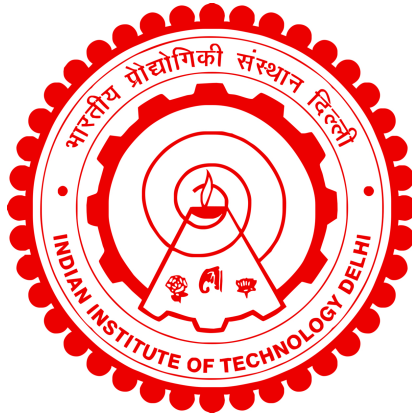


# SELECT STUDIES ON DEMAND MANAGEMENT IN SMART GRID

Chandra Pal



Department of Management Studies

INDIAN INSTITUTE OF TECHNOLOGY DELHI

April 2023

© *Indian Institute of Technology Delhi (IITD), New  
Delhi, 2023*

# Select Studies on Demand Management in Smart Grid

by

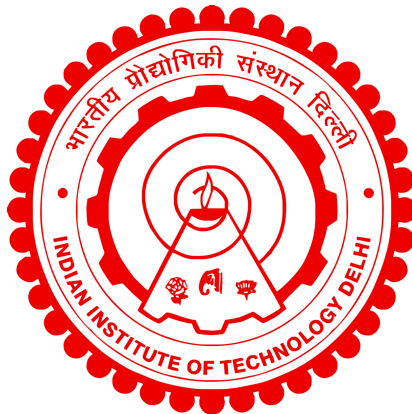
**Chandra Pal**  
**(2017SMZ8019)**

Department of Management Studies

Submitted

in partial fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY  
DELHI**

**April 2023**

*This thesis is dedicated in the memory of my beloved  
Father Brahm Singh*

# Certificate

This is to certify that the thesis entitled “**Select Studies on Demand Management of Smart Grid in India**”, submitted by **Chandra Pal** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in **April 2023**, is a record of the original, bona fide research work carried out by him under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

**Prof. Ravi Shankar**

Department of Management Studies,  
Indian Institute of Technology Delhi.

# *Acknowledgements*

I would like to start by expressing my sincere appreciation and gratitude to Prof. Ravi Shankar, who is the supervisor of my thesis, for his helpful suggestions and guidance all through my studies. I am grateful to him for connecting me to the most effective supply chain and operations management strategies. His kind comments, positive interactions, and positive support through the research's lean periods have been an inspiration to keep going. Without his great interest, direction, and supervision, this thesis could not have developed into its current shape.

I owe my brother Dr. Satyavir Singh for his unwavering encouragement and support as well. I am also grateful to my lab mates and close friends Aayush Gautam, Archana Roy, Laxmi Gupta, Vipin Kumar and Monika Shukla for the many times I talked to them about research when I was stuck. I extend my deepest appreciation to Prashant Gupta, Viney Yadav, Upendra Yadav, Sunil Kumar, and Bishal Sarkar for their assistance throughout the completion of my thesis and for making my experience at IITD genuinely enjoyable and memorable.

My deepest gratitude to Mr. Alok Malik, Mr. Parikshit, Mr. Ditpal, Mr. Vimal, Mr. Amit Tiwari, Mr. Brijender, Mr. Dal Chand, and all the other people who work in the Department of Management Studies at IIT Delhi who helped me with my work.

I want to thank and show my sincere gratitude to my mother Rajendri Devi for their continuous encouragement and support during my Ph.D studies. Furthermore, I am also appreciative to my wife Rajni Chandra for her kindness and patience. Sincere appreciation to my daughters Akshita and Ashwani, who smiled through the toughest things in my doctoral work. I genuinely appreciate their love, unwavering support, and tolerance.

**Chandra Pal**

# *Abstract*

Power generation meets consumer needs and enhances daily life in a world where energy consumption is rising. However, due to the increasing number of consumers and the unpredictability of the electric load, the electricity demand may present difficulties for electric utilities. Therefore, the smart grid is an advanced power system with communication automation, with IoT devices that can track the movement of power from generating to consumption locations and shorten the load to align generation in real-time. A smart grid allows customers to use transparent displays and real-time accounting information more effectively to handle power. Consumers can adjust their electricity consumption during peak demand hours and rely on low-cost power from renewable sources.

Demand Side Management (DSM) is an important aspect of the demand management of the smart grid that provides support in different areas such as power market regulation, management, network building, and decentralized energy resource management. By managing and reducing energy consumption, we aggregate the demand for peak loads, reduce operational expenses and carbon emissions to modify the demand curve. There are numerous DSM techniques that include load shifting by managing and reducing energy consumption, load shedding, peak clipping, stabilization, and dynamic loading. The main aim of the DSM strategies is to reduce peak load demand and operating costs.

The first objective of this study is to develop a conceptual framework for managing the implementation issues of demand management using Soft System Methodology (SSM). To highlight the practical applicability of the proposed framework, a case situation of an Indian power utility has been considered. The perspectives of multiple experts in the relevant functional domains were gathered to create a symptom map, a rich picture, CATWOE for root definition, an initial conceptual model, a final implementable model, and an implementation framework for demand management in smart grid. The second objective of this study is to investigate the interrelationships for critical success factors of demand management in smart grid by the hierarchical structural model using total interpretive structural modeling (TISM). These sets of factors were obtained through past literature studies. Further, to confirm the

relevance of these variables, a questionnaire-based survey was conducted for the different Indian power utilities.

The third objective of this study is to build a hierarchy of critical success factors to develop a framework for evaluating the performance of sustainability perspective. The FAHP is used in this study to determine the weight of economic, operational and environmental criteria. Furthermore, the evidential reasoning algorithm is used to calculate the belief degree of the expert's opinion and expected utility theory for the crisp value of success factors. Therefore, a sensitivity analysis is used to identify the ranking of critical success factors stay constant regardless of how criteria weights are altered. The last objective of this study proposed a holistic, flexible decision framework for energy management in a smart grid. Therefore, Situation Actor Process-Learning Action Performance (SAP-LAP) model has been used. The respective variables have been identified after a comprehensive analysis of the literature and consideration of the opinions of domain experts. Additionally, an Interpretive Ranking Process (IRP) based ranking method is used in this study. This helps to allocate proportionate resource to each SAP-LAP variable to make a better decision for the demand management in the smart grid.

The findings of this research provide important insight for smart grid practitioners, academics, and policymakers. The study, which is based on soft system methodology, adds the body of knowledge by offering a conceptual framework for addressing demand management challenges in Indian power utilities. Therefore, based on the integrated TISM methodology, the study recognized and modeled the interrelationships for critical success factors in demand management. The development of this hierarchical model empowers management to make better decisions dealing with complex issues for better performance. Finally, an integrated SAP-LAP and IRP approach for establishing India's smart grid framework, which would be useful to practitioners and policymakers in addressing the desired needs to mitigate the demand management issues.

## सार

बिजली उत्पादन उपभोक्ता की जरूरतों को पूरा करता है और एक ऐसी दुनिया में दैनिक जीवन को बढ़ाता है जहां ऊर्जा की खपत बढ़ रही है। हालांकि, उपभोक्ताओं की बढ़ती संख्या और बिजली के भार की अप्रत्याशितता के कारण, बिजली की मांग विद्युत उपयोगिताओं के लिए कठिनाइयों को पेश कर सकती है। इसलिए, स्मार्ट ग्रिड ऑटोमेशन, संचार और आईटी सिस्टम के साथ एक विद्युत प्रणाली है जो बिजली के प्रवाह को उत्पादन से खपत स्थानों तक मॉनिटर कर सकती है और वास्तविक समय में पीढ़ी को संरेखित करने के लिए लोड को छोटा कर सकती है। स्मार्ट ग्रिड ग्राहकों को बिजली को संभालने के लिए पारदर्शी डिस्ले और रीयल-टाइम अकाउंटिंग जानकारी का अधिक प्रभावी ढंग से उपयोग करने की अनुमति देता है। उपभोक्ता मांग के व्यस्त समय के दौरान अपनी बिजली की खपत को समायोजित कर सकते हैं और नवीकरणीय स्रोतों से कम लागत वाली बिजली पर भरोसा कर सकते हैं।

डिमांड साइड मैनेजमेंट भविष्य के स्मार्ट ग्रिड के ऊर्जा प्रबंधन में एक महत्वपूर्ण पहलू है जो बिजली बाजार विनियमन, प्रबंधन, नेटवर्क निर्माण और विकेंद्रीकृत ऊर्जा संसाधन प्रबंधन जैसे विभिन्न क्षेत्रों में सहायता प्रदान करता है। ऊर्जा की मांग को नियंत्रित और प्रबंधित करने से पीक लोड की कुल मांग कम हो जाएगी, मांग वक्र को नया आकार मिलेगा और परिचालन लागत और कार्बन उत्सर्जन को कम करके ग्रिड दक्षता में सुधार होगा। कई डीएसएम तकनीकें हैं जिनमें लोड शिफ्टिंग, पीक क्लिपिंग, स्थिरीकरण, लोड बिल्डिंग, वैली फिलिंग और डायनेमिक लोडिंग शामिल हैं। डीएसएम रणनीतियों का मुख्य उद्देश्य पीक लोड मांग और परिचालन लागत को कम करना है।

इस अध्ययन का पहला उद्देश्य सॉफ्ट सिस्टम मेथडोलॉजी (एसएसएम) का उपयोग करके मांग प्रबंधन के कार्यान्वयन के मुद्दों के प्रबंधन के लिए एक वैचारिक ढांचा विकसित करना है। प्रस्तावित ढांचे की व्यावहारिक प्रयोज्यता को उजागर करने के लिए, एक भारतीय बिजली उपयोगिता की स्थिति की स्थिति पर विचार किया गया है। प्रासंगिक कार्यात्मक डोमेन में कई विशेषज्ञों के दृष्टिकोण को एक लक्षण मानचित्र, एक समृद्ध चित्र, रूट परिभाषा के लिए CATWOE, एक प्रारंभिक वैचारिक मॉडल, अंतिम कार्यान्वयन योग्य मॉडल और स्मार्ट ग्रिड में मांग प्रबंधन के लिए कार्यान्वयन ढांचा बनाने के लिए एकत्र किया गया था। इस अध्ययन का दूसरा उद्देश्य कुल व्याख्यात्मक संरचनात्मक मॉडलिंग (TISM) का उपयोग करके पदानुक्रमित संरचनात्मक मॉडल के विकास के माध्यम से स्मार्ट ग्रिड में मांग प्रबंधन के महत्वपूर्ण सफलता कारकों के लिए अंतर्संबंधों की जांच करना है। पिछले साहित्य अध्ययनों के माध्यम से कारकों के इन सेटों को प्राप्त किया गया था। इसके अलावा, इन चरों की प्रासंगिकता की पुष्टि करने के लिए, विभिन्न भारतीय बिजली उपयोगिताओं के लिए एक प्रश्नावली-आधारित सर्वेक्षण किया गया था।

इस अध्ययन का तीसरा उद्देश्य स्थिरता के नजरिए से स्मार्ट ग्रिड के प्रदर्शन के मूल्यांकन के लिए एक ढांचा विकसित करने के लिए महत्वपूर्ण सफलता कारकों का एक पदानुक्रम स्थापित करना है। इस अध्ययन में आर्थिक, परिचालन और पर्यावरणीय मानदंडों के सापेक्ष वजन का आकलन और निर्धारण करने के लिए अस्पष्ट विश्लेषणात्मक पदानुक्रम प्रक्रिया का उपयोग किया जाता है। उसी समय, विशेषज्ञ की राय के विश्वास की डिग्री और प्रदर्शन आकलन में सफलता कारकों के कुरकुरा मूल्य के लिए अपेक्षित उपयोगिता सिद्धांत को निर्धारित करने के लिए साक्ष्य तर्क एल्गोरिथम का उपयोग किया जाता है। इसलिए, महत्वपूर्ण सफलता कारकों की रैंकिंग की पहचान करने के लिए एक संवेदनशीलता विश्लेषण का उपयोग किया जाता है, इससे कोई फर्क नहीं पड़ता कि मानदंड वजन कैसे बदला जाता है, जो प्रस्तावित मॉडल और मूल्यांकन परिणामों की मजबूती और प्रभावशीलता की पुष्टि करता है। इस अध्ययन के अंतिम उद्देश्य ने स्मार्ट ग्रिड में ऊर्जा प्रबंधन के लिए एक समग्र, लचीला निर्णय ढांचा प्रस्तावित किया। इसलिए, सिचुएशन एक्टर प्रोसेस-लर्निंग एक्शन परफॉर्मिस (SAP-LAP) मॉडल का इस्तेमाल किया गया है। साहित्य के व्यापक विश्लेषण और डोमेन विशेषज्ञों की राय पर विचार करने के बाद संबंधित चर की पहचान की गई है। इसके अतिरिक्त, इस अध्ययन में एक व्याख्यात्मक रैंकिंग प्रक्रिया (आईआरपी) आधारित रैंकिंग पद्धति का उपयोग किया जाता है। यह स्मार्ट ग्रिड के ऊर्जा प्रबंधन के लिए बेहतर निर्णय लेने के लिए प्रत्येक एसएपी-एलएपी चर के लिए अनुपातिक संसाधन आवंटित करने में मदद करता है।

इस शोध के निष्कर्ष स्मार्ट ग्रिड व्यवसायियों, शिक्षाविदों और नीति निर्माताओं के लिए महत्वपूर्ण अंतर्दृष्टि प्रदान करते हैं। अध्ययन, जो सॉफ्ट सिस्टम पद्धति पर आधारित है, भारतीय बिजली उपयोगिता में मांग प्रबंधन चुनौतियों को संबोधित करने के लिए एक वैचारिक ढांचे की पेशकश करके ज्ञान के शरीर को जोड़ता है। इसलिए, एकीकृत टीआईएसएम पद्धति के आधार पर, अध्ययन ने मांग प्रबंधन में महत्वपूर्ण सफलता कारकों के लिए अंतर्संबंधों को मान्यता दी और मॉडलिंग की। लंबे समय तक संरक्षित करने के लिए, स्थिरता उपयोगिता अपने आर्थिक, परिचालन और पर्यावरणीय मानदंडों पर जोर देती है। इस पदानुक्रमित मॉडल का विकास बेहतर प्रदर्शन के लिए जटिल मुद्दों से निपटने के लिए बेहतर निर्णय लेने के लिए प्रबंधन को सशक्त बनाता है। अंत में, भारत के स्मार्ट ग्रिड ढांचे की स्थापना के लिए एक एकीकृत एसएपी-एलएपी और आईआरपी दृष्टिकोण, जो मांग प्रबंधन के मुद्दों को कम करने के लिए वांछित जरूरतों को पूरा करने में चिकित्सकों और नीति निर्माताओं के लिए उपयोगी होगा।

# Contents

<b>Certificate</b>	<b>i</b>
<b>Acknowledgements</b>	<b>ii</b>
<b>Abstract</b>	<b>iii</b>
<b>Contents</b>	<b>vii</b>
<b>List of Figures</b>	<b>xiii</b>
<b>List of Tables</b>	<b>xv</b>
<b>Abbreviations</b>	<b>xvii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Overview . . . . .	1
1.2 Demand management in smart grid . . . . .	2
1.3 Technologies used in demand management . . . . .	3
1.4 Need for a smart grid: . . . . .	4
1.5 Motivation for the research . . . . .	6
1.6 Research question and objectives . . . . .	6
1.7 Research methodology . . . . .	7
1.8 Organisation of the thesis . . . . .	8
1.9 Chapter summary . . . . .	11
<b>2 Literature Review</b>	<b>13</b>
2.1 Overview . . . . .	13
2.2 Introduction . . . . .	13
2.3 Systematic literature review on demand management . . . . .	15

2.3.1	Collection of the research articles . . . . .	15
2.3.2	Findings based on descriptive analysis . . . . .	17
2.3.3	Year-wise publication trends . . . . .	17
2.4	Review of literature for smart grid evolution . . . . .	17
2.4.1	Journal wise distribution of articles . . . . .	18
2.4.2	Country-wise distribution of articles . . . . .	19
2.5	Review of literature for benefits of smart grid . . . . .	20
2.6	Review of literature for demand management and environmental issues	21
2.7	Review of literature for Integration of renewable energy resources . . .	22
2.8	Review of literature for key component of demand management . . . .	23
2.9	Review of literature for smart grid applications . . . . .	28
2.10	Bibliometric analysis on selected article . . . . .	30
2.10.1	Co-occurrences of authors keywords . . . . .	30
2.10.2	Co-citation – journal sources citations network visualization: . .	31
2.11	Research gap . . . . .	33
2.12	Insights from literature review . . . . .	34
2.13	Chapter summary . . . . .	36
<b>3</b>	<b>Research Design and Methodology</b>	<b>37</b>
3.1	Overview . . . . .	37
3.2	Introduction . . . . .	37
3.3	Research design . . . . .	38
3.4	Research methodology . . . . .	39
3.4.1	Fuzzy analytical hierarchy process . . . . .	40
3.4.2	Soft system methodology . . . . .	40
3.4.3	Total interpretive structural modeling . . . . .	41
3.4.4	Exploratory Factor Analysis . . . . .	43
3.4.5	DEMATEL . . . . .	43
3.4.6	SAP-LAP and IRP . . . . .	46
3.5	Mapping of research objective to research methodology . . . . .	47
3.6	Justification for using qualitative and quantitative approaches . . . .	48
3.6.1	Soft system methodology for research objective one . . . . .	49
3.6.2	An integrated approach based on a questionnaire survey, TISM, Fuzzy MICMAC, and DEMATEL methods for research objec- tive two . . . . .	49
3.6.3	FERA, EUT and ERA for research objective three . . . . .	50
3.6.4	SAP-LAP and IRP for research objective four . . . . .	51
3.7	Chapter summary . . . . .	52
<b>4</b>	<b>Development of a Comprehensive Framework for Addressing the Demand Management Issues</b>	<b>53</b>
4.1	Overview . . . . .	53

4.2	Introduction and problem description . . . . .	54
4.3	Solution methodology . . . . .	55
4.4	Application of SSM for demand management in smart grid . . . . .	56
4.5	Case analysis . . . . .	58
4.5.1	Phase I: Developing a symptom map to analyze the current problem . . . . .	58
4.5.2	Phase II: Developing a rich picture . . . . .	61
4.5.3	Phase III: Identification of root causes of the current problem . . . . .	63
4.5.4	Phase IV: Identification of root definition for on the CAT-WAOE approach . . . . .	63
4.5.5	Phase V: Development of an initial conceptual model and final implementable model . . . . .	66
4.6	Discussions . . . . .	68
4.7	Chapter summary . . . . .	69
<b>5</b>	<b>Identification and Performance Measurement of Significant Critical Success factors of demand management</b> . . . . .	<b>71</b>
5.1	Overview . . . . .	71
5.2	Introduction and problem description . . . . .	72
5.3	Identification of demand management related success factors . . . . .	74
5.4	Data Collections and EFA . . . . .	80
5.4.1	Administration of questionnaire-based survey . . . . .	80
5.4.2	Data collection and respondents' profile . . . . .	80
5.4.3	Factor analysis . . . . .	81
5.4.4	Exploratory factor analysis . . . . .	82
5.4.5	Total interpretive structural modeling . . . . .	83
5.4.6	Steps in TISM . . . . .	84
5.5	Applications of TISM, DEMATEL and Fuzzy MICMAC . . . . .	87
5.5.1	Application of TISM Methodology . . . . .	87
5.5.1.1	SIM creation VAXO . . . . .	87
5.5.1.2	Initial reachability matrix . . . . .	89
5.5.1.3	Final reachability matrix . . . . .	89
5.5.1.4	Level partitioning . . . . .	90
5.5.1.5	Build TISM Model . . . . .	93
5.5.2	Fuzzy MICMAC . . . . .	93
5.5.2.1	Development linguistic assessment direct reachability matrix . . . . .	93
5.5.2.2	Develop fuzzy MICMAC stabilized matrix . . . . .	94
5.5.3	DEMATEL . . . . .	96
5.6	Result and Discussion . . . . .	97
5.6.1	TISM result . . . . .	97
5.6.2	Comparison of results from EFA and TISM . . . . .	97

5.6.3	Fuzzy MICMAC result . . . . .	99
5.6.4	DEMATEL result . . . . .	101
5.6.5	Managerial implication . . . . .	104
5.7	Discussion . . . . .	105
5.8	Chapter summary . . . . .	106
<b>6</b>	<b>Sustainability Assessment Framework and Profiling of their Associated Ranking for Demand Management</b>	<b>109</b>
6.1	Overview . . . . .	109
6.2	Introduction and problem description . . . . .	110
6.3	Identification of sustainability related success factors . . . . .	111
6.4	Methodology . . . . .	117
6.4.1	Steps to run the FAHP algorithm . . . . .	118
6.4.2	Application of fuzzy belief degree to assess the efficiency of success factors . . . . .	122
6.4.3	Execution of Evidential reasoning algorithm . . . . .	124
6.4.4	Determine the crisp result using expected utility approach . . . . .	126
6.5	Evaluation index system for the performance of smart grid . . . . .	127
6.5.1	Implementation of fuzzy analytical hierarchy process . . . . .	128
6.5.2	Linguistic variable and belief degree . . . . .	130
6.5.3	Implementations of EUT and ERA algorithm . . . . .	130
6.5.4	Sensitivity analysis . . . . .	131
6.6	Result and discussion . . . . .	137
6.7	Managerial implication . . . . .	141
6.8	Chapter summary . . . . .	142
<b>7</b>	<b>A Framework for Establishing Demand Management Platform for the Indian Power Utility</b>	<b>145</b>
7.1	Overview . . . . .	145
7.2	Introduction and problem description . . . . .	146
7.3	Identify the factors that influence demand management . . . . .	148
7.4	Solution methodology . . . . .	155
7.5	Steps for integrated SAP-LAP and IRP approach . . . . .	156
7.6	Discussion of the results . . . . .	160
7.6.1	Actors with respect to processes . . . . .	160
7.6.2	Actions with respect to performances . . . . .	163
7.7	Managerial implications and insights . . . . .	166
7.8	Chapter summary . . . . .	167
<b>8</b>	<b>Synthesis and Conclusions</b>	<b>169</b>
8.1	Overview . . . . .	169
8.2	Introduction . . . . .	170

8.3	Summary of research findings . . . . .	173
8.3.1	Study A . . . . .	173
8.3.2	Study B . . . . .	174
8.3.3	Study C . . . . .	175
8.3.4	Study D . . . . .	175
8.4	Significant research contributions . . . . .	176
8.4.1	Theoretical implications of the research . . . . .	176
8.4.2	Managerial implications of the research . . . . .	178
8.5	Limitations of the research . . . . .	179
8.6	Scope for future research . . . . .	179
8.7	Chapter summary . . . . .	180
<b>A</b>	<b>Questionnaire survey</b>	<b>181</b>
<b>B</b>	<b>Interpretive logic knowledge base ranking</b>	<b>185</b>
	<b>Bibliography</b>	<b>189</b>
	<b>List of Publications</b>	<b>221</b>

# List of Figures

1.1	Install capacity of power in India . . . . .	2
1.2	Organization of the thesis structure . . . . .	9
2.1	Process of article selection . . . . .	16
2.2	Year-wise distribution of research articles . . . . .	18
2.3	Co-occurrence of all keywords (Network visualization) . . . . .	31
2.4	Bibliometric coupling vs source . . . . .	32
2.5	Bibliometric coupling vs countries . . . . .	33
4.1	Checkland’s sevenstage overview of the SSM . . . . .	56
4.2	Symptoms Map . . . . .	60
4.3	Rich Picture . . . . .	62
4.4	Formulation of alternative root defination . . . . .	65
4.5	Conceptual model . . . . .	66
4.6	Final model . . . . .	67
5.1	An overview of the research flow. . . . .	75
5.2	TISM Methodology (modified from Jena et al. (2017)) . . . . .	85
5.3	TISM model of CSFs for Smart Grid. . . . .	98
5.4	Fuzzy MICMAC plot . . . . .	101
5.5	Cause-effect relationship plot . . . . .	104
6.1	Flowchart outlining the methodology for determining the performance of thirteen success factors. . . . .	132
6.2	Triangular fuzzy number containing lower, middle, and upper weights	133
6.3	Membership value for five linguistics variables . . . . .	133
6.4	Evaluation criteria identification procedure . . . . .	134
6.5	A specific model for success factor of smart grid . . . . .	135
6.6	Normalised percentage chart of 13 success factors. . . . .	139
6.7	Sensitivity analysis of social dimension . . . . .	141
6.8	Sensitivity analysis of economic dimension . . . . .	141
6.9	Sensitivity analysis of operational dimension . . . . .	142
7.1	SAP-LAP model for energy management . . . . .	149
7.2	Interpretive ranking model of actor versus processes . . . . .	164

7.3 Interpretive ranking model of action versus performance . . . . . 164

# List of Tables

2.1	Top twenty journals of published literature . . . . .	19
2.2	Country-wise distribution of research articles . . . . .	20
2.3	Machine learning techniques used in research of smart grids . . . . .	25
2.4	IOT application in smart grid research/practices . . . . .	26
3.1	Mapping of research objectives with research methodology . . . . .	48
4.1	Root cause of demand management issues . . . . .	64
4.2	CATWOE analysis for demand management issue . . . . .	65
5.1	Results of factor analysis. . . . .	82
5.2	Factor loading value for sixteen CSFs. . . . .	83
5.3	Factor matrix for selected CSFs. . . . .	83
5.4	Self interaction matrix . . . . .	88
5.5	Initial reachability matrix . . . . .	89
5.6	Final reachability matrix . . . . .	90
5.7	Level partitioning of reachability matrix. . . . .	90
5.8	Linguistic scale . . . . .	94
5.9	Linguistic assessment direct reachability matrix . . . . .	95
5.10	Defuzzyfied matrix of linguistic variables . . . . .	95
5.11	Fuzzy MICMAC stablized matrix . . . . .	96
5.12	Average direct influence matrix . . . . .	96
5.13	Normanlized direct influence matrix . . . . .	103
5.14	Total influence matrix . . . . .	103
6.1	Linguistic variable used to evaluate output derived from TFN . . . . .	119
6.2	Value for RI versus matrix order . . . . .	121
6.3	Linguistic terms with notations and membership value . . . . .	123
6.4	Experts opinion linguistic variable used for performance evaluation . . . . .	136
6.5	Average of experts opinion and belief degree . . . . .	136
6.6	Normalized TFN of seventh success factor . . . . .	137
6.7	Success factor is ranked individually based on various criteria. . . . .	137
6.8	Assessment and rank of individual success factors. . . . .	138
6.9	Sensitivity analysis by changing belief degree . . . . .	140

*List of Tables*

---

7.1	Theory building with SAP-LAP framework for demand management .	152
7.2	Cross-interaction matrix and interpretive logic: actors versus process .	160
7.3	Cross interaction matrix and interpretive logic: actions versus performance . . . . .	161
7.4	Dominating interactions matrix - ranking of actors w.r.t processes . .	162
7.5	Dominance matrix- ranking of actors w.r.t process . . . . .	162
7.6	Dominating interactions matrix-ranking of actions w.r.t performance	163
7.7	Domianting matrix - ranking of actions w.r.t performance . . . . .	163
8.1	Mapping of research objectives and output with research methods . .	172
A.1	Response Table . . . . .	184
B.1	Interpretive logic knowledge base- ranking of actors w.r.t process . .	186
B.2	Interpretive logic knowledge base - influence of action on various performance . . . . .	187

# Abbreviations

ADR	Automated Demand Response
AMI	Advanced Metering Infrastructure
ADR	Automated Demand Response
AMI	Advance Metering Infrastructure
AMR	Automatic Meter Reading
ATC	Aggregate Technical and Commercial Losses
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFL	Compact Fluorescent Lamp
CNG	Compressed Natural Gas
CRM	Customer Relationship Management
CSF	Critical Success Factors
DER	Distributed Energy Resource
DERC	Delhi Electricity Regulatory Commission
DISCOM	Distribution Company
DMS	Distribution Management System
DR	Demand Response
DSM	Demand Side Management
DTC	Delhi Transport Corporation
EE	Energy Efficiency
EMS	Energy Management System
ERP	Enterprises Resource Planning
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographical Information System
GW	Giga Watt

HA	Home Automatic
HVAC	Heating Ventilation Air Conditioning
ICT	Integrated Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
KV, KW, KWHr	Kilovolt, Kilowatt, Kilowatt Hours
LAN	Local Area Network
LED	Light Emitting Diodes
MDM	Metre Data Management
MNRE	Ministry of New and Renewable Energy
MOP	Ministry of Power
MV	Medium Voltage
NTPC	National Thermal Power Corporation
OM	Operation and Management
OEM	Original Equipment Manufacturer
OMS	Outage Management System
OT	Operational Technology
PH	Phase
PLC	Power Line Communication
PSU, PUC	Public Service Commission, Public Utilities Commission
RD	Research and Development
RF	Radio Frequency
ROI	Return on Investment
SAP-LAP	Situation Actor Process- Learning Action Performance
SCADA	Supervisory Control and Data Acquisition
SEB	State Electricity Board
SGI	Smart Grid Index
SWOT	Strength Weakness Opportunity Threat
TD	Transmission and Distribution
TOD	Time of Day
TOU	Time of Use
UDAY	Ujwal Discom Assurance Yojana
UJALA	Unnat Jyoti By Affordable Leds For All
USD	U.S. Dollar

*Abbreviations*

---

V2G	Vehicle To Grid
WIFI	Wireless Fidelity