Performance Analysis of Smart Energy Monitoring System in Real-time

R Govindarajan[1†], S Meikandasivam[2††], D Vijayakumar[3†††]

SCSVMV University, Tamilnadu, India[1†], VIT University, Tamilnadu, India [2††, 3†††].

Summary
The use of smart energy monitoring systems in houses or buildings offers significant potential for energy savings. In this paper, we propose an energy monitoring system based on advanced wireless technology. However, to meet the huge demand, ensure energy conservation and for sustainable economic growth, the introduction of a new kind of energy monitoring system is essential in the consumer side. In this paper, design and implementation of smart energy monitoring systems in real time is analyzed with respect to its performance. The proposed system utilizes advanced wireless technology like zigbee protocol, Internet of Things (IoT), Android based mobile App and Cloud Computing for interfacing the information between meter to consumer end. The digital power meter installed in the main panel is also interfaced with a communication gateway and all the electrical parameters such as voltage, current, power, power factor and harmonics of the household appliances have been measured in real time. Hence the four kinds of energy monitoring systems have been developed to measure the electrical parameters. The system will help to provide the power consumption details to the consumer and also the system interacts with consumers by giving the instant data such as live power tracking, identification of abnormal patterns of energy usage, energy bill estimation and all the energy usage information within handy.

Keywords:
ZigBee, Internet of Things, GSM Communication, Cloud Computing.

1. Introduction

With advancement in the field of computer and wireless communication technology, a wide range of possibilities is available for the design and implementation of smart energy monitoring systems in future smart homes [7]. Computer and wireless communication technology is used to integrate a number of sensor devices, actuators, and computing devices which in turn have great potential to contribute energy efficiency in our everyday usage. Energy efficiency is becoming increasingly important in industry as well as in the residential sector [11]. However, due to the complexity and diversity of computing devices, integrating energy monitoring resources is still in its infancy [10]. Adding advanced devices into the energy metering environment is a very challenging task. After deciding which particular device to integrate, the smart metering developer must determine how to configure it and interface with it [17]. Then the device should be connected and technically integrated with the system. The smart energy monitoring environment makes use of a wireless communication platform to integrate various devices. These devices should communicate with each other independently to provide information to the consumers [19].

Manufacturers of wireless interfacing devices use many different communication protocols. Therefore, the integration of household appliances and consumer electronics is not straightforward, at any layer of the sensor network platform. Additionally, apart from the technical difficulties of the integration, due to the complexity of the systems, users are often unable to fully understand their systems [18]. To fully take advantage of smart energy monitoring technologies, any energy monitoring system should transparently communicate with all the household energy meters and make available all important information to users with respect to saving energy as well as user convenience [20]. Keeping these in mind, we propose a smart energy monitoring system using wireless communication protocol and an intelligent gateway circuit.

The proposed system continually records and updates the electricity consumption data in order to provide real-time information to consumers. Users can easily monitor and control their power consumption of household appliances to save energy. To enable the feasibility of the proposed system, Zigbee transceivers and GSM communication gateway are implemented based on the usage of consumers.

To find out the suitable energy monitoring system for the Consumers, the following systems are designed as follows and implemented using various wireless technologies in real time and the experimental result also discussed.

a) Smart Energy Monitoring system using ZigBee Protocol
b) Smart Energy Monitoring system using IoT
c) Smart Energy Monitoring system using Mobile App
d) Smart Energy Monitoring system using Cloud Computing

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2. System Implementation

Different types of Smart Energy Monitoring systems have been analyzed in real time for the identification of suitable energy monitoring systems for LT Consumers requirement.

2.1 Design and Implementation of Energy Monitoring System using ZigBee Protocol

ZigBee protocol (IEEE 802.15.4) is one of the most economical and reliable systems and also consumes less power for monitoring processes. This ZigBee covers wireless range of 10-100 meters. Energy meter can be interfaced with this ZigBee transmitter Module and a laptop or computer based for data acquisition [4]. In this system, an embedded C programming is specially developed for the interfacing process and a power metering IC is also used to collect the data from energy meters. The collected data will be communicated to the ZigBee Module using the Arduino Controller. Finally the measured electrical parameters will be received by the ZigBee transceiver. This way, all the data is presented in the form of an energy report and made viewable to the consumers, which in turn can be accessed from a computer or a laptop.

The hardware implemented for energy monitoring systems using ZigBee protocol is shown in Fig.1. In this proposed system, the digital meter is interfaced with the ZigBee transmitter board and a personal computer is interfaced with ZigBee receiver board. There is no other wired connection between the energy meter and the user's personal computer. The system implemented for wireless energy monitoring and this wireless setup has covered a distance of maximum 100 meters and the configuration is as per IEEE standard [4, 14].

Hence the system collects energy data from the digital energy meter using an Arduino controller through a power amplifier. Each collected data will be indicated in the Arduino board by the flickering LED, then the signal status is also updated by viewing it [7]. The Power Amplifier IC will act as a data splitter. It is used to provide the data to the controller without any jungle values of the energy meter. The measured energy parameters will be sent to the computer and displayed as a report in notepad screen as shown in the Fig.2. For this system interfacing, the coding developed with the Arduino processor by Embedded C. This coding is also achieved with a minimum number of lines. The system provides the information to users with a delay time of 15 seconds and the data communication speed between energy meter to personal computer is 250 kbps.

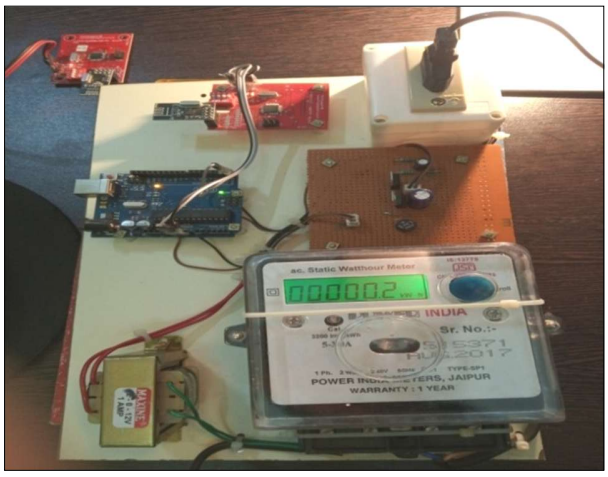

Fig.1.Hardware implementation of zigbee based energy monitoring system

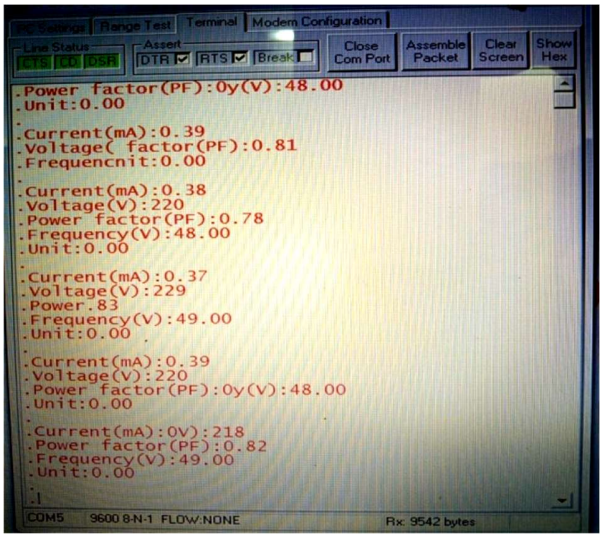

Fig.2.Energy meter values display format on computer screen

2.2 Design and Implementation of Energy Monitoring System using Internet of Things (IoT)

Internet Of Thing (IEEE 1451-99) based Smart Energy Monitoring system allows the devices to sense remotely using existing internet infrastructure and also develop the interfacing process between transmitter end (energy meter) to receiver end. In addition to that, it reduces human participation in handling the process. This system is implemented with customized embedded programming between IoT and Digital Meter through Arduino controller [1,2].

Hence the designed system will provide data transferring speed from the monitoring unit to server is

2mps with delay time of 2 sec. Finally the overall monthly bill with cost will be sent to the consumer in the form of an energy report with IP Address Accessing mode. This proposed work demonstrates the operation of a developed IoT based energy monitoring system. It was experimentally implemented as shown in the Fig 3. The system consists of a user-interface dashboard and it was developed in HTML, which is used to view our data as a energy monitoring report [5].

The report shows voltage, current and power of the electrical utility in live with a minimum delay time of 2 seconds and communication speed is 2mps. The system is designed to find out the minimum period of data transmission delay time with high communication speed. The normal digital energy meter was connected with an interfacing unit [15]. The interfacing unit consists of Arduino, splitter circuit, data amplifier circuit and IoT module. Here the interfacing unit collects the energy parameters from the energy meter and sends it to the local server through IoT techniques.

In this system, the splitter circuit will split the data into voltage, current and power; then send it to the power amplifier circuit. The amplifier circuit and Arduino processor will narrate the values as well as make it a live report as shown in Fig 4. The measured energy parameters were collected using an interfacing unit and then sent to the local server through Wifi router. Before that the energy report is prepared as an HTML file in the background and all the fields are developed based on consumer basic requirements. Based on the programming, the data will appear in the content menu or field [8].

The consumer can view their energy consumption report by accessing the particular IP Address which is already given in the programming [9]. Hence this proposed system achieved fast communication with very less data transmission delay time, customized and efficient electrical energy report for LT consumers.

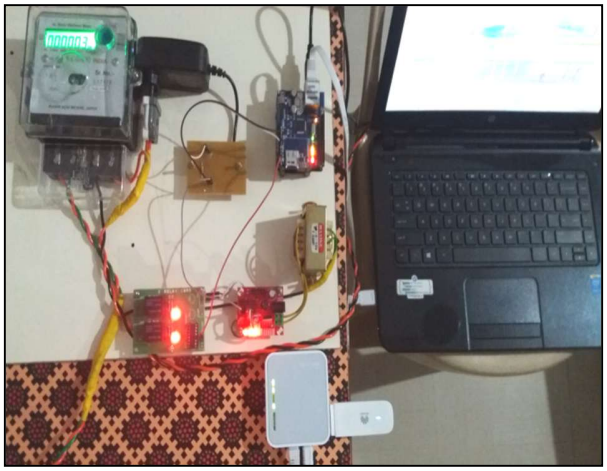

Fig.3. Hardware implementation of energy monitoring system using IoT techniques

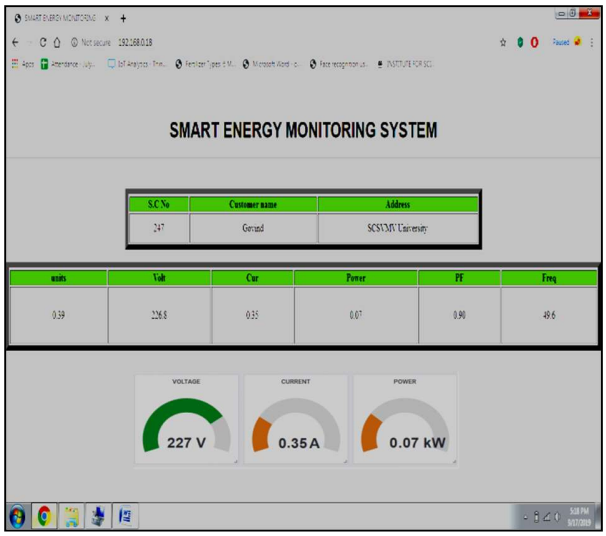

Fig.4.Energy report displayed on HTML Screen

2.3 Design and Implementation of Energy Monitoring System using Android Mobile App

Android Mobile App (IEEE 1914.1) utilized to develop an energy monitoring system in wireless. It can sense the energy meter value as well as communicate to the consumer by showing energy information instantly [11]. It works with the android operating system and the protocol developed with NodeMCU, which is interfaced with our existing digital energy meter. The daily usage of power consumption will be measured as usual by a digital energy meter and the measured data will be received by NodeMCU. Then the data will be sent to the existing mobile app which is called Blynk app. This Blynk app acts as a server, once the data received it will be displayed as a prompt view on the mobile screen. Hence the consumer can view the energy information in their mobile phone by accessing the customized Blynk app. The system is developed as an Android mobile app. The app obtains the energy parameters from the existing energy meter instantly, hence making it easily accessible from a mobile which is user friendly [6]. In other protocols more number of interfacing devices utilized to develop an energy monitoring system. Whereas in this system, the number of interfacing devices are minimal, thereby reducing the data transferring speed considerably to 1 second.

The system consists of an energy meter, NodeMCU, Smart Phone. NodeMCU is a low-cost open source IoT platform. It runs on the ESP8266 Wi-Fi SoC and hardware which was based on the ESP-12 (Espressif system) module. NodeMCU acts as a server which will sense the values from the energy meter as well as display the values on a smartphone screen with the help of an existing android mobile app called Blynk. The Blynk

App is one of the interfacing apps which can be installed on all android smart phones and it works with IoT based platforms. The Blynk is customized one, hence based on the monitoring system requirement the Blynk App page can be designed by the user. Once the app is installed in the mobile phone, the energy meter values will be stored in the mobile App screen by getting NodeMCU log in ID in the App. The developed protocol shown in Fig. 5. The values will be stored in the Blynk App as all data is customized by the user. At an interval of 1 second, the parameters will be updated automatically. The output format of the energy monitoring system shown in Fig. 6.

Fig.5. Hardware implementation of Android Mobile App based energy monitoring system

Fig.6. Energy meter value displayed in mobile screen

2.4 Design and Implementation of Energy Monitoring System using Cloud Computing

This system includes a two way digital energy meter and GSM Communication Gateway (IEEE 802.21). The system implemented in real time to achieve the daily power utilization of consumers without any delay time. The consumer can know about their energy usage as a report instantaneously [3]. The system designed with less number of interfacing devices to reduce the development cost as well as to reduce the data transferring time [12]. Here the Energy Meter is directly connected with the GSM communication gateway and the measured parameters will be stored in our personal cloud. GSM Communication is specially developed to collect the data from the meter and send the data to the server hence it will act as the main processor. In the cloud server to get customized screens, programming is also developed with super java. Based on the consumer requirement the measured energy parameters will be formed as a report which can be chosen for different time periods like daily, monthly or even live report. This prototype achieved using GSM Communication gateway to cloud transmission level is 14 Tbs without any delay [16].

Here the SATEC Power meter is used to collect the data from the main panel to the consumer end. Hence we used GSM Based Communication gateway circuit [13]. This system has been developed keeping in mind the aspects of reducing delay time for data transfer, increasing wireless coverage distance limit and getting more number of values form the meter. In Zigbee based monitoring systems, the power metering IC and Arduino controllers are used. Hence the system provides 15 seconds delay time in transferring data. In the IoT based monitoring system; Splitter circuit, data amplifier and Arduino controller are used to collect the data and send the data to the HTML file through WiFi Router. By IP Address accessing mode we can view the data in an HTML file and the data is updated every 2 seconds. In order to achieve fast communication with reliable data and more number of values from the meter, increase the wireless coverage limit. And to obtain the data storage unit, the cloud based smart energy monitoring is developed. Hence instead of power metering IC and Splitter Circuit we used GSM Communication gateway circuit directly interfaced with the smart meter as shown in the Fig.7. The Communication gateway will send the data to the server and the data will be saved as per our customized programme in the cloud. The data can be accessed from anywhere and we can get a customized report without any difficulties. It consists of a two way Digital Power Meter and GSM Communication gateway to send the values to the cloud server directly. Here the transmission level is 14 Tbs without any delay time as the coding is developed for a fully online system. It gives a master report as shown in the Fig 8 which can be customized. Here the programme coding has been developed with super java for the communication unit and

to view the measured values as a report in front end customized HTML file also developed.

Fig.7. Hardware installation of energy monitoring system using GSM gateway

Fig.8. Energy monitoring live report in real time from cloud

3. Performance Analysis of Energy monitoring system

The Energy Monitoring Systems with their real time measurements employing different communication protocols are compared in the Fig. 9 and Fig.10. The Energy Monitoring System using GSM communication gateway and developed with cloud computing shown in Fig 9.7 proves an improved performance in LT consumers for daily utilization. This proposed system provides detailed information to the LT consumers about their power consumption which includes live chart, day chart and month wise chart. The ZigBee based energy monitoring system gives information with delay time of 15 seconds where as IoT based energy monitoring system gives information with delay time of 2 seconds, android based energy monitoring system transfer the information in 2 seconds and the cloud computing based energy monitoring system provides the information between meter and consumer with the communication speed value of 14 Tbs without any delay time. The overall comparison shown in Table 1.

Table 1. Experimental Performance of various Energy Monitoring System

Developed System	Communi c-ation Speed	Transferring Delay Time	Number of Values	Network Coverage limit
ZigBee based EMS	250 kbps.	15 seconds	4	100 meter
IoT based EMS	2 mps.	2 seconds	6	92 meter
Android based EMS	424 kbps.	1 second	10	Through out global
Cloud based EMS	14 Tbs.	Live transferring	16	Through out global

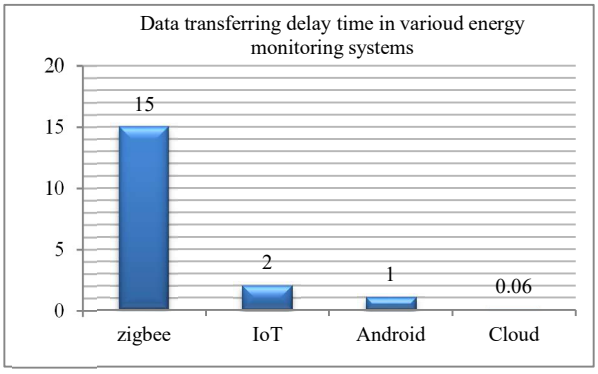

Fig.9. Comparison chart of data transferring delay time in energy monitoring system

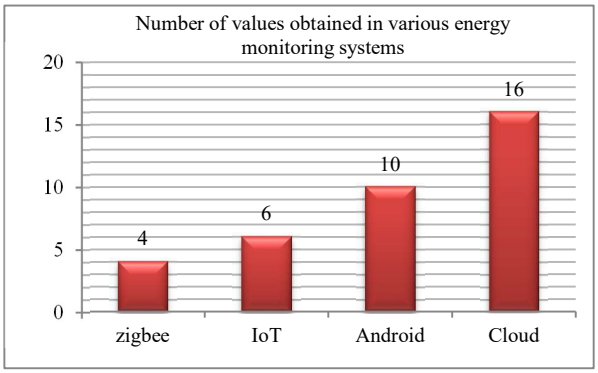

Fig.10. Comparison chart of values obtained by the energy monitoring system

4. Conclusion

Different types of energy monitoring systems are developed in real time and performance of all the aspects the systems are analyzed and investigated by comparing the concept and technology used. The comparison of real time output results based on the communication protocol proves that the cloud computing based smart energy monitoring system using GSM Communication gateway produces improved performance in a number of parameters namely; measurement, high speed data communication, online data transfer, customized report making and in providing instant updated information to the consumers. The consumer can know about their power utilities easily, making their power consumption schedule with their knowledge and calculate their electricity usage cost. Hence the power consumption will be reduced by developing this kind of innovative model in real time.

References

[1] A.Subba Rao and Sri VidyaGarige, " IOT Based Smart Energy Meter Billing Monitoring and Controlling the Loads", International Journal of Innovative Technology and Exploring Engineering, Volume 8, Issue 42, pp.340-344, 2019

[2] Birendrakumar Sahani, Tejashree Ravi, Akibjaved Tamboli and Ranjeet Pisal, " IoT Based Smart Energy Meter", International Research Journal of Engineering and Technology, Volume 04, Issue 04, pp.96-102, 2017

[3] Borse Bhagyashree, Smita Kulkarni and R.D.Patane, "Energy Management Technology Based on Cloud Network", Journal of Electrical and Electronics Engineering (IOSR-JEEE), pp. 23-26, 2014

[4] Champ Prapasawad, Kittitach Pornprasitpol and Wanchalerm Pora, "Development of An Automatic Meter Reading System Based on ZigBee PRO Smart Energy Profile IEEE 802.15.4 Standard", IEEE Transaction,pp.978-980, 2012

[5] Devadhanishini.AY, Malasri R.K, Nan;dinipriya.N, Subashini. V and P.G.Padma Gowri, " Smart Power Monitoring System Using IoT", 5th International Conference on Advanced Computing & Communication Systems - IEEE Explorer, pp.813-816, 2019

[6] Iosif Androulidakis, Gorazd Kandus, "Mobile Phone Brand Categorization vs. Users' Security Practices", ETASR - Engineering, Technology & Applied Science Research, Volume 01, Isuue No. 02, pp.30-35, 2011

[7] Kim Baraka, Marc Ghobril, Sami Malek, Rouwaida Kanj and Ayman Kayssi, "Low cost Arduino/Android-based Energy-Efficient Home Automation System with Smart Task Scheduling", American University international Conference, pp.1-7, 2013

[8] Komkrit Chooruang and Kraison Meekul "Design of an IoT Energy Monitoring System", Sixteenth IEEE International Conference on ICT, pp.18-22, 2018

[9] Lalit Mohan Satapathy, Samir Kumar Bastia and Nihar Mohanty, "Arduino based home automation using Internet of things (IoT)", International Journal of Pure and Applied Mathematics, Volume 118, Issue 17, pp.769-778, 2018

[10] Mark ruth, Annabelle pratt, Monte lunacek, Saurabh mittal, Hongyu wu, Wesley jones, "Effects of home energy management systems on distribution utilities and feeders under various market structures", 23rd International conference on electricity distribution, France, 2015

[11] Mihaela M. Albu," Syncretic Use of Smart Meters for Power Quality Monitoring in Emerging Networks", IEEE Transactions on Smart Grid, pp.1-8, 2016

[12] Nageshwar Dev yadav and Prof. Akash Wanjari, "Cloud Based Smart Metering Security Access and Monitoring System in the Real Time Environment", International Journal of Engineering Research & Technology, Issue 2, pp.1349-1353, 2014

[13] P. Naveen, Wong Kiing Ing, Michael Kobina Danquah, Amandeep S. Sidhu, A. Abu-Siada, "A Cloud Associated Smart Grid Admin Dashboard", ETASR - Engineering, Technology & Applied Science Research, Volume. 8, Issue No. 1, pp. 2499-2507, 2018

[14] R.Govindarajan, Dr.S.Meikandasivam and Dr.D.Vijayakumar, "Energy Monitoring System Using Zigbee and Arduino Controller", International Journal of Engineering & Technology, Volume 07, Issue 04, pp.608-611, November 2018

[15] R.Govindarajan, Dr.S.Meikandasivam and Dr.D.Vijayakumar, "Low Cost Arduino Based Smart Energy Monitoring System Using Internet of Things", Journal of Engineering and Applied Sciences", Volume 14, Issue 01, pp.170-177, January 2019

[16] R.Govindarajan, Dr.S.Meikandasivam and Dr.D.Vijayakumar, "Cloud Computing Based Smart Energy Monitoring System", International Journal of Scientific and Technology Research, Volume 08, Issue 10, pp. 886-890, October 2019

[17] R. Pereira, J. Figueiredo, R. Melicio, V.M.F. Mendesa,d, J. Martins C and J.C. Quadradod, "Consumer energy management system with integration of smart Meters", Energy Reports-Elsevier journal, pp.22-29, 2015

[18] Sudhakar Hallur, Prof. Roopa. R. Kulkarni, Dr. P.P.Patavardhan,"Smart Components for A Smart Energy Meter", International Journal of Advance Research in Engineering, Science & Technology, Volume 4, Issue 3, PP. 544 – 556, 2017

[19] Tae-Seop Choi, Kyung-Rok Ko, Seong-Chan Park, Young-Sik Jang and Yong-Tae Yoon, "Analysis of Energy Savings using Smart Metering System and IHD (In-Home Display)", IEEE Transaction, pp.1-4, 2009

[20] Vishal Kumar Sah, Brinda.S, Jaladi Harish, Akshay.U, Vishal Deo Mahto, Swetha Umapathy, " Smart Energy Meter", International Journal of Engineering Science and Computing, Volume 8, Issue No.3, pp.16578-16581, 2018

R.Govindarajan was born in Tamilnadu, India, on July 17,1982. He received his B.E. degree in Electrical and Electronic Engineering from Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kanchipuram, Tamilnadu, India, M.Tech. degree in Applied Electronics from Bharath University, Chennai, Tamil Nadu, India and he is currently pursuing Ph.D in Electrical Engineering with SCSVMV University, Tamilnadu, India. He has published four research papers in Scopus indexed journal two in other reputed journal. His areas of interest include smart gird, smart energy management, wireless communication, cloud computing.

S.Meikandasivam, he received the Bachelor's degree in Electrical and Electronics Engineering from Anna University, Chennai, Tamilnadu, India in 2002, the Master's degree in power systems in 2005, and the Ph.D. degree from the Maulana Azad National Institute of Technology, Bhopal, India, in 2010. He has been an Associate Professor and Head with the School of Electrical Engineering, Vellore Institute of Technology, Tamilnadu, India.

D.Vijayakumar, he received the B.E. degree in Electrical and Electronic Engineering from Madras University, Chennai, India, in 2002, the M.E. degree in Power System from SCSVMV University Tamil Nadu, India in 2005, and the Ph.D. degree in Electrical Engineering from Maulana Azad National Institute of Technology, Bhopal, India in 2010. He has been professor with the School of Electrical Engineering, Vellore Institute of Technology, Tamilnadu, India.