STUDY OF SELECT ISSUES IN THE MANAGEMENT OF SMART GRID IN INDIA

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Certificate

This is to certify that the thesis entitled "Study of select issues in the management of smart grid in India" being submitted by Praveer Sinha to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy (Ph.D.) is a bonafide record of original research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which has attained the requisite standard required for Ph.D. degree from Indian Institute of Technology Delhi. The results presented in this thesis have not been submitted elsewhere for the award of any degree or diploma.

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Abstract

Since the beginning of 21st century, India has been poised to take the role of top three in the global economy. As India aspires to be the manufacturing hub and a global superpower, the lack of reliable power and adequate power distribution infrastructure plagued with financial & operational challenges in the power sector limits the country's prospects to become one of the largest economies in the world.

Despite availability of 370GW of generation capacity, the peak consumption remains restricted to 180 GW. Multiple factors are responsible for this large gap due to the lack of adequate power distribution infrastructure and operational challenges in the power distribution sector. The remote and rural parts of the country that are still not "on the grid" and do not have access to 24/7 electricity at the point of consumption and are unable to utilize the available generation despite the demand. The core challenges that the power distribution sectors faces are defining the strategic, operational and technological solutions to align it to the emerging smart grid which the power utilities need to follow.

The emphasis on the distributed energy resources (DER) including renewable energy is bringing in new dimensions into the management of the grid, which further adds the need for real-time two way communication and load/demand management.

Thus, the concept of smart grid has to be developed and managed as a vision for a utility, which will eventually help in integrating the generation, transmission and distribution of electricity across all customers.

Given the listed challenges on the power distribution side that are a result of many strategic and operational level issues, this research aims to address broadly by breaking it down into four research objectives of this thesis as listed below:

Research Objective 1] To study and examine the impact on operational efficiency and reliability due to the implementation of key smart grid technologies

Research Objective 2] To study, develop and test hypothesis of real-time demand and load forecasting due to the integration of distributed energy resources such as rooftop solar, demand response, battery storage, EV charging

Research Objective 3] To analyze the customer benefits, participation & empowerment due to smart grid solutions

Research Objective 4] To evaluate the operational & financial performance metrics due to implementation of smart grid

Based on benchmark analysis, the Delhi utility was identified for the purpose of case study. Delhi utility was examined from the perspective of understanding automation and implementation of foundational technologies and how do these building-blocks leverage the implementation of the smart grid road map.

The primary research of 655 electricity consumers was conducted through a field study in North Delhi. This survey was done to understand the perception of the consumers on participating on these programs of the utility and the value they see in such programs when smart grid is implemented in an integrated way. In addition to statistical tools, the thesis research also utilized various management tools like Porter's Five Force Model, SAP-LAP, Strategy Map, Balanced Score card, etc, to substantiate research findings.

The case study research revealed the importance of foundational technologies such as distribution automation, Supervisory Control and Data Acquisition system (SCADA), Geographical Information System (GIS), smart metering, billing and collection solution, Enterprise Resource Planning (ERP) and how it results in the effectiveness of a utility's performance. The case study validated the importance of load analysis for optimal sourcing of power and considering that the existing grid is becoming complex with penetration of distributed energy resources (DERs) such as - rooftop solar, battery storage, demand response and EV charging and its ability to respond to changes to demand on a real-time basis.

The outcome of the case study findings contributed in developing the operational and financial metrics for a power distribution utility to help establish the technology adoption roadmap. This metrics provides a blueprint for technology adoption and associated functions, benefits and target area of deployment within the grid.

The research has used the SAP-LAP methodology to analyze the case study of the Delhi utility where the impact of EV charging, automated demand response, energy storage was examined by conducting primary survey across its customer segment. SAP stands for "Situation", "Actor" and "Process" and its interplay comprises of the SAP framework where the freedom of choice lies with the Actor. An interplay of SAP leads to Learning-Action-Performance (LAP).

The thesis, “Study of Select Issues in the Management of Smart Grid in India” has successfully demonstrated that in the given environment of Indian Power Sector, what steps a distribution utility should take in its journey to smart grid. The thesis revealed that Delhi utility chose an integrated approach of smart grid technologies deployment and to achieve operational efficiency and reliability, developed a defined technology roadmap foundational technologies, information and communication technologies, automation technologies supported with advanced metering infrastructure.

Establishing performance benchmarks is seen a critical component as part of strategic planning process (SPP) and establishing a new order that will drive the vision, mission and mode of operation for an electricity distribution company.

As a result of these findings, the research supported by the case study of a Delhi utility, can conclusively establish that to develop a well-defined smart grid roadmap for any utility, it needs to successfully develop and implement a detailed technology adoption roadmap, integrate distributed energy resources, address operational challenges and establish reliability by following business processes with emphasis on customer engagement component.

सार

21 वीं सदी की शुरुआत के बाद से, भारत वैश्विक अर्थव्यवस्था में शीर्ष तीन की भूमिका लेने के लिए तैयार हो गया है। जैसा कि भारत विनिर्माण हब और एक वैश्विक महाशक्ति बनने की इच्छा रखता है, विश्वसनीय बिजली की कमी और बिजली क्षेत्र में वित्तीय और परिचालन चुनौतियों से त्रस्त पर्याप्त बिजली वितरण बुनियादी ढांचे के कारण देश की संभावनाएं दुनिया की सबसे बड़ी अर्थव्यवस्थाओं में से एक बन जाती हैं।

370 GW जनरेशन क्षमता की उपलब्धता के बावजूद, पीक की खपत 180 GW तक सीमित है बिजली वितरण क्षेत्र में पर्याप्त बिजली वितरण बुनियादी ढांचे और परिचालन चुनौतियों की कमी के कारण इस बड़े अंतर के लिए कई कारक जिम्मेदार हैं। देश के दूरस्थ और ग्रामीण हिस्से जो अभी भी "ग्रिड पर" नहीं हैं और उपभोग के बिंदु पर 24/7 बिजली तक पहुंच नहीं है और मांग के बावजूद उपलब्ध बिजली का उपयोग करने में असमर्थ हैं। कोर चुनौतियां जो बिजली वितरण क्षेत्रों का सामना करती हैं, रणनीतिक, परिचालन और तकनीकी समाधानों को परिभाषित कर रही हैं ताकि उभरते स्मार्ट ग्रिड को संरेखित किया जा सके जिसे बिजली उपयोगिताओं को पालन करने की आवश्यकता है।

अक्षय ऊर्जा सहित वितरित ऊर्जा संसाधनों (DER) पर जोर ग्रिड के प्रबंधन में नए आयामों में ला रहा है, जो आगे वास्तविक समय, दो तरह से संचार और लोड / मांग प्रबंधन की आवश्यकता को जोड़ता है।

इस प्रकार, स्मार्ट ग्रिड की अवधारणा को एक उपयोगिता के लिए एक दृष्टि के रूप में विकसित और प्रबंधित किया जाना है, जो अंततः सभी ग्राहकों में बिजली के उत्पादन, पारेषण और वितरण को एकीकृत करने में मदद करेगा।

बिजली वितरण पक्ष पर सूचीबद्ध चुनौतियों को देखते हुए जो कई का परिणाम हैं रणनीतिक और परिचालन स्तर के मुद्दे, इस शोध का उद्देश्य मोटे तौर पर इस शोध के चार शोध उद्देश्यों को नीचे सूचीबद्ध करके इसे संबोधित करना है:

अनुसंधान उद्देश्य 1] प्रमुख स्मार्ट ग्रिड प्रौद्योगिकियों के कार्यान्वयन के कारण परिचालन दक्षता और विश्वसनीयता पर प्रभाव का अध्ययन और परीक्षण करना

अनुसंधान उद्देश्य 2] वितरित ऊर्जा संसाधनों जैसे छत सौर, मांग प्रतिक्रिया, बैटरी भंडारण, ईवी चार्जिंग के एकीकरण के कारण वास्तविक समय की मांग और लोड पूर्वानुमान का अध्ययन, विकास और परीक्षण करना

अनुसंधान उद्देश्य 3] स्मार्ट ग्रिड समाधानों के कारण ग्राहक लाभ, भागीदारी और सशक्तिकरण का विश्लेषण करना

अनुसंधान उद्देश्य 4] परिचालन और वित्तीय प्रदर्शन मेट्रिक्स का मूल्यांकन करना है स्मार्ट ग्रिड के कार्यान्वयन के लिए

बेंचमार्क विश्लेषण के आधार पर, दिल्ली उपयोगिता की पहचान केस स्टडी के उद्देश्य से की गई थी। दिल्ली उपयोगिता को स्वचालन की समझ और मूलभूत प्रौद्योगिकियों के कार्यान्वयन के परिप्रेक्ष्य से जांच की गई थी और ये इमारत-ब्लॉक स्मार्ट ग्रिड रोड मैप के कार्यान्वयन का लाभ कैसे उठाते हैं।

655 बिजली उपभोक्ताओं का प्राथमिक शोध उत्तरी दिल्ली में एक क्षेत्र अध्ययन के माध्यम से किया गया था। यह सर्वेक्षण उपयोगिता के इन कार्यक्रमों में भाग लेने पर उपभोक्ताओं की धारणा को समझने के लिए किया गया था और वे ऐसे कार्यक्रमों में देखते हैं जब स्मार्ट ग्रिड को एकीकृत तरीके से लागू किया जाता है। सांख्यिकीय उपकरणों के अलावा, थीसिस अनुसंधान ने शोध निष्कर्षों को पुष्ट करने के लिए Porter's Five Force Model, SAP-LAP, स्ट्रेटेजी मैप, बैलेंस्ड स्कोर कार्ड आदि जैसे विभिन्न प्रबंधन उपकरणों का भी उपयोग किया।

केस स्टडी के शोध में Distribution Automation, Supervisory Control and Data Acquisition System (SCADA), Geographical Information System (GIS), Smart Metering, Billing and collection solution, Enterprise Resource Planning (ERP) जैसी मूलभूत तकनीकों के महत्व का पता चला और यह कैसे परिणाम देता है एक उपयोगिता के प्रदर्शन की प्रभावशीलता में। केस स्टडी ने शक्ति के इष्टतम सोर्सिंग के लिए लोड विश्लेषण के महत्व को मान्य किया और विचार किया कि मौजूदा ग्रिड वितरित ऊर्जा संसाधनों (DER) जैसे - रूफटॉप सोलर, बैटरी स्टोरेज, डिमांड रिस्पांस और ईवी चार्जिंग और इसकी क्षमता के साथ जटिल हो रहा है। वास्तविक समय के आधार पर मांग में परिवर्तन का जवाब।

केस स्टडी निष्कर्षों के परिणाम ने प्रौद्योगिकी अपनाने के रोडमैप को स्थापित करने में मदद करने के लिए बिजली वितरण उपयोगिता के लिए परिचालन और वित्तीय मैट्रिक्स विकसित

दिल्ली उपयोगिता के मामले के अध्ययन का विश्लेषण करने के लिए अनुसंधान ने एसएपी-एलएपी पद्धति का उपयोग किया है जहां ईवी चार्जिंग, स्वचालित मांग प्रतिक्रिया, ऊर्जा भंडारण के प्रभाव की जांच अपने ग्राहक खंड में प्राथमिक सर्वेक्षण करके की गई थी। एसएपी का मतलब "सिचुएशन", "एक्टर" और "प्रोसेस" होता है और इसके इंटरप्ले में एसएपी फ्रेमवर्क शामिल होता है जहां पसंद की स्वतंत्रता एक्टर के पास होती है। Situation Actor Process (SAP) के एक परस्पर क्रिया से Learning-Action-Performance (LAP) होता है।

थीसिस, "भारत में स्मार्ट ग्रिड के प्रबंधन में चुनिंदा मुद्दों का अध्ययन" है सफलतापूर्वक प्रदर्शित किया गया कि भारतीय विद्युत क्षेत्र के दिए गए वातावरण में, स्मार्ट ग्रिड में अपनी यात्रा के लिए वितरण उपयोगिता के लिए कौन से कदम उठाने चाहिए।

प्रदर्शन बेंचमार्क स्थापित करना रणनीतिक नियोजन प्रक्रिया (SPP) के हिस्से के रूप में एक महत्वपूर्ण घटक के रूप में देखा जाता है और एक नया आदेश स्थापित करता है जो बिजली वितरण कंपनी के लिए दृष्टि, मिशन और संचालन के मोड को चलाएगा।

इन निष्कर्षों के परिणामस्वरूप, दिल्ली उपयोगिता के केस स्टडी द्वारा समर्थित अनुसंधान, निर्णायक रूप से यह स्थापित कर सकता है कि किसी भी उपयोगिता के लिए एक अच्छी तरह से परिभाषित स्मार्ट ग्रिड रोडमैप विकसित करने के लिए, इसे सफलतापूर्वक विकसित करने और एक विस्तृत प्रौद्योगिकी अपनाने रोडमैप को लागू करने की आवश्यकता है, एकीकृत वितरित ऊर्जा संसाधन, परिचालन चुनौतियों का समाधान और ग्राहक सगाई घटक पर जोर देने के साथ व्यापार प्रक्रियाओं का पालन करके विश्वसनीयता स्थापित करना।

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List of Abbreviations

ACS	Average Cost of Supply
ADMS	Advanced Distribution Management System
ADR	Automated Demand Response
AMI	Advanced Metering Infrastructure
AMP	Ampere
AMR	Automatic Meter Reading
APDRP	Accelerated Power Development and Reforms Program
ASAI	Average System Availability Index
AT&C	Aggregate Technical & Commercial Losses
BESS	Battery Energy Storage System
BI	Business Intelligence
BNEF	Bloomberg New Energy Finance
BSC	Balance Score Card
BST	Bulk Supply Tariff
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CATI	Computer Aided Telephonic Interview
CCC	Consumer Care Center
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CESU	Central Electricity Supply Utility of Odisha
CFL	Compact Fluorescent Lamp
CIS	Customer Information System
CNG	Compressed Natural Gas
CRM	Customer Relationship Management
CSF	Critical Success Factors
DA	Distribution Automation
DELP	Domestic Efficient Lighting Program
DER	Distributed Energy Resources
DER	Distributed Energy Resources
DERC	Delhi Electricity Regulatory Commission
DG	Distributed Generation
DISCOM	Distribution Company
DMS	Distribution Management System

DOE	Department of Energy (United States)
DR	Demand Response
DSM	Demand Side Management
DT	Distribution Transformer
DT	Distribution Transformer
DTC	Delhi Transport Corporation
DVB	Delhi Vidyut Board
EA	Enterprise Architecture
EBPP	Electronic Bill Presentment and Payment
EE	Energy Efficiency
EMS	Energy Management System
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning
ESCO	Energy Services Companies
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FAME	Faster Adoption and Manufacturing Of (Hybrid &) Electric Vehicles
FFA	Field Force Automation
FLISR	Fault Location, Isolation & Service Restoration
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographical Information System
GW	Giga Watt
HA	Home Automation
HAN	Home Area Network
HVAC	Heating Ventilation Air Conditioning
ICCP	Inter-Control Center Communication Protocol
ICE	Internal Combustion Engine
ICRA	Investment Information & Credit Rating
ICT	Integrated Communication Technology
IEEE	Institute of Electrical And Electronics Engineers
IoT	Internet of Things
IPP	Independent Power Producers
IT	Information Technology
KEMA	A Global Consultancy and Test Lab Started In 1927 In The Netherlands
KPI	Key Performance Indicator

KV, KW, KWHr	Kilovolt, Kilowatt, Kilowatt Hours
LAN	Local Area Network
LED	Light Emitting Diode
LIB	Lithium-Ion Batteries
LT	Low Tension
LV	Low Voltage
MAPI	Mobile Assisted Personal Interview
MDM	Meter Data Management
ME	Margin of Error
MNRE	Ministry of New and Renewable Energy
MOP	Ministry of Power
MTOE	Million Tons of Oil Equivalent
MV	Medium Voltage
MVA	Mega Volt Ampere
MW, MWH	Megawatt, Megawatt-Hour
NEMMP	National Electric Mobility Mission Plan
NOC	Network Operations Center
NTPC	National Thermal Power Corporation
O&M	Operation and Management
OD	Over Drawl
OECD	Organization for Economic Co-Operation And Development
OEM	Original Equipment Manufacturer
OMS	Outage Management System
OPEX	Operating Expenditure
OSEB	Orissa State Electricity Board
OT	Operational Technology
PESTLE	Political Economical Social Technological Legal Environment
PH	Phase
PLC	Power Line Communication
PPA	Power Purchase Cost
PPM	Power Portfolio Management
PPP	Public–Private Partnership
PSU, PUC	Public Service Commission, Public Utilities Commission
PV	Photovoltaic
R&D	Research and Development
RAPDRP	Restructured Accelerated Power Development & Reforms Program

RF	Radio Frequency
ROI	Return on Investment
RPO	Renewable Purchase Obligation
RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAP-LAP	Situation Actor Process - Learning Action Performance
SCADA	Supervisory Control and Data Acquisition
SDG7	Sustainable Development Goal 7
SEB	State Electricity Board
SGI	Smart Grid Index
SGIG	Smart Grid Investment Grant
SLDC	State Load Dispatch Center
SPP	Strategic Planning Process
SWOT	Strength, Weakness, Opportunities, Threat
T&D	Transmission & Distribution
TOD	Time of Day
TOU	Time of Use
UD	Under Drawl
UDAY	Ujwal Discom Assurance Yojana
UJALA	Unnat Jyoti By Affordable Leds For All
USD	US Dollar
V2G	Vehicle to Grid
VVO	Volt-ampere reactive (Var) Optimization
WACC	Weighted Average Cost of Capital
WIFI	Wireless Fidelity