

**STUDY OF SELECT ISSUES IN THE MANAGEMENT OF
SERVICE SUPPLY CHAIN FOR INTEGRATED SMART
GRID IN INDIA**

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by

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Submitted

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CERTIFICATE

This is to certify that the thesis entitled “**Study of Select Issues in the Management of Service Supply Chain for Integrated Smart Grid in India**” being submitted by **Laxmi Gupta** to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy is a bonafide record of original research work carried out by her. She has worked under my supervision and has fulfilled the requirements for the submission of thesis, which has reached the requisite standard for Ph.D. degree of this institute. The results presented in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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(Laxmi Gupta)

ABSTRACT

As the world economy becomes more and more service oriented, services have taken great interest in improving customer satisfaction, service modeling and design and important components of service delivery. The service sector is expanding quickly worldwide, even in developing nations like the BRICS (Brazil, Russia, India, China, and South Africa). As a result, many estimates state that services would eventually dominate the global economy.

Across the globe, utilities are attempting to transform conventional power grids into smart distributed power systems with great efforts to resolve the challenges that arise on the way. In developing countries like India, Smart grid (SG) is emerging as a new facet of power industry. It incorporates numerous advanced technologies to deal issues prevailing with conventional electric networks. Though capable to resolve many of these issues, SG is still facing challenges in deployment. The existing grid network is inadequate to accommodate the upcoming needs of clean energy and distributed generation which may throw several challenges in design, erection, operation, and maintenance. The services of the smart grid are intended to improve grid observability, asset controllability, performance, and security as well as financial elements of operations, maintenance, and planning.

The purpose of this study is to identify the factors related with service supply chain of smart grid, identify the most significant service variable, and then analyze that variable in depth in terms of integration with grid. This research provides the overview on the most important operational component of Smart Grid i.e., Energy Storage System. Further, the research will lay out the introduction on the factors that are pulling and pushing the utilities to change the way they operate to improve the current services of SG. For this, various qualitative as well as quantitative methods were employed to model and implement framework for deployment of service-oriented supply chain of smart grid in Indian Context. Therefore, this research aims to address these concerns related with services in Smart Grid and bring out useful suggestions. To do so *six studies* are undertaken in this thesis,

Study 1 was to develop a conceptual framework for managing the implementation issues in supply chain of power sector using Soft System Methodology (SSM). To highlight the practical applicability of the proposed framework, a case illustration of an Indian transmission grid system has been considered. This research establishes a mechanism to manage grid integration problems by comparing established problems with their potential solutions. This analysis helps to develop a conceptual model that suggests attaining the final delivery system

as an integration of ESS in the grid system. The battery energy storage system (BESS) would enable the implementation of an effective and stable power supply. BESS helps to improve the efficiency, flexibility, reliability, resiliency, and security of the power delivery system.

Study 2 develops a hierarchical model using TISM for smart grid supply chain variables to understand their driving and dependence power in the electricity sector and MICMAC method is used for categorizing the identified factors into four groups. The results specify that energy storage plays as a central role which will enhance the operation of the smart grid and has ability to provide application-specific energy services across different components throughout the smart grid. This model will support policymakers in building rational decisions in the smart grid system to improve performance of power grid through services offered in its supply chain. Further, empirical analysis is used to analyze relationship among different variable of service supply chain of smart grid to identify the most significant factor among all service components classifies the factors of service supply chain of smart grid. For this, Regression analysis is used to analyze relationship among different element of service supply chain component of smart grid which is essential for integration in smart grid. The results also reveal that, Distributed Energy Storage System/ BMS have most important role in integration of smart grid services. Hence, findings of both TISM and Regression analysis reveal that Energy storage is pinpointed as a key technological component that can transform the current structure and operation of the power grid more efficiently.

Study 3 aims to acknowledge different barriers of battery integration and evaluate them to develop approaches for restricting their influence Firstly, it identifies barriers of battery integration with SG in Indian transmission power sector and develop a hierarchical framework to establish inter-relationship among the significant barriers and chronologically assemble the various issues from the greatest severe to the slightest severe. Here, A multi-model approach (TISM +MICMAC +AHP) is used to illustrate how these challenges are interrelated by systematically handling expert views and helps to chronologically assemble various issues from the greatest severe to the slightest severe ones. Further, these barriers are grouped using the cross-impact matrix multiplication applied to the classification analysis (MICMAC) study grounded on their driving and dependence power. Also, hypothesis testing was done to validate the obtained model. It provides a complete thoughtful on directional interrelationships between the barriers and delivers the best possible solution for the active operation of the smart grid and its performance.

Study 4 analyse the performance management of ESS, which can address the Technology-centric Triple Bottom Line (TcTBL) framework concerning sustainability goals. Here, portfolio of methodologies such as FAHP (Fuzzy Analytical Hierarchy Process), ERA (Evidential Reasoning Algorithm), and EUT (Expected Utility Theory) is used. An ERA synthesizes performance indicators (PIs) based on chosen parameters. EUT helps to obtain accurate values of PIs for the total performance approximation. This study highlights ESSs' competitive priorities and assists managers in identifying significant PIs that lead to higher competitive performance in smart grid. PIs can also help decision-makers classify an ideal solution between different alternative technologies, which offers maximum sustainability performance. The model's sensitivity analysis gives accurate conclusions and knowledge of the model's results' robustness. This objective brings out a systematic decision support system for decision-makers to conduct the evaluation process and select the best performance indicator for determining ESS.

Study 5 enhances the understanding of ESS adoption and its success rate in grid utility. This study addresses the concerns regarding which factors are essential for ESS adoption in smart grid and how they impact the adoption rate. This study describes empirical testing of a structural model based on the TOE (Technology-Organization-Environment) theory. Here, confirmatory factor analysis (CFA) and structural equation modeling (SEM) techniques were used to test the research model's validity, reliability, and model fitness based on relevant responses obtained from a questionnaire survey. This model illustrates how these factors can influence the power industry positively or negatively through statistical analysis. The results indicate that for adopting ESS in a grid, knowledge about available energy storage technologies is crucial, followed by cost competition, perceived benefits of innovation, environmental awareness, the public attitude towards ESS technology, perceived social trust, and perceived risk. Moreover, the findings of this study have important implications for energy policymakers, utility companies and have consequences for managerial practice and policymaking

Study 6 aims to investigate and evaluate the current state of energy storage system implementation within the grid in the Indian context. Analyzing the current state of the power industry is critical for facilitating a seamless transition to ESS. This research addresses the following research objectives: (1) To develop an analysis framework for Energy Storage implementation in the Power Grid in the Indian context based on the SAP-LAP approach.

(2) To prioritize the actors' rank and actions with various dominance measures. To accomplish this objective, the SAP-LAP model was presented, built on six fundamental elements to understand each variable that affects ESS implementation in the grid. These elements include SAP i.e. (Situation, Actor and Process) and LAP i.e. (Learning, Action, Performance). The sub-elements of SAP-LAP were based on the input of many stakeholders and from an intensive literature review. Furthermore, the e-IRP analysis is used to find the interrelationships among the actors concerning processes and the actions concerning performance.

Synthesis of these six studies brings out some important contribution that include:

- Energy storage is pinpointed as a key technological component that can transform the current structure and operation of the power grid.
- This research gives possible ways to run the future smart grid supply chain in an efficient secure and reliable manner.
- This research explains how a unified battery management system is an important part in building a smart grid environment and discussed the role of ESS in service management layer of proposed approach.
- We conclude that ESS/ BMS will handle the complexity and size of smart grid.
- This study gives an insight into the current energy scenarios of India, potential, initiatives, and policy regulation, including the potentialities of renewable energy sources to achieve sustainability in energy to meet the sustainable development goals.

सार

जैसे-जैसे विश्व अर्थव्यवस्था अधिक से अधिक सेवा उन्मुख होती जा रही है, सेवाओं ने ग्राहकों की संतुष्टि, सेवा मॉडलिंग और डिजाइन और सेवा वितरण के महत्वपूर्ण घटकों में सुधार करने में बहुत रुचि ली है। ब्रिक्स (ब्राजील, रूस, भारत, चीन और दक्षिण अफ्रीका) जैसे विकासशील देशों में भी सेवा क्षेत्र तेजी से दुनिया भर में विस्तार कर रहा है। नतीजतन, कई अनुमान बताते हैं कि सेवाएं अंततः वैश्विक अर्थव्यवस्था पर हावी होंगी।

दुनिया भर में, उपयोगिताएं रास्ते में आने वाली चुनौतियों को हल करने के लिए बड़े प्रयासों के साथ पारंपरिक पावर ग्रिड को स्मार्ट वितरित पावर सिस्टम में बदलने की कोशिश कर रही हैं। भारत जैसे विकासशील देशों में, स्मार्ट ग्रिड (एस जी) बिजली उद्योग के एक नए पहलू के रूप में उभर रहा है। इसमें पारंपरिक विद्युत नेटवर्क के साथ प्रचलित मुद्दों से निपटने के लिए कई उन्नत प्रौद्योगिकियां शामिल हैं। हालांकि इनमें से कई मुद्दों को संबोधित करने में सक्षम होने के बावजूद, स्मार्ट ग्रिड को अभी भी तैनाती में चुनौतियों का सामना करना पड़ रहा है। मौजूदा ग्रिड नेटवर्क स्वच्छ ऊर्जा और वितरित उत्पादन की आगामी जरूरतों को समायोजित करने के लिए अपर्याप्त है जो डिजाइन, निर्माण, संचालन और रखरखाव में कई चुनौतियों का सामना कर सकता है। स्मार्ट ग्रिड की सेवाओं का उद्देश्य ग्रिड निगरानी, संपत्ति नियंत्रण, प्रदर्शन और सुरक्षा के साथ-साथ संचालन, रखरखाव और योजना के वित्तीय तत्वों में सुधार करना है।

इस अध्ययन का उद्देश्य स्मार्ट ग्रिड की सेवा आपूर्ति श्रृंखला से संबंधित कारकों की पहचान करना, सबसे महत्वपूर्ण सेवा चर की पहचान करना और फिर ग्रिड के साथ एकीकरण के संदर्भ में उस चर का गहराई से विश्लेषण करना है। यह शोध स्मार्ट ग्रिड के सबसे महत्वपूर्ण परिचालन घटक यानी एनर्जी स्टोरेज सिस्टम पर अवलोकन प्रदान करता है। इसके अलावा, अनुसंधान उन कारकों पर परिचय देगा जो स्मार्ट ग्रिड की वर्तमान सेवाओं को बेहतर बनाने के लिए उपयोगिताओं को कम करने और सुधारने के तरीके को बदलने के लिए काम कर रहे हैं। इसके लिए, भारतीय संदर्भ में स्मार्ट ग्रिड की सेवा-उन्मुख आपूर्ति श्रृंखला की तैनाती के लिए मॉडल बनाने और ढांचे को लागू करने के लिए विभिन्न गुणात्मक और मात्रात्मक तरीकों को नियोजित किया गया था। इसलिए, इस शोध का उद्देश्य स्मार्ट ग्रिड में सेवाओं से संबंधित इन मुद्दों का समाधान करना और उपयोगी सुझाव देना है। ऐसा करने के लिए इस थीसिस में छह अध्ययन किए गए हैं,

अध्ययन 1 को सॉफ्ट सिस्टम मेथडोलॉजी (एस एस एम) का उपयोग करके बिजली क्षेत्र की आपूर्ति श्रृंखला में कार्यान्वयन के मुद्दों के प्रबंधन के लिए एक वैचारिक ढांचा विकसित करना था। प्रस्तावित ढांचे की व्यावहारिक प्रयोज्यता को उजागर करने के लिए, भारतीय पारेषण ग्रिड प्रणाली के मामले के चित्रण पर विचार किया गया है। यह शोध स्थापित समस्याओं की उनके संभावित समाधानों के साथ तुलना करके ग्रिड एकीकरण समस्याओं का प्रबंधन करने के लिए स्थापित करता है। यह विश्लेषण एक वैचारिक मॉडल विकसित करने में मदद करता है जो ग्रिड सिस्टम में ईएसएस के एकीकरण के रूप में अंतिम वितरण प्रणाली को प्राप्त करने का सुझाव देता है। बैटरी ऊर्जा भंडारण प्रणाली (बी ई एस एस) एक प्रभावी और स्थिर बिजली आपूर्ति के कार्यान्वयन को सक्षम करेगी। बिजली वितरण प्रणाली की दक्षता, लचीलापन, विश्वसनीयता, लचीलापन और सुरक्षा में सुधार करने में मदद करता

है।

अध्ययन 2 बिजली क्षेत्र में उनकी ड्राइविंग और निर्भरता शक्ति को समझने के लिए स्मार्ट ग्रिड आपूर्ति श्रृंखला चर के लिए टी आई एस एम का उपयोग करके एक पदानुक्रमित मॉडल विकसित करता है और पहचान किए गए कारकों को चार समूहों में वर्गीकृत करने के लिए (एम आई सी एम ए सी) विधि का उपयोग किया जाता है। परिणाम निर्दिष्ट करते हैं कि ऊर्जा भंडारण एक केंद्रीय भूमिका निभाता है जो स्मार्ट ग्रिड के संचालन को बढ़ाएगा और स्मार्ट ग्रिड में विभिन्न घटकों में एप्लिकेशन-विशिष्ट ऊर्जा सेवाएं प्रदान करने की क्षमता रखता है। यह मॉडल आपूर्ति श्रृंखला में प्रदान की जाने वाली सेवाओं के माध्यम से पावर ग्रिड के प्रदर्शन में सुधार के लिए स्मार्ट ग्रिड प्रणाली में तर्कसंगत निर्णय लेने में नीति निर्माताओं का समर्थन करेगा। इसके अलावा, अनुभवजन्य विश्लेषण का उपयोग स्मार्ट ग्रिड की सेवा आपूर्ति श्रृंखला के विभिन्न चर के बीच संबंधों का विश्लेषण करने के लिए किया जाता है ताकि सभी सेवा घटकों के बीच सबसे महत्वपूर्ण कारक की पहचान की जा सके और स्मार्ट ग्रिड की सेवा आपूर्ति श्रृंखला के कारकों को वर्गीकृत किया जा सके। इसके लिए, स्मार्ट ग्रिड के सेवा आपूर्ति श्रृंखला घटक के विभिन्न तत्वों के बीच संबंध का विश्लेषण करने के लिए प्रतिगमन विश्लेषण का उपयोग किया जाता है जो स्मार्ट ग्रिड में एकीकरण के लिए आवश्यक है। परिणाम यह भी बताते हैं कि वितरित ऊर्जा भंडारण प्रणाली की स्मार्ट ग्रिड सेवाओं के एकीकरण में सबसे महत्वपूर्ण भूमिका है। इसलिए, टी आई एस एम और प्रतिगमन विश्लेषण दोनों के निष्कर्षों से पता चलता है कि ऊर्जा भंडारण को एक प्रमुख तकनीकी घटक के रूप में इंगित किया गया है जो पावर ग्रिड की वर्तमान संरचना और संचालन को अधिक कुशलता से बदल सकता है।

अध्ययन 3 का उद्देश्य बैटरी एकीकरण की विभिन्न बाधाओं को स्वीकार करना और उनके प्रभाव को सीमित करने के लिए दृष्टिकोण विकसित करने के लिए उनका मूल्यांकन करना है। सबसे पहले, यह भारतीय ट्रांसमिशन पावर सेक्टर में एसजी के साथ बैटरी एकीकरण की बाधाओं की पहचान करता है और महत्वपूर्ण बाधाओं के बीच अंतर-संबंध स्थापित करने के लिए एक श्रेणीबद्ध ढांचा विकसित करता है और कालानुक्रमिक रूप से विभिन्न मुद्दों को सबसे गंभीर से लेकर मामूली गंभीर तक इकट्ठा किया। यहाँ, एक बहु-मॉडल दृष्टिकोण (टी आई एस एम + एम आई सी एम ए सी + ए एच पी) का उपयोग यह बताने के लिए किया जाता है कि कैसे ये चुनौतियाँ विशेषज्ञ विचारों को व्यवस्थित रूप से संभालने के द्वारा आपस में जुड़ी हुई हैं और विभिन्न मुद्दों को कालानुक्रमिक रूप से सबसे गंभीर से लेकर मामूली गंभीर तक इकट्ठा करने में मदद करती हैं। इसके अलावा, इन बाधाओं को उनकी ड्राइविंग और निर्भरता शक्ति के आधार पर (एम आई सी एम ए सी) अध्ययन का उपयोग करके समूहीकृत किया गया है। साथ ही, प्राप्त मॉडल को मान्य करने के लिए परिकल्पना परीक्षण भी किया गया था। यह बाधाओं के बीच दिशात्मक अंतर्संबंधों का पूर्ण विचार प्रदान करता है और स्मार्ट ग्रिड के सक्रिय संचालन और इसके प्रदर्शन के लिए सर्वोत्तम संभव समाधान प्रदान करता है।

अध्ययन 4 ऊर्जा भंडारण प्रणाली के प्रदर्शन प्रबंधन का विश्लेषण करता है, जो स्थिरता लक्ष्यों से संबंधित प्रौद्योगिकी-केंद्रित ट्रिपल बॉटम लाइन (टी सी टी बी एल) ढांचे को संबोधित कर सकता है। यहां, फ़ज़ी एनालिटिकल हाइरार्की प्रोसेस (एफ ए एच पी), एविडेंट रीजनिंग एल्गोरिथम (ई आर ए), और एक्सपेक्टेड यूटिलिटी थ्योरी (इ यू टी) जैसी कार्यप्रणालियों के पोर्टफोलियो का उपयोग किया जाता है। ई आर ए, चुने हुए मापदंडों के

आधार पर प्रदर्शन संकेतकों (पी आई) को संश्लेषित करता है। इ यू टी कुल प्रदर्शन सन्निकटन के लिए पी आई के सटीक मान प्राप्त करने में मदद करता है। यह अध्ययन ईएसएस की प्रतिस्पर्धी प्राथमिकताओं पर प्रकाश डालता है और प्रबंधकों को महत्वपूर्ण पीआई की पहचान करने में सहायता करता है जो स्मार्ट ग्रिड में उच्च प्रतिस्पर्धी प्रदर्शन की ओर ले जाता है। (पी आई) निर्णयकर्ताओं को विभिन्न वैकल्पिक तकनीकों के बीच एक आदर्श समाधान वर्गीकृत करने में भी मदद कर सकते हैं, जो अधिकतम स्थिरता प्रदर्शन प्रदान करता है। मॉडल का संवेदनशीलता विश्लेषण सटीक निष्कर्ष देता है और मॉडल के परिणामों की मजबूती का ज्ञान देता है। यह उद्देश्य मूल्यांकन प्रक्रिया का संचालन करने और (ई एस एस) निर्धारित करने के लिए सर्वश्रेष्ठ प्रदर्शन संकेतक का चयन करने के लिए निर्णयकर्ताओं के लिए एक व्यवस्थित निर्णय समर्थन प्रणाली लाता है।

अध्ययन 5 ई एस एस अपनाने की समझ और ग्रिड उपयोगिता में इसकी सफलता दर को बढ़ाता है। यह अध्ययन उन चिंताओं को संबोधित करता है जो स्मार्ट ग्रिड में ईएसएस के लिए आवश्यक हैं और वे कैसे प्रभावित कर रहे हैं। यह अध्ययन प्रौद्योगिकी-संगठन-पर्यावरण (टी ओ ई) सिद्धांत पर आधारित एक संरचनात्मक मॉडल के अनुभवजन्य परीक्षण का वर्णन करता है। यहां, प्रश्नावली सर्वेक्षण से प्राप्त प्रासंगिक प्रतिक्रियाओं के आधार पर अनुसंधान मॉडल की वैधता, विश्वसनीयता और मॉडल फिटनेस का परीक्षण करने के लिए पुष्टि कारक विश्लेषण (सी एफ ए) और संरचनात्मक समीकरण मॉडलिंग (एस ई एम) तकनीकों का उपयोग किया गया था। यह मॉडल दिखाता है कि कैसे ये कारक सांख्यिकीय विश्लेषण के माध्यम से बिजली उद्योग को सकारात्मक या नकारात्मक रूप से प्रभावित कर सकते हैं। परिणाम बताते हैं कि ईएसएस को ग्रिड में अपनाने के लिए, उपलब्ध ऊर्जा भंडारण तकनीकों के बारे में ज्ञान महत्वपूर्ण है, इसके बाद लागत प्रतियोगिता, नवाचार के कथित लाभ, पर्यावरण जागरूकता, ईएसएस प्रौद्योगिकी के प्रति जनता का रवैया, कथित सामाजिक विश्वास और कथित जोखिम आवश्यक हैं। इसके अलावा, इस अध्ययन के निष्कर्षों का ऊर्जा नीति निर्माताओं, उपयोगिता कंपनियों के लिए महत्वपूर्ण प्रभाव पड़ता है और प्रबंधकीय अभ्यास और नीति निर्माण के लिए परिणाम होते हैं

अध्ययन 6 का उद्देश्य भारतीय संदर्भ में ग्रिड के भीतर ऊर्जा भंडारण प्रणाली कार्यान्वयन की वर्तमान स्थिति की जांच और मूल्यांकन करना है। बिजली उद्योग की वर्तमान स्थिति का विश्लेषण ईएसएस में निर्बाध परिवर्तन की सुविधा के लिए महत्वपूर्ण है। यह शोध निम्नलिखित शोध उद्देश्यों को संबोधित करता है: (1) एस ए पी -एल ए पी दृष्टिकोण के आधार पर भारतीय संदर्भ में पावर ग्रिड में ऊर्जा भंडारण कार्यान्वयन के लिए एक विश्लेषण ढांचा विकसित करना। (2) विभिन्न प्रभुत्व उपायों के साथ अभिनेताओं के रैंक और कार्यों को प्राथमिकता देना। इस उद्देश्य को पूरा करने के लिए, एस ए पी -एल ए पी मॉडल प्रस्तुत किया गया था, जो ग्रिड में ईएसएस कार्यान्वयन को प्रभावित करने वाले प्रत्येक चर को समझने के लिए छह मौलिक तत्वों पर बनाया गया था। इन तत्वों में एस ए पी यानी (सिचुएशन, एक्टर एंड प्रोसेस) और एल ए पी यानी (लर्निंग, एक्शन, परफॉर्मैस) शामिल हैं। एस ए पी -एल ए पी के उप-तत्व कई हितधारकों के इनपुट और एक गहन साहित्य समीक्षा से आधारित थे। इसके अलावा, ई-आईआरपी विश्लेषण का उपयोग प्रक्रियाओं से संबंधित अभिनेताओं और प्रदर्शन से संबंधित कार्यों के बीच अंतर्संबंधों को खोजने के लिए किया जाता है।

इन छह अध्ययनों के संश्लेषण से कुछ महत्वपूर्ण योगदान सामने आते हैं जिनमें शामिल हैं:

- ऊर्जा भंडारण को एक प्रमुख तकनीकी घटक के रूप में चिन्हित किया गया है जो पावर ग्रिड की वर्तमान संरचना और संचालन को बदल सकता है।
- यह शोध भविष्य की स्मार्ट ग्रिड आपूर्ति श्रृंखला को कुशल, सुरक्षित और विश्वसनीय तरीके से चलाने के संभावित तरीके बताता है।
- यह शोध बताता है कि कैसे एक एकीकृत बैटरी प्रबंधन प्रणाली एक स्मार्ट ग्रिड वातावरण के निर्माण में एक महत्वपूर्ण हिस्सा है और प्रस्तावित दृष्टिकोण की सेवा प्रबंधन परत में ईएसएस की भूमिका पर चर्चा की।
- हमारा निष्कर्ष है कि ई एस एस / बी एम एस स्मार्ट ग्रिड की जटिलता और आकार को संभालेगा।
- यह अध्ययन सतत विकास लक्ष्यों को पूरा करने के लिए ऊर्जा में स्थिरता प्राप्त करने के लिए नवीकरणीय ऊर्जा स्रोतों की क्षमता सहित भारत के वर्तमान ऊर्जा परिदृश्य, क्षमता, पहल और नीति विनियमन में एक अंतर्दृष्टि प्रदान करता है।

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LIST OF ABBREVIATIONS

ADR	Adoption rate
ADR	Automatic Demand Response
AEIA	American Energy Innovation Act
AGFI	Adjusted Goodness of Fit Index
AHP	Analytical Hierarchy Process
AMI	Advanced metering infrastructure
AND	Adjusted Net Dominance
ANOVA	Analysis of Variance
AVE	Average Variance Extracted
BD	Belief Degree
BESS	Battery Energy storage System
BMS	Battery Management System
BNP	Best Non-fuzzy Performance
BRICS	Brazil, Russia, India, China and South Africa
BSS	Battery Storage System
CATWOE	Customers, Actors, Transformation process, Weltanschauung (world view), Owner, and Environmental constraint
CC	Cost Competition
CEA	Central Electricity Authority
CEA	Central Electricity Authority
CERC	Central Energy Regulatory Commission
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
Chi²/df	Chi-square to a degree of freedom
CI	Consistency index
CI	Customer information interface
CIM	Cross Interpretive Matrix

CMB	Common Method Bias
CO2	Carbon Dioxide
CR	Composite Reliability
CR	Consistency ratio
DER	Distributed Energy Resources
DES	Distributed energy storage system
DG	Distributed Generation
DI	Dominance Index
DOE	Department of Energy
DR	Demand Response
D-S Theory	Dempster –Shaffer (D-S) theory
DSM	Demand Side Management
DSOs	Distribution system operators
DST	Department of Science and Technology
EA	Environmental Awareness
E-IRP	Efficient- Interpretive Ranking Process
EMS	Energy Management System
EMS	Energy Management System
EPRI	Electric Power Research Institute
ERA	Evidential Reasoning Algorithm
ES	Energy Storage
ESS	Energy Storage System
EST	Energy Storage Technologies
EUT	Expected Utility Theory (EUT)
EV	Electric Vehicle
FAHP	Fuzzy Analytical Hierarchy Process
FERA	Fuzzy Evidential Reasoning Approach
FS	Financial Strength
GDP	Gross Domestic Product

GEST	Grid-scale electrical energy storage technologies
GFI	Goodness of Fit Index
GoI	Government of India
HV	High Voltage
I4SEA	Industry 4.0 Service Enabler Architecture
IC	Integrated communication
ICT	Information and Communication Technology
ID	Implicit dominance
IEA	International Energy Agency
IESA	India Energy Storage Alliance
IFI	Incremental Fit Index
IND	Implicit Non-Dominance
InD	Interpretive dominance
IoT	Internet of Things
ISGF	The India Smart Grid Forum
ISO	Independent System Operator
ISTS	Interstate Transmission System
IT	Information Technology
IUSSTF	Indo-US Science and Technology Forum
JUICE	Joint UK-India Clean Energy System
KAT	Knowledge or Awareness about ESS technology
LCSA	Life Cycle Sustainability Assessment
MCDM	Multi Criteria Decision Making
MICMAC	Cross-impact matrix multiplication applied to the classification analysis
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
NFI	Non-Normed Fit Index
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory

OR	Operation Research
PAT	Public Attitude towards technology
PBI	Perceived Benefits of innovation
PIs	Performance Indicators
PR	Perceived risk/ Competitive Pressure
PST	Perceived Social Trust
PV	Photovoltaic
RD&D	Research, Development, and Demonstration
RE	Renewable Energy
REG	Renewable Energy Generation
RERs	Renewable Energy Resources
RES	Renewable Energy Source
RI	Random index
RMSEA	Root Mean Square Error of Approximation
ROI	Return on Investment
RTO	Regional Transmission Organization
SAP-LAP	(Situation, Actor, Process and Learning, Action, Performance)
SC	Substation Controller
SCM	Supply Chain Management
SECI	Solar Energy Corporation of India
SEM	Structural Equation Modelling
SG	Smart Grid
SLR	Systematic literature review
SM	Smart Meters
SSC	Service Supply Chain
SSCM	Service Supply Chain Management
SSM	Soft System Methodology
TAM	Technology Acceptance Model
TBL	Triple Bottom Line

TcTBL	Technology-centric Triple Bottom Line (TcTBL) framework
TD	Transitive dominance
TFN	Triangular Fuzzy Number
TGS	Transmission Grid system
TISM	Total Interpretive Structural Modeling
TLI	Tuker -Lewis Index
TOE	Technological Organizational Environmental
TSOs	Transmission system operators
US	United States
VIF	Variance inflation factor
VRE	Variable Renewable Energy