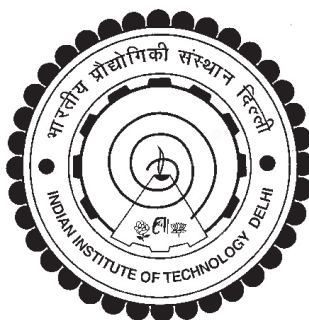


**DISTRIBUTED AGENT-BASED
ARCHITECTURE FOR SMART GRID
ANALYSIS AND OPERATION**

KRITIKA SAXENA



DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
OCTOBER 2018

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**DISTRIBUTED AGENT-BASED
ARCHITECTURE FOR SMART GRID
ANALYSIS AND OPERATION**

by

KRITIKA SAXENA

Department of Electrical Engineering

Submitted

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

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI
OCTOBER 2018

To my parents and husband for their unconditional love and support.

Certificate

This is to certify that the dissertation entitled '**Distributed Agent-Based Architecture for Smart Grid Analysis and Operation**', being submitted by **Mrs. Kritika Saxena** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by her in the Department of Electrical Engineering at Indian Institute of Technology Delhi, New Delhi.

Mrs. Kritika Saxena has worked under my supervision and has fulfilled the requirements for the submission of this dissertation, which to our knowledge has reached the requisite standard. The results obtained here have not been submitted to any other University or Institute for the award of any degree.

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Abstract

The thesis proposes to introduce a paradigm shift from centralized to distributed operation and control of a smart grid. This shift is apparent due to computational complexities, communication saturation and fault-tolerant architecture. The concept of a smart grid has already gained much attention in past decade for designing a new age robust, self-sufficient, self-organized and resilient grid. It integrates Cyber-Physical System (CPS) and communication models to design and facilitate various grid operation and control. Traditional centralized approaches prove insufficient to operate the grid which is highly dynamic as evident from the literature survey. This has instigated research on developing decentralized/distributed models using CPSs. Multi-Agent System (MAS) is a category of CPS which is highly efficient in designing and implementing distributed systems. Thus, the thesis will discuss about the agent technology and its associated features. And finally the designing of MAS based architectures for smart grid operation and control have been dealt with.

A wide range of articles have suggested different methodologies and architectures for implementing MAS technologies in power system. However, the lack of common architecture for similar grid objective will make its implementation challenging on account of grid sustainability and future upgrade. The thesis will introduce two MAS based architectures on account of their uniformity all grid applications and advantages to validate their practical implementation.

Post-adoption of the distributed architectures, simulation and analysis tools for power system operation needs to be redesigned for distributed computations. The foremost fundamental tool to analyze a power system is the power flow method. The

thesis proposes three different frameworks concerning: (1) Single-phase power flow solution of distribution system; (2) Three-phase power flow solution distribution system; and (3) Single-phase power flow solution of the transmission system. These frameworks are developed to handle truly distributed computations. BA (Bus Agent) is designed to implement distributed power flow computations. They utilize local information and coordination with neighboring BAs to get local or partial power flow solution of their representative bus.

The designed distributed power flow tool is further utilized to develop a methodology for self-organizing distribution grid. Self-organizing here refers to the grid's capability to detect events and configure/organize the grid on its own to reduce system losses and restore load under emergency. This framework is easily extended with the above power flow framework by addition of new behaviors in BAs because of its extensible nature.

Another important analysis tool is state estimation for wide area monitoring systems which provides a snapshot of the system. Most of the distributed state estimation scheme partition a big system into smaller operating areas which further have a central operator. The thesis proposes state of the art distributed state estimation architecture which disregards any type of centrality in the system and assist node-to-node computations. The state estimation problem is formulated as distributed constraint satisfaction problem. BAs communicate asynchronously to minimize measurement error of local constraints to estimate the state of their representative bus. The proposed architecture is compared with the centralized methodology to establish its accuracy, time performance and fault-tolerance.

The thesis also introduces distributed market architecture to facilitate bilateral trading among small prosumer and consumer entities. The architecture provides a platform for DER (Distributed Energy Resources) based entities to sell energy to the local consumers and empower them. The agent-based market frameworks in reported articles use simple negotiation model which does not address the uncertainty of generation and

consumption profiles of entities and regulatory settlement aspects of markets. In the proposed distributed market architecture, a novel negotiation strategy is designed for the seller-buyer bilateral transaction to include energy imbalance aspect. The strategy also aims for the seller to maximize its profit and buyer to minimize its payment under energy imbalance constraints. The case studies will showcase the benefits of the proposed negotiation strategy where the buyer and seller report increase in their economic benefits.

सार

थीसिस केंद्रीयकृत से वितरित संचालन और एक स्मार्ट ग्रिड के नियंत्रण से एक प्रतिमान शिफ्ट पेश करने का प्रस्ताव करता है। यह बदलाव कम्प्यूटेशनल जटिलताओं, संचार संतृप्ति और गलती सहनशील वास्तुकला के कारण स्पष्ट है। एक स्मार्ट ग्रिड की अवधारणा को पिछले एक दशक में पहले से ही एक नई उम्र मजबूत, आत्मनिर्भर, आत्म-संगठित और लचीला ग्रिड डिजाइन करने के लिए काफी ध्यान दिया गया है। यह विभिन्न ग्रिड संचालन और नियंत्रण को डिजाइन और सुविधा के लिए साइबर-भौतिक प्रणाली (सीपीएस) और संचार मॉडल को एकीकृत करता है। पारंपरिक केंद्रीयकृत दृष्टिकोण ग्रिड को संचालित करने के लिए अपर्याप्त साबित होते हैं जो साहित्य सर्वेक्षण से स्पष्ट रूप से अत्यधिक गतिशील हैं। इसने सीपीएस का उपयोग करके विकेन्द्रीकृत / वितरित मॉडल विकसित करने पर शोध को बढ़ावा दिया है। मल्टी-एजेंट सिस्टम (एमएस) सीपीएस की एक श्रेणी है जो वितरित सिस्टमों को डिजाइन और कार्यान्वित करने में अत्यधिक कुशल है। इस प्रकार, थीसिस एजेंट प्रौद्योगिकी और इसकी संबंधित सुविधाओं के बारे में चर्चा करेगा। और अंत में स्मार्ट ग्रिड ऑपरेशन और नियंत्रण के लिए एमएस आधारित आर्किटेक्चर डिजाइन बनाया गया है।

लेखों की एक विस्तृत श्रृंखला ने बिजली व्यवस्था में एमएस प्रौद्योगिकियों को लागू करने के लिए विभिन्न पद्धतियों और वास्तुकला का सुझाव दिया है। हालांकि, समान ग्रिड उद्देश्य के लिए सामान्य वास्तुकला की कमी से गर्ड स्थिरता और भविष्य के उन्नयन के कारण इसका कार्यान्वयन चुनौतीपूर्ण हो जाएगा। थीसिस दो समानता के आधार पर दो एमएस आधारित आर्किटेक्चर पेश करेगा, सभी ग्रिड अनुप्रयोगों और उनके व्यावहारिक कार्यान्वयन को मान्य करने के फायदे।

वितरित आर्किटेक्चर, सिमुलेशन और पावर सिस्टम ऑपरेशन को विश्लेषण लिए वितरित कंप्यूटेशंस के फिर से डिजाइन किया जाना आवश्यक है। बिजली व्यवस्था का विश्लेषण करने के लिए सबसे महत्वपूर्ण मौलिक उपकरण बिजली प्रवाह विधि है। थीसिस संबंधित तीन अलग-अलग ढांचे का प्रस्ताव है: (1) वितरण प्रणाली के एकल चरण बिजली प्रवाह समाधान; (2) तीन चरण बिजली प्रवाह समाधान वितरण प्रणाली; और (3) ट्रांसमिशन सिस्टम के एकल चरण बिजली प्रवाह समाधान। वास्तव में वितरित गणनाओं को संभालने के लिए ये ढांचे विकसित किए गए हैं। बीए (बस एजेंट) वितरित बिजली प्रवाह गणनाओं को लागू करने के लिए डिजाइन किया गया है। वे अपने प्रतिनिधि बस के स्थानीय या आंशिक बिजली प्रवाह समाधान प्राप्त करने के लिए पड़ोसी बीए के साथ स्थानीय सूचना और समन्वय का उपयोग करते हैं।

डिज़ाइन किए गए वितरित विद्युत प्रवाह उपकरण का आगे आत्म-आयोजन वितरण ग्रिड के लिए एक पद्धति विकसित करने के लिए उपयोग किया जाता है। स्व-आयोजन यहां घटनाओं का पता लगाने और सिस्टम नुकसान को कम करने और आपातकाल के तहत लोड बहाल करने के लिए ग्रिड को कॉन्फ़िगर / व्यवस्थित करने की क्षमता को संदर्भित करता है। इस ढांचे को बीएस में अपने व्यवहार योग्य प्रकृति के कारण नए व्यवहार के अतिरिक्त उपरोक्त विद्युत प्रवाह ढांचे के साथ आसानी से बढ़ाया गया है।

एक अन्य महत्वपूर्ण विश्लेषण उपकरण व्यापक क्षेत्र निगरानी प्रणालियों के लिए राज्य अनुमान है जो सिस्टम का एक स्नैपशॉट प्रदान करता है। अधिकांश वितरित राज्य अनुमान योजना छोटे ऑपरेटिंग क्षेत्रों में एक बड़ी प्रणाली का विभाजन करती है जिसमें आगे एक केंद्रीय ऑपरेटर होता है। थ्रीसिस कला वितरित राज्य अनुमान वास्तुकला की स्थिति का प्रस्ताव करता है जो सिस्टम में किसी भी प्रकार की केंद्रीयता को नजरअंदाज करता है और नोड-टू-नोड कंप्यूटेशंस की सहायता करता है। राज्य अनुमान समस्या वितरित बाधा संतुष्टि समस्या के रूप में तैयार की जाती है। बीएस अपनी प्रतिनिधि बस की स्थिति का अनुमान लगाने के लिए स्थानीय बाधाओं की माप त्रुटि को कम करने के लिए असीमित रूप से संवाद करते हैं। प्रस्तावित आर्किटेक्चर की इसकी सटीकता, समय प्रदर्शन और गलती सहनशीलता स्थापित करने के लिए केंद्रीकृत पद्धति के साथ तुलना की जाती है।

थ्रीसिस छोटे उपभोक्ता और उपभोक्ता संस्थाओं के बीच द्विपक्षीय व्यापार की सुविधा के लिए वितरित बाजार वास्तुकला भी पेश करता है। आर्किटेक्चर स्थानीय उपभोक्ताओं को ऊर्जा बेचने और उन्हें सशक्त बनाने के लिए डीईआर (वितरित ऊर्जा संसाधन) आधारित इकाइयों के लिए एक मंच प्रदान करता है। रिपोर्ट किए गए लेखों में एजेंट आधारित बाजार ढांचे में सरल वार्ता मॉडल का उपयोग होता है जो कि पीढ़ियों और उपभोग प्रोफाइल की अनिश्चितता और बाजारों के नियामक निपटान पहलुओं की अनिश्चितता को संबोधित नहीं करता है। प्रस्तावित वितरित बाजार वास्तुकला में, ऊर्जा असंतुलन पहलू को शामिल करने के लिए विक्रेता-खरीदार द्विपक्षीय लेनदेन के लिए एक उपन्यास वार्ता रणनीति तैयार की गई है। रणनीति का लक्ष्य विक्रेता को ऊर्जा असंतुलन बाधाओं के तहत अपने भुगतान को कम करने के लिए अपने लाभ और खरीदार को अधिकतम करने के लिए भी है। केस स्टडीज प्रस्तावित वार्ता रणनीति के लाभ प्रदर्शित करेंगे जहां खरीदार और विक्रेता की रिपोर्ट उनके आर्थिक लाभ में वृद्धि होगी।

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