.

Web-Based Graphical User Interface

GUI software which works only through a browser & does not require loading of any client software.

Web crawling (Also known as web harvesting or web scraping.)

A technique that uses algorithms to automatically collect information from websites.

Workload (datacentre)

In computing, the workload is the amount of processing that the computer has been given to do at a given time.

Zettabyte

A measurement of data equivalent to 1021 bytes, or a billion terabytes.

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