Smart Distribution Network with Integration of Stochastic Renewable Energy Sources and Plug-in Electric Vehicles: Challenges and Issues

K. Ramakrishna Reddy and S. Meikandasivam

Vellore Institute of Technology, Vellore, India
E-mail: ramu.svce@gmail.com; meikandasivams@gmail.com

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Abstract

In order to ensure the longevity of electricity supply for human living and comfort on earth, electric grid should be an intelligent, well established, automated and more importantly environmental friendly energized network. Demand crises and CO_2 emissions all over the globe have led to deploy more number of Renewable Energy Sources (RESs). The Smart grid technologies are becoming the most important entities in the electric power sector, in terms of modernizing the legacy grid with high-level penetration of RES and maintain reliability and quality of electric power. Exploitation of advanced technologies to optimize the power usage and reduce greenhouse gasses emission is inevitably the main concerns for the electric utility. RES integration brought so many issues along with their advantages. Plug-in Electric Vehicles (PEV) during last decade has shown drastic market growth with reduced cost and higher energy density storage. Bulk number of PEV integration with uncoordinated charging schedule is a big hurdle to power system operation. This paper mainly focuses on the challenges and issues that will arise in Smart Distribution System (SDS) because of high-level penetration of both RES and PEV. The impacts of intermittent PES and uncoordinated PEVs

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on distribution network stability are discussed. Exploitation of PEV as a storage unit with bi-directional power flow is discussed to mitigate solar and wind power generation fluctuations. Real time data from Danish distribution network is used for case study to demonstrate PEV utilization for grid ancillary support.

Keywords: Integration of RES, Demand Side Management (DSM), PEV, ESS, State Estimation, Smart Protection, V and f control, Smart Home and Micro Grid.

1 Introduction

In recent years, it has become a big challenge to conserve electricity and to reduce the CO_2 emissions. The global initiatives regarding environmental issues lead to so many changes in government policies all over the world, out of which cleaner power generation becomes the most important and primary concern. The report produced by the Renewable Energy Policy Network for the 21st Century (REN21) [1] on the ‘RES 2016 global status’, says that 23.7% of electricity accounts for RES including hydropower generation whereas the hydropower generation accounts for 16.6% and remaining i.e., only 7.1% is from RES (the wind, solar, bio and others). US Energy Information Administration (EIA) forecast reports that India is at the top of the list, which is depending on coal-based electricity generation followed by china, other Asian countries, and Africa etc., as shown in Figure 1. The world energy consumption is going to be increased by 48% from 2012 to 2040, which implies that there will be drastic increase in consumption of electricity in the future. It is projected renewable and natural gas will play a major role in energy production across the world whereas the electricity generation by coal, liquid and nuclear fusions are expected to be saturated in the upcoming decades [1].

Organization for Economic Cooperation and Development (OECD) countries have almost less increment in CO_2 emissions, whereas non-OECD countries are projected to have one fourth of increment from 2012 to 2040 (Figure 1). By 2015, the RES total generation capacity excluding hydro was 785GW [2], in which China is on the top and followed by USA, Germany, India, Spain, Italy and Japan (REN21). The wind power generation is in the top place in RES and followed by solar PV and then Bio-power. Geothermal energy production is more in the USA and China.

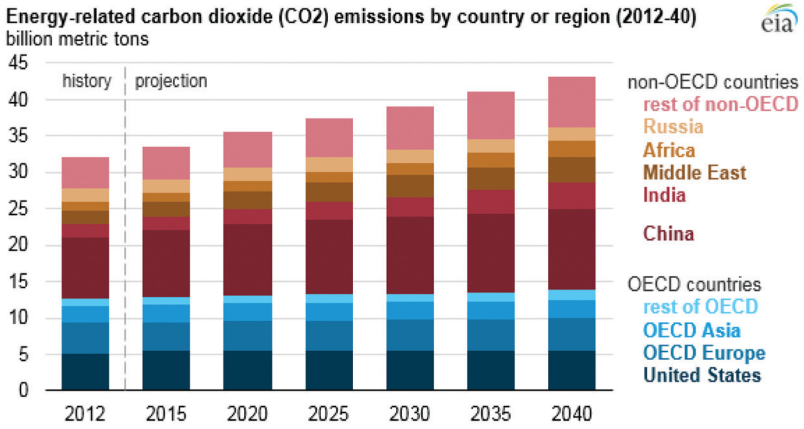

Figure 1 Projected energy-related CO_2 emissions by OECD and non-OECD countries (2012–2040) [1].

The wind and solar PV are the major sources of cleaner power generation. Integration of these RESs (which are basically intermittent in nature) into the existing grid brings a lot of issues and challenges along with the advantages. Another advantage of abundant RESs is the autonomous operation of distribution system without main grid. However, micro grid autonomous operation needs very intelligent and accurate control strategies failing of which causes micro grid block out. And also, the distribution system with high-level penetration of Distributed Generations (DGs), PEVs and Energy Storage Systems (ESSs) along with variable stochastic load demand is said to be a very complex network, which needs the better understanding of states (voltages magnitudes and phase angles) of vertices (nodes) to carryout complete monitoring and control. With the accurate state estimation of the distribution network, EMS can now take correct control actions against contingencies and dynamics. The continuous frequency and voltage fluctuations that will violate the stability of the system are the major concerns of EMS. So, for these actions to get implemented accurately needs sophisticated data from all remote terminals, loads, substations and network data (states). Smart grid technologies (mainly ICT) will help a lot in this regard along with the new metering infrastructure.

With the advent of smart meters and other distribution automation technologies, it is possible to make the electricity as the costumer friendly commodity. From past decade, there has been huge progress in the smart grid deployments all over the world, mainly concentrating on customer-side energy management and towards distribution automation and RES integration [3, 4]. With the smart grid technology proliferation, integration, operation scheduling of DGs at the distribution side became flexible and economical. Nevertheless, the intermittent DGs like solar and wind generations brought problems in the grid stability, power quality, and other issues like uncertainty in the generation, network topology changes, and harmonics, voltage and frequency fluctuations. At the same time most of the above-mentioned DG's interfacing converters could heal problems, and optimal placement of DGs, ESS and PEV scheduled in the distribution network [5, 6]. Therefore, in view of future energy demand and environmental issues, RES integration into the grid creates healthier and sustainable energy network [7].

In this article, the challenges and issues pertaining to high level DGs, ESS and PEVs penetration are discussed along with micro grid operations. The role of smart meters in demand side management and data acquisition are also discussed in smart home perspective. The organization of the remaining part of this paper is as follows: Section 2 introduces smart grid scenario and technologies involved. Section 3, explains about Smart Distribution System (SDS) and the main issues regarding DG penetration into the distribution network. Section 4 aims at smart home related concepts. Micro Grid challenges related to its operation and coordination of DGs in different modes of operations are discussed in Section 5. A case study on PEV exploitation for grid support is presented in Section 6.

2 Smart Grid

Smart grid is referred to as modernization of existing grid with advanced communication and information technologies (ICT) along with smart metering. Though there exist different ways of defining Smart grid, the ultimate aim of smartening electric grid is quite same. Smart grid implementations and research have grabbed a lot of attention from last two decades. There have been many surveys done on Smart grid deployments in recent years [8–10]. In [11], a clear smart grid survey has been presented mainly focusing on EMS, protection and smart infrastructure and focussing on ICT used for Smart grid operations.

The idea of smart grid has evolved into the whole grid and each part of the electric network is going to be transformed into a smart power network with digitalized control. The idea of Smart Meter implementations in home premises at early stages lead to the technological widespread all over the distribution system (DS) and then to the transmission network. During initial stages, smart meters were deployed with an intention of customer flexibility and access to utility energy monitoring. Later with the integration of cleaner energy sources, (RES) and advanced storage systems, brought so many changes to the legacy distribution and transmission systems.

The EMS is responsible for reliable and quality power supply. It is very difficult to manage the tasks assigned to EMS without adequate data and state of the distribution network. The main entities that make the DS more complex are intermittent RES, PEV, Micro grid operations etc. It also needs forecasted data from load and RES in order to plan future energy scheduling. The key factors of smart operation and control are:

√ Demand side management.
√ Real-time pricing (RTP)
√ RES penetration issues/challenges.
√ Energy efficiency and Reliability.
√ Self and quick healing grid.
√ Greenhouse gasses reduction.
√ Plug-in electric vehicles.

With the encouragement towards the cleaner energy, in recent years many countries are actively showing interest in modernization of grids by incorporating information and communication technologies (ICT) mostly in DS atomization. The following are the main entities in smart grid:

√ Smart metering.
√ Advanced meter Infrastructure (AMI),
√ Remote terminal units (RTU).
√ Advanced ICTs.
√ Intelligent electronic devices (IED).
√ Data and Control canters.
√ Energy management canters.
√ Smart Substations.

Role of ICT in smart grid: Deployment of AMI, Smart Meters, RTUs, PMUs IEDs and other smart meter infrastructures along with communication and data handling features creates a smart and intelligent distribution system [12]. The present grid mainly depends on centralized communication infrastructure for the SCADA systems. In [13], authors have discussed scalable SCADA with multiprotocol smart grid devices that mainly focus on home automation with minimizing the cost. The effectiveness and advantages of PMUs and RTUs used with SCADA systems to improve the state estimation is discussed [14]. The legacy power grid transformation into smart grid needs well-advanced technologies to be implemented in all dimensions of the electric network. The smart grid has been evolving into a modern digital electric grid (smart grid) with new communication standards [15] and there are two ways of communications available, one is wired communications and another one is wireless communication. Both of them have their advantages and disadvantages depending on their circumstances and necessity. The smart grid differs from traditional grid as shown in Table 1.

In wired communications, Power Line Communication (PLC) is considered cheaper as it uses the existing power lines as the medium of communication. During the Second World War, the PLC has been considered as a mode of communication. In recent years, PLC grabbed a lot of attention towards its implementation in smart grid. PLC can be used along with wireless communication as a backhaul and in home area networking also [16]. There are so many experimental studies carried out on PLC implementations in smart homes, smart city, and distribution automation [17]. Hsieh et al. proposed

Table 1 Comparisons between traditional and smart grid

Traditional Grid	Smart Grid
√ One-way/no communication	√ Two-way communication
√ Fixed tariff over all time usage of power	√ Real-time-pricing causes flat load profile
√ Unidirectional power flow	√ Bidirectional power flow
√ Less control over remote terminals	√ Full control over remote terminals
√ DG integration is a big task in DS	√ DG integration is flexible in DS
√ Manual operations of feeders, relays etc.	√ Online operation/state estimation
√ Inadequate data of whole network status	√ Adequate data for post/forecast analysis
√ Cascading failures	√ Quick in clearing outages/fault isolation
√ Electromechanical controllers	√ Electronic/digital controllers
√ SCADA with partial atomization of DS	√ Full-fledged DS atomization
√ Manual metering	√ Advanced meter infrastructure
√ No remote monitoring from substation	√ Complete monitoring of grid network
√ Manual relay setting	√ Online relay setting
√ Few sensors	√ Full of sensors with communication
√ Micro grid operations not possible	√ Micro grid operations are flexible
√ Network topology won't change	√ Network changes because of DGs
√ No more investment except few requirements	√ Needs lot of investment.

PLC technology that is implemented to issues the control commands to air conditions with respect to demand profile [18]. Apart from these, there are other PLC applications like vehicle commanding, trains, aircraft, naval robotics etc. Along with PLC implementations, Digital Subscriber Lines (DSL) will also play a major role in ICT for smart grid. DSL uses shared access link to transfer data, video, and voice simultaneously over the same channel [19].

In smart grid communications, advanced wireless technologies offer higher bandwidth, low cost of installation and higher reliability and security [20, 21]. The wireless communication technologies that are used in smart grid are Zigbee, WiMax, 3G, GPRS, and GSM etc. The type of communication used in smart grid depends on the extent of area of coverage, accuracy, speed of operation and other factors like accessibility and infrastructure. The communication protocols for smart grid can be broadly classified into three categories depending on area of coverage:

HAN (Home area network): It connects the smart appliances in the home with the smart meter in order to send the data that is useful to calculate energy, tariff, power factor etc. This communication can also be used to switching the electrical appliances remotely. Machine-to-Machine interaction is required for coordination of all the entities [22]. Depending on the type of service area there are other communication networks namely building area network and industrial area network etc.

In [23], wireless sensor networks that are suitable for smart grid applications are presented according to NIST standards and it has been projected that ZigBee is a suitable networking system for home automation. Machine-to-Machine (M2M) communication is a very important aspect of smart grid in order to achieve interoperability among the different entities in smart grid environment, authors in [24] have reviewed different standardized technologies for M2M. The interaction among the appliances and smart phone is a necessary thing for smart home applications. Usman et al., in his paper, has discussed different communication technologies that are apt for smart grid two-way communication for home area, vehicle to vehicle and substation automation [25]. In [26], Erol-Kantarci and Mouftah have shown that the reduction in energy bills due to efficient communication aided in-home energy management.

LAN (Local area network): In this network, it covers few feeders in the distribution zone and collects the data from all consumers and feeders to transfers to the nearby control centre/EMS. Once the data retrieved by the EMS is processed the appropriate actions can be assigned to the IEDs, as an example closing or opening of a feeder. The main objectives of this communication network to implement protection, optimum operation of DGs, real-time-pricing, PEV, Storages and other distribution automation operations. Yi et al., have proposed wireless LAN model for smart grid and he has considered the interference caused by overlapping ZigBee communications [27]. C. Kalalas et al., have presented a survey on neighbourhood area networks with cellular technology suitable for smart grid applications and especially demand side management [28]. In [29] authors have addressed the challenges and issues regarding the communication security, reliability and compatibility.

WAN (Wide area network): It covers the huge area of several kilometres that includes part of the whole grid and connects so many LAN networks. The main objectives of this communication network are to monitor the transmission lines power flow, congestion management of tie lines, protection, optimal operation of generation, FACTS devices controlling and monitoring. Ahmed et al., have proposed a new wireless data transferring and acquisition system for smart grid applications in which, the latency and throughput have been improved remarkably [30]. Wimax based WAN communication technology has been used for adaptive protection of micro grid with less latency [31]. ZigBee base WAN communications are used for the protection of distribution system with high-speed data delivery with respect to demand based queuing [32]. PMUs are the key role players in providing real time data for state estimation, in [33], authors have proposed WiMAX communication implemented on PMUs for data transfer.

The power and data flow in the entire power system network are shown in a concise manner in Figure 2. The DGs of medium sizes are expected to be mostly connected to the distribution network. The information regarding DGs, PEVs, ESS and feeders at distribution has to reach the EMS thereby control actions will be takes place. And the information regarding bulk power generation has to reach transmission level EMS in order to maintain optimal power generation and tie line congestion management. Smart meters from homes will send the data pertaining to loading which helps in demand side management (DSM) and load forecasting.

Adverse effects of smart grid technologies implementations are also to be taken into consideration as they may lead to entire system disturbance. The very first dangerous thing is cyber security [34] which causes miss-operation of protection system and other key control equipment when control action falls in wrong hands. Along with the cyber-attacks, the reliability of measurements and data transfer also affects the operation of the grid. The smart grid is said

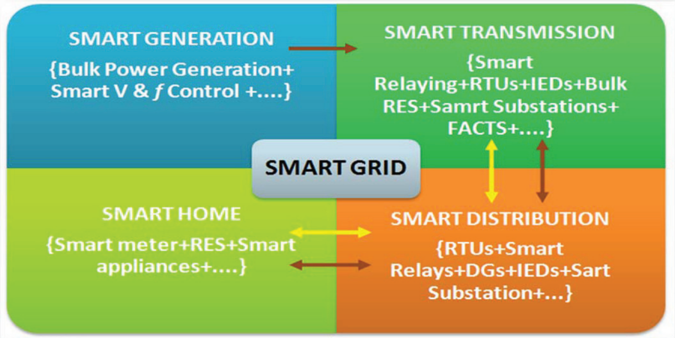

Figure 2 Power and communication flow in smart grid.

to be a complex interconnection of both power and communication networks which in turn needs a sophisticated monitoring and reliability assessment system. The appreciable technological developments in today's smart grid are mainly concerning about communication and data handling. Hence the cyber security is an adverse effect which needs counter measures to avoid miss operation [35]. A game theoretical approach has been proposed in [36] in which multiple attacks are considered in the wrong data injection with a single defender. C. Kalalas et al. presented a game-theoretical approach for mitigation of switching based cyber-attacks [37]. As this article is mainly dedicated for energy related issues, ICT are not discussed.

3 Smart Distribution System

Smart grid lies on two major issues; one is greenhouse gases emissions and another one being efficient and reliability power supply. The DS can be a more prominent area to deal with. In DS starting from consumer level to substation level control, there must be a clear and transparent power management. In DS, the main objectives are totally linked with DG integration into the network, more importantly, the RES with intermittent nature like solar and wind power generations and storage unit scheduling.

The Figure 3 shows the possible interconnections among the entities in DS both in communication and power flow aspects. RES with power electronic converters are the main entities in DS and followed by ESS and then the actual

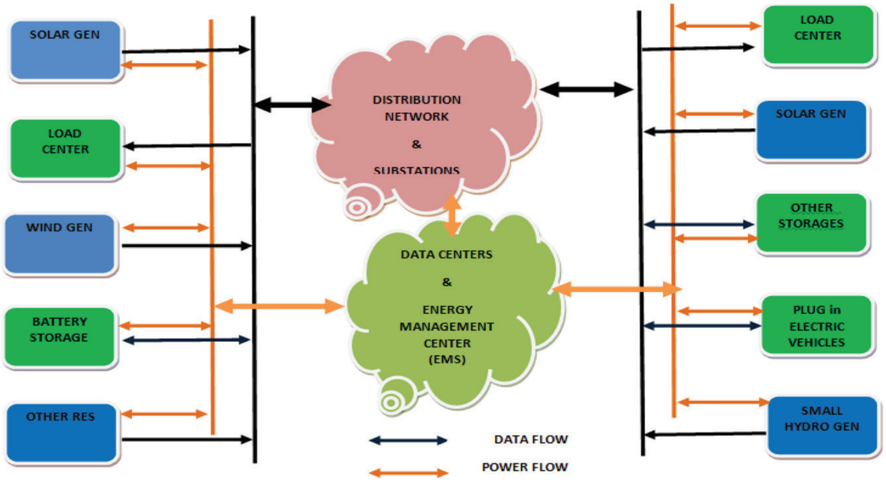

Figure 3 Smart distribution systems.

loads. Figure 3 explains the way communication flow and power flow occurs in distribution network to make the control and scheduling actions flexible with adequate data. The EMS gathers the data from all remote terminals, feeders, loads and other IEDs in order to analyse the state of the whole network. EMS, once done with the analysis by using the availed data, the control actions will be initiated by sending signals to respective devices. In earlier days, Supervisory Control and Data Acquisition (SCADA) was built to do this process, but lack of adequate communication and advanced sensor technologies made it partially successful in controlling and monitoring of DS.

Modernization of DS with advanced ICT and with other smart grid technologies like smart meters, AMI, RTUs, IEDs, EMS, data centres etc., can be called as Smart Distribution System (SDS) [38]. Using these diversified technological advancements, tasks pertaining to SDS can be carried out in a more sophisticated way. The challenges in SDS are listed in Figure 4.

3.1 DGs Integration into DS

The first and foremost step towards CO_2 emissions reduction is to increase the number of different kinds of RES in power generation [39]. In the recent years there has been a lot of research work done on the integration of DGs especially RES and yet there is lot to do with the issues pertaining to intermittent to

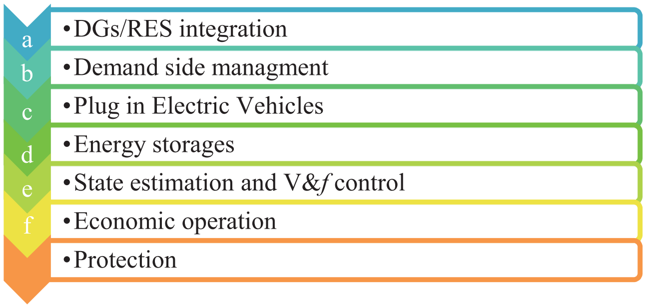

Figure 4 SDS areas of challenges/issues.

integration of RES like wind and solar power generations. The intermittent RES integration into DS imposes a lot which are mentioned below.

√ Optimal placement of DGs
√ Generation forecasting
√ Network topological changes
√ Protection
√ Generation optimization
√ Bidirectional/reverse power flow
√ Grid synchronization and stability
√ Power quality

3.2 Placement of DGs

Optimal placement of DGs in DS helps to heal problems mentioned above to improve the voltage profile and reduce power losses. DG's placement may cause large amount short circuit current flow in random directions on the network which in turn causes miss operation of over current protection scheme. Hongxia Zhan et al., proposed a novel DG placement method using the genetic algorithm which also decides the optimal size of the generator [40]. Particle swarm optimization technique has been used for optimal placement of DGs aiming to reduce the line losses at maximum extent [41]. In [42], authors have considered the power loss and voltage profiles in order to decide the optimal size and location of DGs on the distribution network, here authors have solved the multi-objective function with many constraints using harmony search algorithm. The uncertainty nature of DGs (RESs) is considered in [43] to solve the DG placement and sizing problem aiming to reduce the cost and to maximize the profit. However, stochastic nature of RES will have appreciable effect on DS operations.

3.3 Role of Wind and Solar PV

Wind and solar PV are the main contributors of electric power generation out of all available RES in the world [44]. As these sources of power generation are uncertain in nature (weather dependent sources), apart from their advantages as a cleaner energy source, they cause many problems when they are integrated to the grid [45]. A multi-source DC power supply system with intelligent energy management system has been proposed in [46] for a building integrated solar PV along with battery storage, in which a hierarchical control strategy implemented with the assumption of variable DC loads. The wind power conversion systems of three different places are connected with smart home and along with energy storage system has been proposed in [47]. Optimal scheduling is another challenge with the intermittent DGs, as the unpredictable nature cause disturbances in prior scheduling. Though the forecasting tools are available for power generation estimation, it is still a complex problem for utility operator.

In near future, it is expected to have excess power generation by the RES which in turn exceeds power demand. This excess power flows backward and in random directions into the network. Reverse Power Flow (RPF) problem is another main concern of DS with high penetration of intermittent DGs, which causes voltage raise and disturbs regular protection schemes. In [49], impedance measurement based technique has been proposed to identify reverse power flow in the DS with solar PV integration. Customer side energy management helps in this regard for RPF reduction with heat pump water heaters to store the energy in the thermal form [50] and optimal placement of DGs like solar PVs in the distribution lines can help to reduce the reverse power flow [51]. In [52], communication-based voltage control methodology has been proposed to mitigate RPF where the controlling of voltage is achieved by tap changing transformer and along with solar PV generation. Storage scheduling of PEV charging and discharging will be an economical choice to mitigate both voltage and frequency fluctuations. Exploitation of PEV for grid support is discussed in Section 6 in detail.

3.4 Demand Side Management

The first and foremost constraint of the electric power system is 'Power-Demand' balance. Coming to the DS which is a complex network with different types of power sources with different characteristics, the generation optimization problem becomes more difficult to solve as it involves heterogeneous entities. Demand Side Management (DSM) is proven to be a more prominent way of maintaining power demand imbalance up to some extent. DSM came into the picture since the early 1980s. The DSM is no more a theoretical discussion with the advent of smart grid technologies like smart meters and other AMI and ICT.

The concept of real-time pricing (RTP) is best among all the available pricing methods to shave the peaks in the load curve. RTP helps both the consumers (bill cutting) and also the utility (flat load profile). There are so many approaches proposed in the literature for tariff management load curtailment. Celebi and Fuller have proposed Time-of-Use tariff scheme in prospect to regulatory bodies and electricity market [53]. With the flexible pricing mechanism for the customers, a cost efficiency based metric system is proposed in [54] and the results showed that load shifting effects the cost of electricity appreciably with the integration of RES.

Smart meters help a lot in real-time-pricing as the real time data can be retrieved without much delay through advanced communication channels. ICT plays a vital role in dealing with the data obtained from smart meters and other RTUs and then to process it. Demand side management has grabbed lot of focus in terms of research under the smart grid perspective [55]. Ramteen proposed RTP for the high-level wind generation dependant load zone with uncertainty in the generation and the method was compared with other cases without consideration of uncertainty in wind generation and without RTP [56]. Roozbehani et al., have introduced the concept of price elasticity and shown that the volatility price will increase without proper future prediction of both load and demand [57]. In [58], the RTP has been applied with major schedulable house loads namely: heating, ventilation, and air conditions. The adequate data communications in two ways between utility and customers laid a new path for DSM with economic prospects for both utility and customers. Mohsenian-Rad et al., have used game-theoretic approach [59] for demand side management where the customers are the players and an incentive scheme for customers was adopted to attract the customers at off-peak periods [60]. In [61], Logenthiran et al. have adopted the heuristic evolutionary method for the cost minimization problem in day ahead scheduling. Smart grid technology promises intelligent ways of load scheduling techniques with the help of ICT [62].

3.5 Plug in Electric Vehicles

In contrast to the RTP in DSM, the concept of Plug-in-Electric Vehicles (PEVs) which are considered to be future smart vehicles will play a vital role in power demand balancing. Advanced battery technologies are the future of PEV market [63]. V2G or G2V is not limited to housing infrastructure but it can be a distributed plug point (fleet) in the entire electric network at suitable places [64].

A hybrid electric vehicle, which operates with both battery storage and extra renewable source, in addition, will bring new challenges in demand side play. In [64], authors have designed communication assisted mobile PEV model by considering the vehicle random travel among the districts. Pang et al., worked on DSM using battery storage vehicles and hybrid electric vehicles with the bidirectional flow [65]. Dynamic programming methods are used for optimal charging of the PEV when it is at home under the constraint that vehicle should be at full charge when it is leaving home and another constraint is that it should have constant charge flow at all timings [66]. Authors have used moving horizon technique for to identify the random travelling of PHEV where the optimization problem was solved using water-filling algorithm [67]. Akhavan-Rezai et al., discussed on-line charging of PEV where the fuzzy system has been used to allocate scores to the vehicles aiming to optimal charging and to maximize the benefit of the owner without violating the grid operational constraints [68]. Intelligent control strategies are required in order effectively utilize PEV storage capacity with V2G technology [71]. Better exploitation of PEVs will reflect in prefect scheduling of PEV'S charging and discharging in accordance with the fluctuating RES and load demand. Detailed discussion on PEV effective utilization for grid ancillary support is presented in Section 6.

3.6 Energy Storages

It is always preferable to have energy storage system (ESS) along with RES especially with those of intermittent nature. There are so many energy storage technologies available in the present market: Battery Energy Storage System (BESS), Fly Wheel Energy Storage System (FWESS), and Super Conducting Magnetic Energy Storage System (SCMESS). For wind energy conversion system, we can use Electric Double-Layer Capacitor (EDLC) or Static Synchronous Compensator to smoothen power output.

Pumped storage plants (PSP) can be used for bulk power management. To schedule the excess power generated by the wind or solar at below half peak load periods, the excess power generated by these RES can be utilized to pump the water. As the hydro plants usually are far away from load centres, it is not economical to pump the water using main grid power; rather it can be a better choice if there exists a wind plant nearby the hydro [72]. In [73], the Solar PV along with ESS is designed to supply the power to the home and also to/from the grid depending on operational constraints and economy. While deploying ESS and DGs the size and location are major concerns as they affect the operation of micro grid [74].

A conventional energy storage system in coordination with storage available (charging/discharging) with PEV brings lot of advantages. The fluctuating load and RES can be compensated by controlling charging and discharging timings of both ESS and PEV in coordination. PEV's availability is uncertain and so scheduling for grid support needs accurate mobility model.

3.7 State Estimation and V&F Control

Voltages along with their angles at all the buses give the information about the state of the electric network. State Estimation (SE) is required in power system both in transmission and distribution areas in order to achieve the real-time monitoring and control through EMS [75, 76]. In early days the state estimation is considered for only transmission network to know the status of all buses. Methods of SE used for transmission cannot be applied directly to the distribution system because of complex network topology (more nodes), high R/X ratio and different network configurations in DS.

In DS, with the integration of DGs and energy storages, it has become very important that SE should be done very accurately in order to identify the problems encountered in the network. With the aid of smart grid technologies SE became more easy and useful for the online monitoring and control by the distribution system EMS (DS-EMS). It is noteworthy that the high penetration of DGs and storages causes modification of legacy distribution network, which in turn leads to complications in analysing the network status. Hence there must be well established and sophisticated algorithms to accurately estimate the network status, thereby to execute appropriate control actions.

State Estimation (SE) procedure is depicted in the Figure 5. The data from all the remote meters/smart homes, RTUs, PMUs and IEDs will be sent to the data centre. The measurements data gathered from the meters have to be processed to eliminate the bad and false data that has been injected by meter errors. The voltage and angle themselves describe the system behaviour. Once the wrong measurement is identified then control signal from network operator acknowledges the fault meter. Using Hamilton-cycle theory, Leite and Mantovani have proposed an algorithm for state estimation of distribution network under normal operating condition [77]. The smart meters are expected to enhance the data availability and accuracy, but the problem

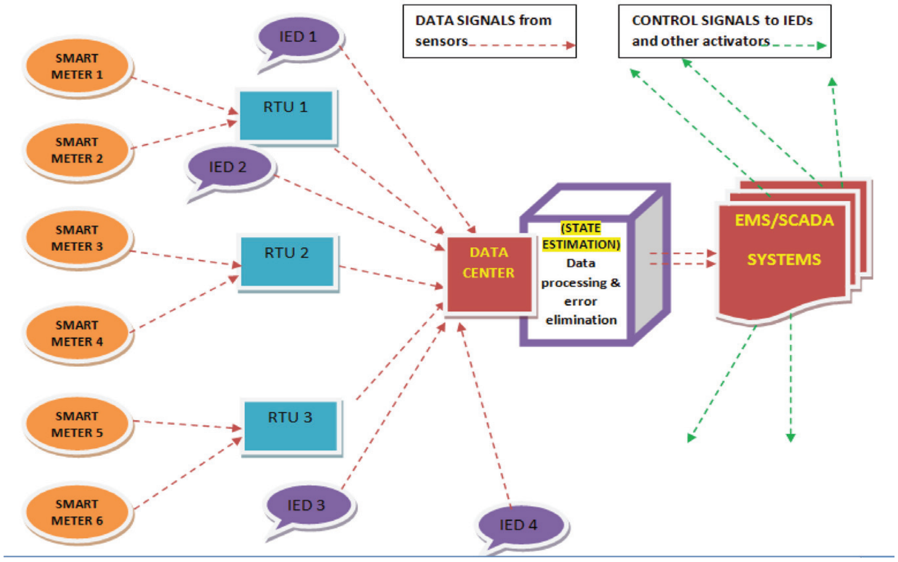

Figure 5 Data gathering and power system monitoring and control through SE.

with theses meters is that they provide non-synchronized measurements. There are so many methods proposed in the literature: linear state estimation [80], the quasi-symmetric impedance method [78], using pseudo-measurements correlation [79], using artificial neural networks [81], and recursive Bayesian approach [82].

3.8 Protection of Distribution Network

Distribution network Protection is a challenging task because of high penetration of DGs into the distribution network. The conventional protection scheme doesn't work well for the SDS as it includes so many entities like RES, ESS etc., and hence causes random variations in network topology [83]. The bidirectional power flow because of excess energy by RES causes unusual current flows in the network branches which in turn makes the protection scheme to misguide the relay functioning and hence causes unnecessary tripping of feeders without faults. Along with the variation of the direction of fault current, the amount of short circuit current will get increase in the presence of DG near the faulted zone. The main considerations that make the protection of SDS more difficult are: RPF, high short circuit current, network topological changes and intermittent RES. The effect of short circuit currents has been discussed in [84]. There are so many algorithms available in the literature for the protection of DS with intermittent RES and constant DGs along with ESS [85, 86]. A new communication-based protection algorithm has been proposed by Xyngi and Popov in [87] which operates with multi-function schemes in different modes. In [88], authors have discussed an adaptive over-current protection scheme, and the tripping settings can be changed instantly with the change of network topology.

An efficient way of adaptive protection in highly DG penetrated distribution network is proposed in [89], the algorithm uses discrete Fourier transform to track the power system fundamental signals. The DGs placement plays a vital role in changing the protection scenario of existing protection system. Reconfiguration of protection system is an expensive task and needs a lot of changes which is not desirable. The option now is to place the DGs in appropriate locations to ensure the normal operation of protection relays without any mislead. Optimal placement of DGs in terms of achieving maximum penetration and unchanged network protection scheme has been discussed in [90]. The impact of an inverter based DGs on the distribution network protection is discussed with few case studies in [91]. In [92], the smarter way of eliminating DG's contribution to increasing the fault current was proposed, in which the DG output current is controlled with respect to voltage variations.

4 Smart Home

Smart meters along with other ICT technologies are the main entities in Smart Home (SH) infrastructure. Energy management at the customer premises with innovative concepts and attractive tariff plans leads to well flattened load profile. Scheduling of residential loads with respect to variable tariff throughout the day helps to deal with the uncertainty in the RES generation. There is lot of research contribution on these issues and challenges of SH in recent years [93, 94].

SH needs an EMS to manage the loads in accordance with the power generation/demand uncertainties. EMS takes charge of all the appliances control, for which it needs data from Distribution Management System and residential DGs like solar PV, Battery storage and PEV storage in the home. To manage the energy usage in SH, the data from DSO like tariffs and supply interruption predictions can be utilized along with the residential data, like solar PV generation forecasting and loading requirements.

Tariff calculations and economic scheduling of consumer loading is an advantage for both customer and utility. RTP [95] gives better results over conventional tariff plans like flat-rate and time-of-use schemes. RTP encourages the consumer to shift their loading timings to off peak hours in order to cooperate with the utility. And there are disadvantages of RTP as all the consumers are tending towards low price scheduling leads to stability issues.

Solar PV assisted SH is grabbing a lot of focus in research, as it has become the better choice to reduce the impact of economic and environmental issues. Solar PV with thermal loads (heating, air conditioning and ventilation) scheduling and coordination helps in energy management at consumer premises appreciably [96]. SH with solar or any other RES integration creates an active consumer, where the some or all appliances can be supplied by on its own source or battery. In Figure 6, SH entities are depicted along with the data and power flow directions. The data from smart appliances is shared to home EMS and smart meter and from smart meter to DS-EMS. The smart meter along with EMS in the home helps in scheduling the load timings of different appliances throughout the day with the help of tariff data availed

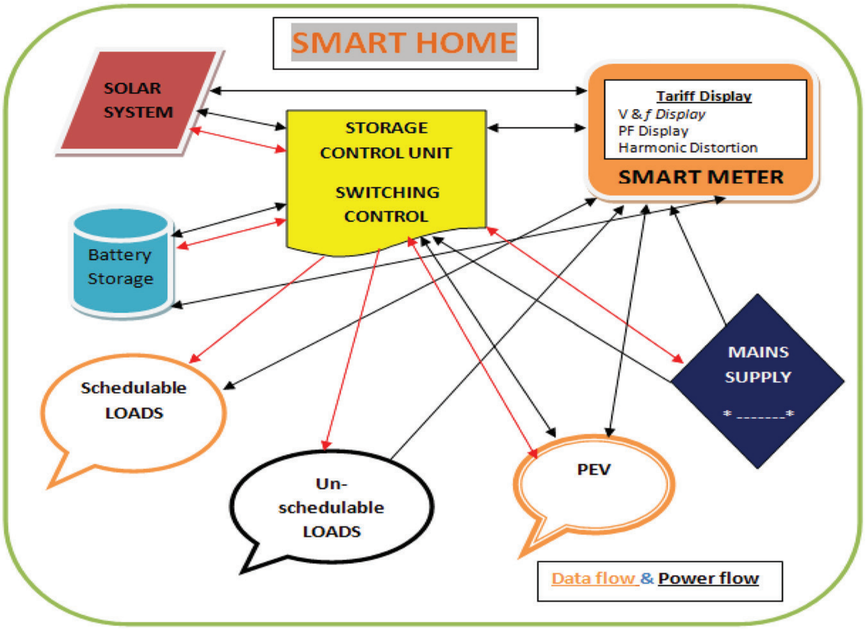

Figure 6 A smart home layout of interconnections with smart meter and control unit.

from DS-EMS. Electric appliances can be controlled by smart phones once there is a pre-scheduled usage timings are fixed at least hours ahead [97].

5 Micro Grid Operations

Micro grid is considered to be a part of the existing main grid at the distribution side. It is a self-sourcing distribution network which includes different types of DGs, PEVs, ESS and different loads. A Smart Micro Grid (SMG) is the Micro grid which is facilitated with smart grid technologies like smart Meters, smart Homes, ICT, EMS, data centres, RTUs, IEDs, AMI, and IEDs etc.

5.1 Modes of Operation

Micro grid can be operated in two modes, one is 'Island mode' where the local DGs along with storage units can feed the whole connected load, and another one is grid connected mode, in which part of the load will be supplied by main grid [98]. Micro grid modes of operation depend mainly on two factors, one is active DGs (importantly RES with intermittent nature) and another one is load at present. Intermittent nature of RES causes a lot of uncertainties in power supply; hence RES with ESS is preferably a better choice to deal with the continuous supply. The Micro grid basically has two different network topologies depending on its modes of operation. But the Micro grid network complexity increases with the DG penetration density.

5.2 Challenges/Issues in Island Mode

Micro grid operation, when it is in island mode is quite complicated than in parallel mode. In this context, the major issue is frequency fluctuations, which would be taken care of by the main grid if it is in the parallel mode of operation. Frequency deviations should be corrected within very less time duration without much delay. Several methods have been proposed in the literature for the islanded micro grid frequency correction. Bevraani et al. proposed a robust frequency control technique which uses μ-synthesis approach to include the uncertainties in the micro grid [99]. In [100] a consensus based droop control has been proposed where converter interfaced generators are assumed to be virtual synchronous generators. Sara et al. proposed a new concept both voltage and frequency control for islanded micro grid during contingencies [101]. Hajimiragha et al. discussed cost effective frequency regulation inspired by real world Micro grids operational experiences [102]. V2G advantage in micro grid as storage for ancillary services is discussed in [103] on the other hand unscheduled PEV plugging cause disturbances in micro grid operations [104].

5.3 Micro Grid Community

Apart from AC conventional Micro grids, there are DC- Micro grids and Hybrid Micro grids proposed in the literature with different architectures. DC/hybrid Micro grids are attracting a lot of attention in recent years [105]. This is mainly because of residential solar PV and more DC loads (electronic loads). Data centres in the smart grid context are consuming the huge amount of DC power. In recent years there is a lot of research has been done on Hybrid- Micro grid [106, 107] on the issue of AC and DC micro grids coordination. As mentioned earlier the Hybrid- Micro grid can also be operated in coordination with other Micro grids [108], anyhow the network complexity increases with this kind of interconnections among the nearby Micro grids. Micro grid can be either operated individually with a certain frequency or there could be mutual power exchange among the neighbouring Micro grids. Sometimes it is usual to call a group of neighbouring Micro grids as ‘Micro grid community’ [109]. There must be perfect synchronism to be maintained for mutual power exchange among the Micro grids. The Micro grid can be considered as a system of systems (SOS). SOS is generally a collection of heterogeneous systems integrated to achieve a common goal [110]. In SOS each system can also operate to achieve its goal regardless of coordination with other systems in the whole connected system (SOS).

5.4 Grid Synchronization

Along with the numerous advantages of micro grid formations, there are so many issues that are pertaining to both technical and economic issues pulling down the micro grid deployments. Grid synchronization, reverse power flow, protection, and stability are the major issues in the micro grid. Once the islanded micro grid started undergoing the wide variations in frequency and stability, necessary control must be done in order to get into stable operation. If self-healing is not done in permissible time duration, severe consequences will take place which in turn causes micro grid black-out. It will continue to the other micro grids which are operating in coordination. A perfect synchronization needs to be done before closing PCC.

Thale and Agarwal have proposed an advanced grid synchronization method in which every DG is set to get in synchronism with main grid voltage magnitude and the angle at a specified frequency [111]. Researchers came up with different types of synchronization techniques by considering phase imbalance, harmonics, and frequency deviation. These techniques are not as popular as they are developed with consideration of distorted voltage and also require complex control circuits. In [112], traditional PLL based synchronization technique has been proposed which uses instantaneous three-phase voltages of the main grid.

6 Exploitation of PEV for Grid Support

Major restrictions on electric vehicle market growth are energy density and cost. From last decade, drastic reduction in cost and improvement in energy density has led to remarkable growth in PEV market growth [113]. PEV penetration into the grid creates disturbance to the utility operator if there is no control over their charging (G2V) and discharging (V2G) scheduling [114]. Uncoordinated PEVs cause voltage instability and frequency deviations [115–117]. On the other hand PEV can be an important asset through which grid ancillary support can be carried out. Ancillary support may be voltage regulation, frequency regulation, DSM, solar and wind generation support and load flattening etc, [118, 119]. Utilization of existing PEV storage capacity needs no extra investment but it requires customer cooperation. Government involvement to implement policy regulations in order to effective utilization of PEVs for grid support is very important.

Advantages/Scheduled PEV	**Disadvantages/Unscheduled PEV**
√ Voltage Regulation	√ Voltage fluctuation
√ Frequency regulation	√ Frequency deviation
√ Solar Generation support	√ Reverse power flow
√ Wind Generation support	√ Stochastic Loading
√ Load flattening	√ Battery degradation
√ Peak demand shaving	√ Network complexity
√ Spinning reserve	√ Needs communication technology
√ Revenue through regulation support	√ Customer interest
√ Electricity cost reduction	√ Needs accurate mobility modelling

Numbers of articles are published on different ways of exploiting PEV storage capacity. In [120], authors have proposed an approach to utilize PEV aggregator storage capacity to compensate stochastic wind power generation.

Mitigation of impact due to solar PV and PEV together was discussed by J. R. Aguero et al. and F. Marra et al. [121]. Utilization of V2G technology for unbalanced voltages in distribution grid is discussed in [122]. Available PEV capacity was utilized to suppress solar PV fluctuations to avoid additional storage capacity [123]. Alam et al. have developed an intelligent control strategy for peak demand support at evening times and to reduce solar PV impact (during midday) using battery storage integrated to solar PV [124].

Customer revenue is the key factor that encourages PEV's owners to participate in grid support. It is utility's prime task towards customer to maximize revenue. However, primary purpose of the electric vehicle is travelling and hence it has to be given priority. So, PEV's usage for the grid support should not create inconvenience to customer travel schedule. Particle swarm optimization based control strategy was used in [125] to minimize virtual cost of electricity, and improve battery life time while shaving peak load using PEV's available storage capacity. In [126], dynamic programming method was adopted for frequency regulation using PEVs in which final state of charge (SOC) set point and customer revenue are the main considerations. Studies on customer profit maximization (due to participation in grid ancillary support) and electricity cost minimization were carried out in [127, 128]. As a matter of fact, to accomplish coordination among all PEVs and to schedule them strategically requires sophisticated smart grid technology. Another important factor that influences customer inclination to participate in grid support is net revenue (including battery degradation cost). Reduction of emissions and operating cost by optimized use of PEV storage units in grid support [129]. So, with strict and liable government policies, utility operators can utilize PEVs support for grid ancillary services. The major challenges and requirements in order to a better utilization of PEVs are listed below:

Key Requirements of PEV for Grid Support
√ PEV mobility model
√ Estimation of available storage capacity
√ Forecasting renewable power generation
√ Demand forecasting
√ Scheduling of PEV charging /discharging
√ Estimation of storage capacity
√ Forecasting upcoming demand fluctuations
√ Time-of-use price consideration
√ Customer revenue maximization
√ Ensuring trip timings and battery energy level
√ Coordination with static energy storage systems (ESS)

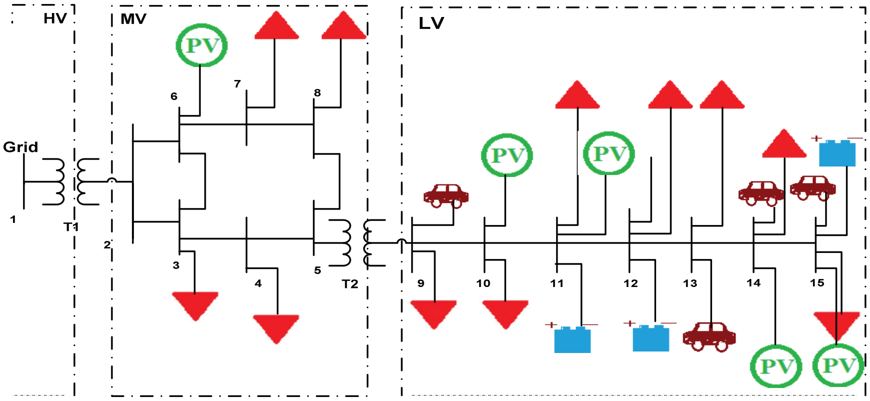

Figure 7 Active distribution networks with ESS and PEV.

An active distribution network consisting of solar PV, different loads ESS and PEVs connected to low voltage distribution feeder is considered (Figure 7) [130]. Bus-1 is connected to main grid (slack bus), buses 3, 4, 7 and 8 are connected to commercial, industrial, agriculture and residential loads and all low voltage side buses are connected to residential loads with PEVs and static storage units. Assume that total power generation (solar PV power) including storage capacity (both ESS and PEV) is less than what is required by the load at any given time in a day. Equation (1) gives the power needed from grid mains and Equation (2) gives energy needed during time interval ‘t’. The terms in right hand side of Equation (1), represents Solar PV power, load power, ESS charging power, PEV charging power, ESS discharging power and PEV discharging power respectively. The graphical representation of energy demand during a typical day is shown in Figure 8 which is the representation of Equation (2). In this scenario, PEV’s storage capacity is used to accommodate solar PV power and load demand fluctuations while maximizing the revenue for the PEV owner. In others words the objective can be described as to minimize power deviations from the slack bus around a specified value and to reduce cost of electricity (for customer). 24 hours are divided into 96 equal time intervals each of 15 minutes duration, lesser the interval duration more accurate will be the monitoring and control. However, it depends on available measurements data resolution and communication.

$$\mathrm{P}_{\mathrm{bal}}^{\mathrm{t}} = \mathrm{P}_{\mathrm{res}}^{\mathrm{t}} - \mathrm{P}_{\mathrm{load}}^{\mathrm{t}} - \mathrm{P}_{\mathrm{es}}^{\mathrm{t,c}} - \mathrm{P}_{\mathrm{es}}^{\mathrm{t,dc}} + \mathrm{P}_{\mathrm{pev}}^{\mathrm{t,dc}} \tag{1}$$

$$\mathrm{E}_{\mathrm{bal}}^{\mathrm{t}} = \int_{\mathrm{t=1}}^{\mathrm{t+15}} \mathrm{P}_{\mathrm{bal}}^{\mathrm{t}}(\mathrm{t}) * \mathrm{dt} \tag{2}$$

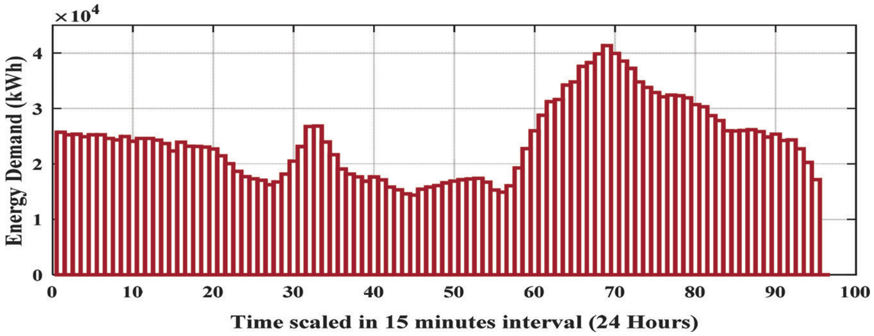

Figure 8 Energy demand during a day from main grid.

6.1 Modelling of PEV Availability

While accounting the storage capacity available for grid support during given time interval ‘t’, utility operator has to ensure the primary purpose of PEV (travelling). It implies that travelling schedule and battery requirements should be given highest priority. For the case considered in this paper to demonstrate maximum utilization of PEV storage capacity, PEV availability modelling [131–133] gives information about vehicle flexibility to participate in grid support. Data from National travel survey (NTS) of Great Britain sued in modelling vehicle mobility. For ‘N’ number of PEVs in the given active distribution network, let ‘L’ number of PEVs are not available at plug point. Hence ‘N-L’ many PEVs are currently available for grid support. As next levels of eliminating PEVs from grid support, the following steps are followed in order to schedule the storage with future perspective.

1. Identify the storage units (ESU and PEV) to participate in grid support, available PEVs are accounted (from mobility model).
2. ESUs that are within SoC limits are taken into consideration.
3. PEVs that are about to leave immediately are preferred for charging mode and those are about to stay long at plug point are chosen to operate discharge mode.
4. The units that are outside the SoC limits are eliminated.
5. In case of excess storage capacity, the storage units eliminated based on SoC levels while DoD is reduced for those that are participating.
6. If the required storage capacity is lesser than the available capacity (for charging/discharging), then next level of filtering will be initiated through step 2.

6.2 Regulation Up/Down by PEV

Slack bus is intended to supply power to distribution network at a specified value. It is very important to reduce the deviations in power drawing from slack bus (P-slack) by the distribution network from a specified value to reduce overall spinning reserves. In an active distribution network, the aggregate power demand shown in Figure 9(a). The power demand is estimated in terms of energy demand in order to easily evaluate the energy requirement from electric vehicles' storage units. The energy demand is shown in Figure 9(b). In Figure 9(c), energy requirement is shown. Here, positive values (above specified value) indicates discharging mode of operation is to be initiated by storage units and charging mode of operation is required in the opposite case (below

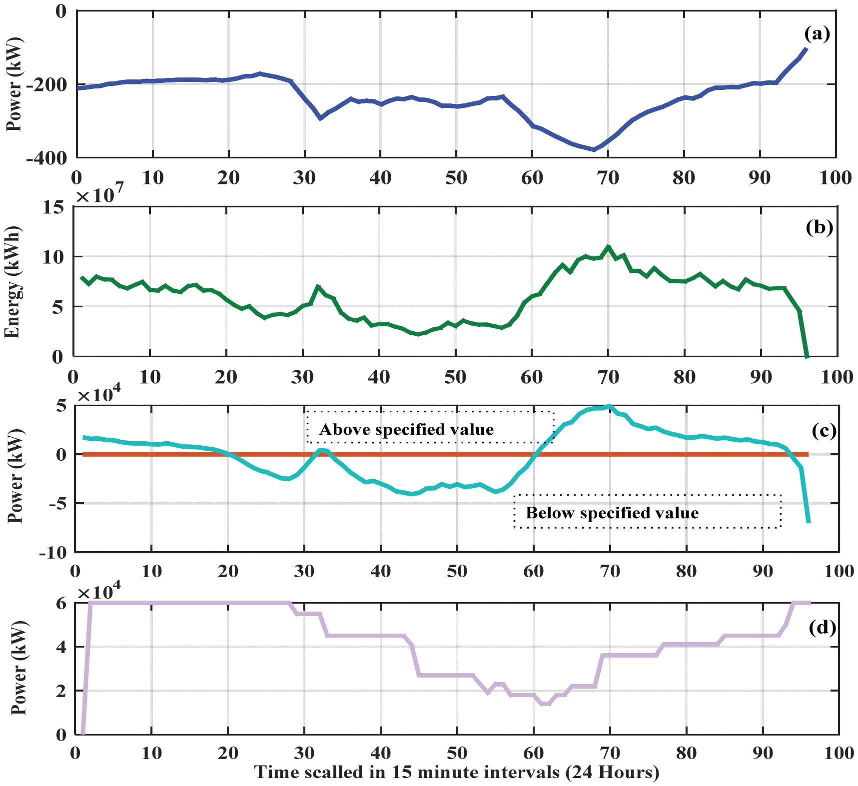

Figure 9 The estimation for the following day in terms of Power and Energy demand (a) Load demand (b) Energy Demand (c) Deviation in Power from specified value (d) Expected available power from PEVs.

specified value). Depending on whether available storage capacity is more or less than required, utility operator has to take decision on choosing or prioritizing storage units (PEV and ESS) in order to bring out optimal usage of available storage capacity. The aggregated power available from vehicle's storage can be estimated from their mobility model which is shown in Figure 9(d).

Once the energy requirement is estimated, the available storage capacity (charging/discharging) is to be calculated by following all the battery constraints. Flowchart in Figure 10 represents step by step procedure to commit the PEV units for grid support. Coefficients 'p' represents ratio between energy available ($\mathrm{E}_{\mathrm{bal}}^{\mathrm{t}}$) and specified energy ($\mathrm{E}_{\mathrm{sep}}^{\mathrm{day}}$) whereas 'q' represents ratio between Energy available ($\mathrm{E}_{\mathrm{savail}}^{\mathrm{t}}$) with storage units and storage capacity needed ($\mathrm{E}_{\mathrm{sneed}}^{\mathrm{t}}$) during time interval 't'.

$$\mathrm{p} = \frac{\mathrm{E}_{\mathrm{bal}}^{\mathrm{t}}}{\mathrm{E}_{\mathrm{sep}}^{\mathrm{day}}}; \qquad \mathrm{q} = \frac{\mathrm{E}_{\mathrm{savail}}^{\mathrm{t}}}{\mathrm{E}_{\mathrm{sneed}}^{\mathrm{day}}}$$

6.3 Storage Unit Commitment for Grid Support

It is assumed that PEV owner is in agreement with DSO and will follow the policy regulations. In the process of selecting or eliminating PEVs for grid support, the steps discussed earlier are followed (Figure 10). The ratio 'p' decides charging or discharging operation ('$p>1$ indicates Discharging (V2G) and '$p<1$' indicates charging (G2V)') and ratio 'q' decides whether storage capacity available with PEVs is excess or deficit for grid support ('$q>1$' indicates excess whereas '$q<1$' indicates deficit).

6.4 Battery Constraints and Revenue for PEV Owner

Constraints that are involved in PEVs prioritization are shown in below Equations (3, 4) and revenue obtained by customer through participation in regulation support is represented by 'r' (\$/kWh) in Equation (6) [134].

$$\mathrm{SoC}_{\mathrm{min}} \leq \mathrm{SoC}(\mathrm{t}) \leq \mathrm{SoC}_{\mathrm{max}}, \tag{3}$$

$$\mathrm{P}_{\mathrm{rate}}^{\mathrm{min}} \leq \mathrm{P}_{\mathrm{rate}}(\mathrm{t}) \leq \mathrm{P}_{\mathrm{rate}}^{\mathrm{max}} \tag{4}$$

$$|\mathrm{P}_{\mathrm{rate}}(\mathrm{t}-1) - \mathrm{P}_{\mathrm{rate}}(\mathrm{t})| \leq \mathrm{P}_{\mathrm{rate}}^{\mathrm{dif}} \tag{5}$$

$$\mathrm{r} = \mathrm{p}_{\mathrm{cap}}\mathrm{Pt}_{\mathrm{plug}} + \mathrm{p}_{\mathrm{el}}\mathrm{PE}_{\mathrm{disp}} \tag{6}$$

$$\text{Here } \mathrm{E}_{\mathrm{disp}} = \sum_{\mathrm{i}=1}^{\mathrm{N}_{\mathrm{disp}}} \mathrm{P}_{\mathrm{disp}}\mathrm{t}_{\mathrm{disp}}$$

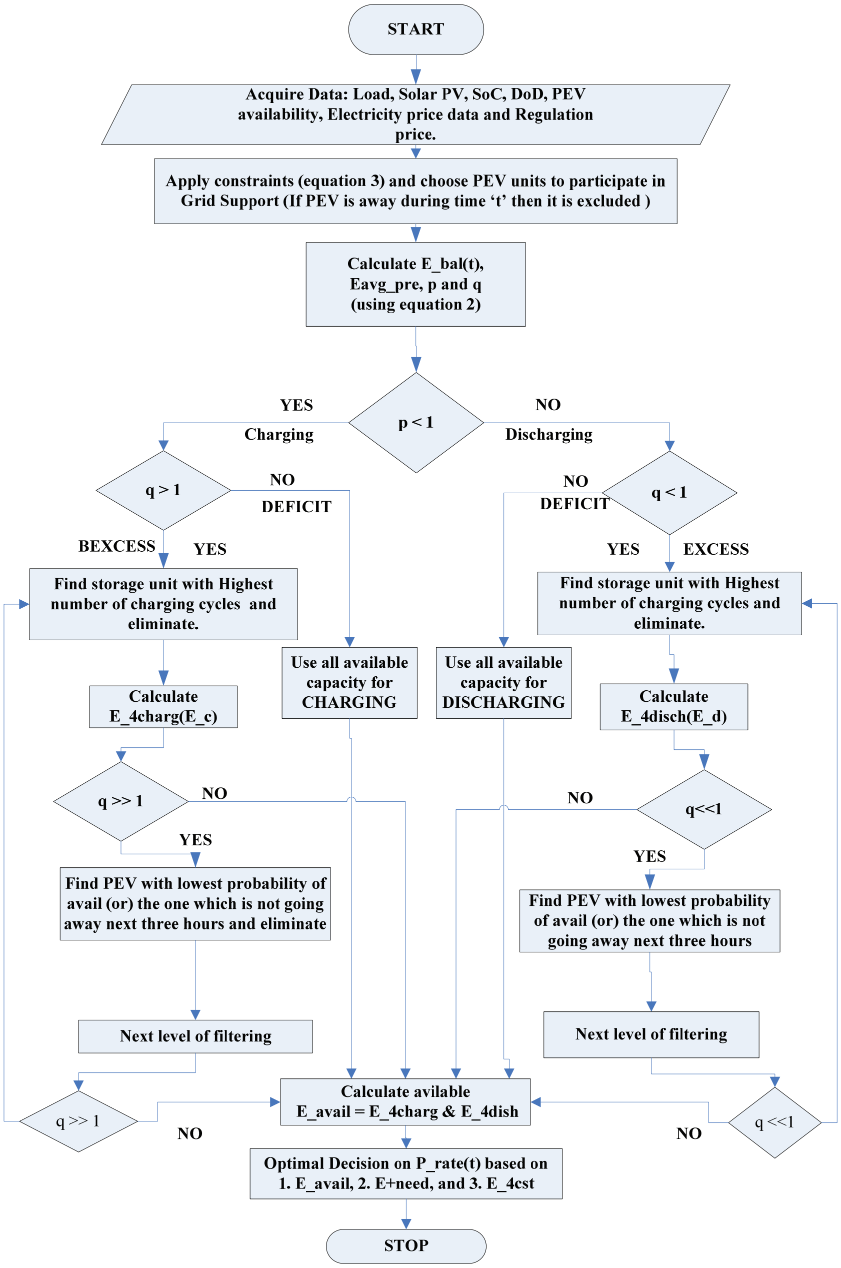

Figure 10 PEV prioritization for grid support.

Here SoC (t) state of charge and P(t) is power rate of a given PEV during time interval ‘t’ in kWh and kW respectively, $\mathrm{p_{el}}$ is market rate of electricity \$/kWh, $\mathrm{P_{disp}}$ is power dispatched in kW, $\mathrm{t_{disp}}$ is dispatch duration in hours and $\mathrm{E_{disp}}$ is energy dispatched in kWh. $\mathrm{P_{rate}^{dif}}$ is step change in power rate, $\mathrm{P_{rate}^{max}}$ and $\mathrm{P_{rate}^{min}}$ are maximum and minimum power rates, and Prate (t) denotes power rate during interval ‘t’.

In order to encourage owners of PEV to participate in grid ancillary support, utility operator should ensure customer revenue maximization. PEVs which are in authentication DSO for grid support are assumed to be under utility operator control. Utility operator will take decision on prioritization and setting charging or discharging rates depending on grid requirements. While analysing revenue for the customer too many factors will come into picture: Storage cost, degradation cost, Depth-of-Discharge (DoD), battery replacement cost, electricity price and regulation price etc. Regulation price is money paid to PEV owner for participation in grid support in \$/KWh. In broadened sense, PEV storage utilization cannot be a single objective rather it involves multiple objectives while maximizing its utilization for grid support. Keeping in mind that prime purpose of PEV is to travel; the second main objective from customer point of view is to maximize revenue or to minimize electricity cost. On behalf of agreement, utility operator has to ensure that there is a flexible trade off among all the objectives that are associated with grid ancillary support maximization.

For the scenario considered in this paper, Figure 11(a) shows impact of PEV coordination (through any proposed strategy) on P-slack deviations from a specified value. In case of without PEV support, impact of unscheduled PEV’s charging is aiding to increase slack bus power deviation. Impact of uncoordinated PEV could be a leading cause for power system instability if huge number of PEVs is integrated in to the distribution network. As an example case, slack bus power flattening is discussed in this paper to demonstrate strategic scheduling of PEVs and its effect on main grid. The histogram representation is shown in Figures 11(a) and (b) for with and with control strategy respectively. It can be seen that in proposed case, the slack bus power is almost around 60 to 80 kW whereas in uncoordinated case, it is scattered between 30 kW and 85 kW. However, the flattening of load curve depends on available power from PEVs. The grid specified power (65 kW) is taken as the load dispatch setting from the main grid which may vary time to time. Meeting this specified power helps in reducing spinning reserves.

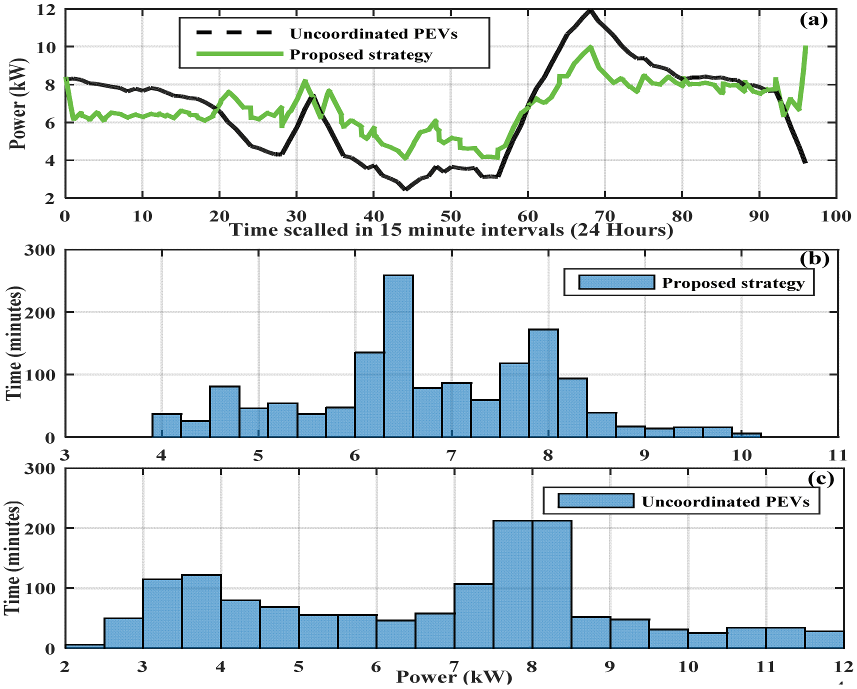

Figure 11 Comparison of power drawn from grid (a) with and without PEVs coordination (b) Deviation of power from specified value without PEV coordination and (c) Deviation of power from specified value with PEV coordination.

In case of vehicle prioritization for grid support it is possible to maximize the usage of storage capacity and to minimize the Cost-of-Charging (CoC). Here, the benefit to the utility can be observed from Figure 12(a) in terms of load flattening. It indirectly reduces the burden on transformer. In Figure 12(b), the aggregate vehicle's power availability for grid support is shown. In Figure 12(c), the cost paid by the customer in view of regulation support is shown. Here, the term Laxity refers to the time lapse for an electric vehicle to participate in grid support. The cost paid for PEV charging with and without consideration of electricity price and revenue is presented in Figure 12(c). Here, the *–ve* sign indicates that the customer is getting revenue out of grid support participation which also includes battery degradation cost. The vehicles 12 and 13 are not gained any profit rather they paid for charging unlike others. The reason is that they are not present at plug point during low electricity price in charging case or during peak price in discharging case.

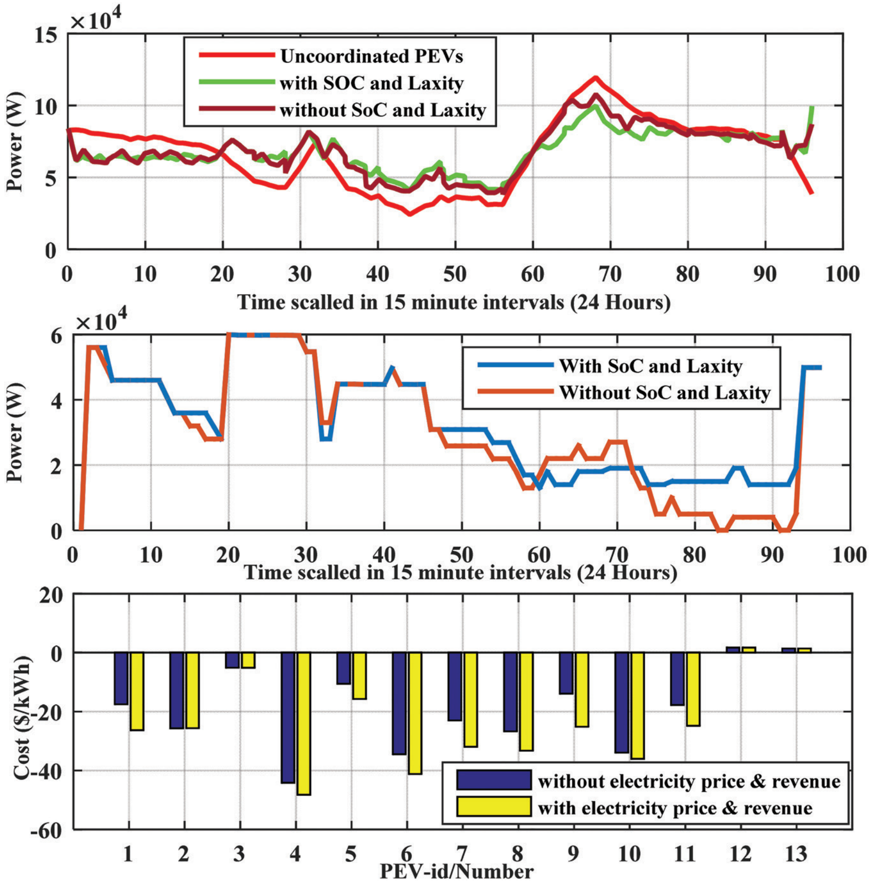

Figure 12 (a) Comparison of power and cost with and without SoC and Laxity consideration in prioritization (a) Power drawn from grid (b) Aggregated power available with PEVs and (c) Costa paid by PEV owner with and without consideration of electricity price and revenue.

Also the SoC is not with allowable limits to participate in grid support. However, consideration of revenue maximization will not affect utility need as energy dispatched is not dependant on PEVs priority.

In this article, a smart energy management strategy is presented for scheduling PEVs charging and discharging. Based on day ahead forecast power demand and solar PV power generation, charging (-ve) and discharging (+ve) zones are identified. From PEV availability model, available power, power requirement for charging the vehicle and laxity are estimated. Each zone is considered individually for optimum power dispatch among the time intervals included in that zone. Let N be the number of zone and M be the number of time intervals in each zone on a given day. Four cases will arise depending on type of zone (charging/discharging), energy need and energy availability. Let E_{need}^{z} and $E_{avail}^{z,pev,ch}$ be the energy need for load flattening in eah zone and available energy from all electric vehicles.

Case 1: Discharging zone & $\mathrm{E_{need}^{z}} \leq \mathrm{E_{avail}^{z,pev,ch}}$

In this case, energy need is less than what is available during zone period. However, power availability cannot be predicted in advance as it depends on SoC and Laxity of PEV. So, there must be some prioritization process through which we can maximize the effective utilization of available energy. Higher SoC vehicles can be given highest priority and vice-versa. If lowest SoC vehicle is used at early intervals of a give zone and once it exceeds SoC limits ($<$0.2) then PEV will be excluded from the grid support. Hence, though the available energy is more than what is needed, aggregated power from PEVs at given time interval may not be sufficient. Vehicle which is about to leave will be considered as a load and hence available capacity get reduced by its power rate.

Case 2: Discharging zone & $\mathrm{E_{need}^{z}} \geq \mathrm{E_{avail}^{z,pev,ch}}$

As discussed in case 1, vehicle charging load will be added up to increase need in energy demand. Available energy is distributed among all the intervals based on energy needed. Priority of PEVs does not hold any importance during the interval where available power with PEVs is less than what is needed. If any interval has excessive power available then prioritization need to be carried out.

Case 3: Charging zone & $\mathrm{E_{need}^{z}} \leq \mathrm{E_{avail}^{z,pev,ch}}$

Vehicles that are about to leave will be assigned highest priority based on their Laxity and time of charging. Though the energy need is less than what is available, vehicle charging for trip purpose cannot be avoided. So, there is a chance that power drawn from grid exceeds the specified value. This can be avoided by prioritizing PEVs based on SoC also. In this case, if vehicle with higher SoC is used during early intervals of given zone and if it exceeds SoC limit ($>$0.8) then that PEV power rate will be discounted for grid support.

Case 4: Charging zone & $\mathrm{E_{need}^{z}} \geq \mathrm{E_{avail}^{z,pev,ch}}$

As discussed in case 3, vehicles about to go for trip will be assigned for charging according to trip timing requirements. However, WFA will dispatch the available energy based on trip requirements by all PEVs and prioritization will later considers starting time for charging to avoid power deficit in each interval.

7 Conclusion

Smart Grid technological advancements brought many changes in the legacy grid with integration of heterogeneous entities, which are eventually creating a complex power system network. Along with the proliferation of technological implementations mainly ICT, there is a need for sophisticated monitoring control over the network operations to make the grid really smart enough to deal with contingencies. Rapid global inclination towards cleaner energy generation (RES) has brought challenges and issues with their uncertainty nature. In this article, advantages and challenges in the present era smart grid are discussed. Storage capacity available with PEV which are in idle condition can be utilized for grid regulation activities. But this requires sophisticated technology support. With the advent of SG technologies, PEV can be monitored and scheduled by utility operator depending on grid conditions and owner's flexibility. In this paper, issues and challenges due to integration of heterogeneous entities like RES, PEV, are MG is discussed. PEV role and its usage as storage for grid ancillary support are discussed in detail. As a case study, effective utilization of PEVs to mitigate solar and load demand fluctuations is presented. Operational challenges pertaining to micro grid operations and smart home management are also presented.

References

[1] Projected growth in CO_2 emissions driven by countries outside the OECD, (2016). http://www.eia.gov/todayinenergy/detail.php?id=26252/.

[2] Renewables Global Status Report (2016). http://www.ren21.net/status-of-renewables/global-status-report.

[3] Nguyen, H. K., Song, J. B., and Han, Z. (2015). Distributed demand side management with energy storage in smart grid. *IEEE Transactions on Parallel and Distributed Systems*, 26(12), 3346–3357.

[4] Ma, J., et al. (2014). Incentive mechanism for demand side management in Smart grid using auction. *IEEE Transactions on Smart Grid*, 5(3), 1379–1388.

[5] Su, C., et al. (2014). An adaptive control strategy of converter based DG to maintain protection coordination in distribution system. *Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, IEEE.

[6] Malekpour, A. R., Pahwa, A., and Natarajan, B. (2014). Distributed volt/var control in unbalanced distribution systems with distributed generation. In *IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG),* (pp. 1–6). IEEE.

[7] Lund, H. (2007). Renewable energy strategies for sustainable development. *Energy*, 32(6), 912–919.

[8] Yan, Y., et al. (2013). A survey on Smart grid communication infrastructures: Motivations, requirements and challenges. *IEEE Communications Surveys & Tutorials*, 15(1), 5–20.

[9] Bhatia, R. K., and Varsha Bodade. (2014). Smart grid Security and Privacy: Challenges Literature Survey and Issues. *IJARCSSE* 4(1).

[10] Su, W., et al. (2012). A survey on the electrification of transportation in a Smart grid environment. *IEEE Transactions on Industrial Informatics*, 8(1), 1–10.

[11] Fang, X., et al. (2012). Smart grid-The new and improved power grid: A survey. *IEEE Communications Surveys & Tutorials*, 14(4), 944–980.

[12] Meliopoulos, A. S., et al. (2011). Smart grid technologies for autonomous operation and control. *IEEE Transactions on Smart Grid*, 2(1), 1–10.

[13] Rathnayaka, R. M. J., and Hemapala, K. T. M. U. (2016). Developing of scalable SCADA in view of acquiring multi-protocol Smart grid devices. *2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB),* IEEE.

[14] Rendon, A., C. R. Fuerte, J. G. Calderon (2015). State Estimation of Electrical Power Grids Incorporating SCADA and PMU Measurements. *IEEE Latin America Transactions*, 13(7), 2245–51.

[15] Gungor, V. C., et al. (2011). Smart grid technologies: Communication technologies and standards. *IEEE Transactions on Industrial Informatics*, 7(4), 529–539.

[16] Jin, C., and Thomas K. (2011). Smart home networking: Combining wireless and powerline networking. In *7th International Wireless Communications and Mobile Computing Conference (IWCMC)*, IEEE.

[17] Mlynek, P., Misurec, J., Kolka, Z., Slacik, J., and Fujdiak, R. (2015). Narrowband power line communication for smart metering and street lighting control. *IFAC-PapersOnLine*, 48(4), 215–219.

[18] Hsieh, S. C., Ku, T. T., Chen, C. S., Lin, C. H., and Tsai, J. C. (2015). Broadcasting control of intelligent air conditioners using power-line-carrier technology. *IEEE Transactions on Industry Applications*, 51(2), 1890–1896.

[19] Habib, A., and Saiedian, H. (2002). Channelized voice over digital subscriber line. *IEEE Communications Magazine*, 40(10), 94–100.

[20] Gungor, V. C., et al. (2011). Smart grid technologies: Communication technologies and standards. *IEEE Transactions on Industrial Informatics*, 7(4), 529–539.

[21] Parikh, P. P., Kanabar, M. G., and Sidhu, T. S. (2010). Opportunities and challenges of wireless communication technologies for Smart grid applications. *Power and Energy Society General Meeting*, IEEE.

[22] Li, Z., and Liang, Q. (2016). Capacity Optimization in Heterogeneous Home Area Networks With Application to Smart Grid. *IEEE Trans. Vehicular Technology*, 65(2), 699–706.

[23] Kailas, A., Cecchi, V., and Mukherjee, A. (2012). A survey of communications and networking technologies for energy management in buildings and home automation. *Journal of Computer Networks and Communications*.

[24] Fan, Z., Haines, R., and Kulkarni, P. (2014). M2M communications for E-health and smart grid: an industry and standard perspective. *IEEE Wireless Communications*, 21(1), 62–69.

[25] Kalalas, C., Thrybom, L., and Alonso-Zarate, J. (2016). Cellular communications for smart grid neighborhood area networks: A survey. *IEEE Access*, 4, 1469–1493.

[26] Usman, A., and Shami, S. H. (2013). Evolution of communication technologies for smart grid applications. *Renewable and Sustainable Energy Reviews*, 19, 191–199.

[27] Yi, P., Iwayemi, A., and Zhou, C. (2011). Developing ZigBee deployment guideline under WiFi interference for smart grid applications. *IEEE Transactions on Smart Grid*, 2(1), 110–120.

[28] Abdullah, M. M., and Dwolatzky, B. (2009). Smart demand-side energy management based on cellular technology-a way towards Smart Grid technologies in africa and low budget economies. In *AFRICON, 2009. AFRICON'09*. (pp. 1–5). IEEE.

[29] Niu, Y, et al. (2015). Exploiting device-to-device communications in joint scheduling of access and backhaul for mm Wave small cells. *IEEE Journal on Selected Areas in Communications*, 33(10), 2052–2069.

[30] Ahmed, M. H. U., Alam, M. G. R., Kamal, R., Hong, C. S., and Lee, S. (2012). Smart grid cooperative communication with smart relay. *Journal of Communications and Networks*, 14(6), 640–652.

[31] Ustun, T. S., et al. (2013). An adaptive microgrid protection scheme based on a wide-area Smart grid communications network. *Latin-America Conference on Communications (LATINCOM)*, IEEE.

[32] Nafi, N. S., et al. (2014). A novel Zigbee based pilot protection scheme for smart distribution grid. *Telecommunication Networks and Applications Conference (ATNAC), Australasian*. (pp. 146–151), IEEE.

[33] Khan, R. H., and Khan, J. Y. (2012). Wide area PMU communication over a WiMAX network in the smart grid. In *2012 IEEE Third International Conference on Smart Grid Communications (Smart Grid Comm),* (pp. 187–192). IEEE.

[34] Yadav, S. A., Kumar, S. R., Sharma, S., and Singh, A. (2016). A review of possibilities and solutions of cyber attacks in smart grids. In *2016 International Conference on Innovation and Challenges in Cyber Security (ICICCS-INBUSH),* (pp. 60–63). IEEE.

[35] Komninos, N., Philippou, E., and Pitsillides, A. (2014). Survey in smart grid and smart home security: Issues, challenges and countermeasures. *IEEE Communications Surveys and Tutorials*, 16(4), 1933–1954.

[36] Sanjab, A., and Saad, W. (2016). Data injection attacks on Smart grids with multiple adversaries: A game-theoretic perspective. *IEEE Transactions on Smart Grid*, 7(4), 2038–2049.

[37] Farraj, A. K., et al. (2014). A game-theoretic control approach to mitigate cyber switching attacks in Smart grid systems. *IEEE International Conference on Smart Grid Communications (Smart Grid Comm),* IEEE.

[38] Kim, J. C., Cho, S. M., and Shin, H. S. (2013). Advanced power distribution system configuration for smart grid. *IEEE Transactions on Smart Grid*, 4(1), 353–358.

[39] Junjie, M. A., Yulong, W., and Yang, L. (2012). Size and location of distributed generation in distribution system based on immune algorithm. *Systems Engineering Procedia*, 4, 124–132.

[40] Zhan, H., et al. (2016), Relay protection coordination integrated optimal placement and sizing of distributed generation sources in distribution networks. *IEEE Transactions on Smart Grid*, 7(1), 55–65.

[41] Bhumkittipich, K., and Weerachai P. (2013). Optimal placement and sizing of distributed generation for power loss reduction using particle swarm optimization. *Energy Procedia*, 34, 307–317.

[42] Nekooei, K., et al. (2013). An improved multi-objective harmony search for optimal placement of DGs in distribution systems. *IEEE Transactions on Smart Grid*, 4(1), 557–567.

[43] Wang, Z., et al. (2014). Robust optimization based optimal DG placement in microgrids. *IEEE Transactions on Smart Grid*, 5(5), 2173–2182.

[44] Esmaili, A., et al. (2013). A hybrid system of Li-Ion capacitors and flow battery for dynamic wind energy support. *IEEE Transactions on Industry Applications*, 49(4), 1649–1657.

[45] L'Abbate, A., Fulli, G., Starr, F., and Peteves, S. D. (2007). Distributed Power Generation in Europe: technical issues for further integration. *Joint Research Center Institute for Energy*. www.CaRBoN WaRRooM.CoM

[46] Serban, E., Ordonez, M., Pondiche, C., Feng, K., Anun, M., and Servati, P. (2016). Power management control strategy in photovoltaic and energy storage for off-grid power systems. In *IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG),* (pp. 1–8). IEEE.

[47] Howlader, A. M., Urasaki, N., and Saber, A. Y. (2014). Control strategies for wind-farm-based smart grid system. *IEEE Transactions on Industry Applications*, 50(5), 3591–3601.

[48] Reddy, S. S., and Momoh, J. A. (2015). Realistic and transparent optimum scheduling strategy for hybrid power system. *IEEE Transactions on Smart Grid*, 6(6), 3114–3125.

[49] Mortazavi, H., Mehrjerdi, H., Saad, M., Lefebvre, S., Asber, D., and Lenoir, L. (2015). A monitoring technique for reversed power flow detection with high PV penetration level. *IEEE Transactions on Smart Grid*, 6(5), 2221–2232.

[50] Scott, N. C., Atkinson, D. J., and Morrell, J. E. (2002). Use of load control to regulate voltage on distribution networks with embedded generation. *IEEE Transactions on Power Systems*, 17(2), 510–515.

[51] Al-Sabounchi, A., Gow, J., Al-Akaidi, M., and Al-Thani, H. (2011). Optimal sizing and location of a PV system on three-phase unbalanced radial distribution feeder avoiding reverse power flow. In *Electrical Power and Energy Conference (EPEC),* (pp. 74–79). IEEE.

[52] Oshiro, M., et al. (2011). Optimal voltage control in distribution systems using PV generators. *International Journal of Electrical Power & Energy Systems*, 33(3), 485–492.

[53] Celebi, E., and Fuller, J. D. (2012). Time-of-use pricing in electricity markets under different market structures. *IEEE Transactions on Power Systems*, 27(3), 1170.

[54] Ma, Jinghuan, et al. (2016). Residential load scheduling in Smart grid: A cost efficiency perspective. *IEEE Transactions on Smart Grid* 7(2), 771–784.

[55] Palensky, P., and Dietmar D. (2011). Demand side management: Demand response, intelligent energy systems, and smart loads. *IEEE Transactions on Industrial Informatics*, 7(3), 381–388.

[56] Sioshansi, R. (2010). Evaluating the impacts of real-time pricing on the cost and value of wind generation. *IEEE Transactions on Power Systems*, 25(2), 741–748.

[57] Yoon, J. H., Baldick, R., and Novoselac, A. (2014). Dynamic demand response controller based on real-time retail price for residential buildings. *IEEE Transactions on Smart Grid*, 5(1), 121–129.

[58] Roozbehani, M., Dahleh, M. A., and Mitter, S. K. (2012). Volatility of power grids under real-time pricing. *IEEE Transactions on Power Systems*, 27(4), 1926–1940.

[59] Saad, W., et al. (2012). Game-theoretic methods for the Smart grid: An overview of microgrid systems, demand-side management, and Smart grid communications. *IEEE Signal Processing Magazine*, 29(5), 86–105.

[60] Cecati, C., et al. (2013). Optimal operation of Smart grids with demand side management. *IEEE International Conference on Industrial Technology (ICIT)*, IEEE.

[61] Logenthiran, T., Srinivasan, D., and Shun, T. Z. (2012). Demand side management in smart grid using heuristic optimization. *IEEE Transactions on Smart Grid*, 3(3), 1244–1252.

[62] Davito, B., Tai, H., and Uhlaner, R. (2010). The smart grid and the promise of demand-side management. *McKinsey on Smart Grid*, 3, 8–44.

[63] Karden, E., Ploumen, S., Fricke, B., Miller, T., and Snyder, K. (2007). Energy storage devices for future hybrid electric vehicles. *Journal of Power Sources*, 168(1), 2–11.

[64] Tomiæ, J., and Willett K. (2007). Using fleets of electric-drive vehicles for grid support. *Journal of Power Sources*, 168(2), 459–468.

[65] Haddadian, G., et al. (2015). "Optimal scheduling of distributed battery storage for enhancing the security and the economics of electric

power systems with emission constraints." *Electric Power Systems Research* 124, 152–159.

[66] Turker, H., and Seddik B. (2014). Smart Charging of Plug-in Electric Vehicles (PEVs) in Residential Areas: Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) Concepts. *International Journal of Renewable Energy Research*, 4(4), 859–871.

[67] Mou, Y., et al. (2015). Decentralized optimal demand-side management for PHEV charging in a Smart grid. *IEEE Transactions on Smart Grid*, 6(2), 726–736.

[68] Akhavan-Rezai, E., et al (2016). Online intelligent demand management of plug-in electric vehicles in future smart parking lots. *IEEE Systems Journal*, 10(2), 483–494.

[69] Agrawal, A., Kumar, M., Prajapati, D. K., Singh, M., and Kumar, P. (2014). Smart public transit system using an energy storage system and its coordination with a distribution grid. *IEEE Transactions on Intelligent Transportation Systems*, 15(4), 1622–1632.

[70] Xu, X., Bishop, M., Oikarinen, D. G., and Hao, C. (2016). Application and modeling of battery energy storage in power systems. *CSEE Journal of Power and Energy Systems*, 2(3), 82–90.

[71] Khayyam, H., Ranjbarzadeh, H., and Marano, V. (2012). Intelligent control of vehicle to grid power. *Journal of Power Sources*, 201, 1–9.

[72] Ding, L., et al. (2012). The optimal allocation of pumped storage station in wind farm. Power and Energy Engineering Conference (APPEEC), *Asia-Pacific*. IEEE.

[73] Sechilariu, M., Baochao W., and Fabrice L. (2013). Building integrated photovoltaic system with energy storage and Smart grid communication. *IEEE Transactions on Industrial Electronics*, 60(4), 1607–1618.

[74] Atia, R., and Noboru Y. (2016). Sizing and analysis of renewable energy and battery systems in residential microgrids. *IEEE Transactions on Smart Grid*, 7(3), 1204–1213.

[75] Perez, F., Custódio, J. F., de Souza, V. G., Ribeiro Filho, H. K., Motoki, E. M., and Ribeiro, P. F. (2015). Application of energy storage elements on a PV system in the smart grid context. In *Innovative Smart Grid Technologies Latin America (ISGT LATAM),* (pp. 751–756). IEEE.

[76] Schweppe, F. C., and Wildes, J. (1970). Power system static-state estimation, Part I: Exact model. *IEEE Transactions on Power Apparatus and Systems*, 1, 120–125.

[77] Leite, J. B., and Mantovani, J. R. S. (2016). Distribution system state estimation using the Hamiltonian cycle theory. *IEEE Transactions on Smart Grid*, 7(1), 366–375.

[78] De Oliveira-De Jesus, P. M., and Quintana, A. A. R. (2015). Distribution system state estimation model using a reduced quasi-symmetric impedance matrix. *IEEE Transactions on Power Systems*, 30(6), 2856–2866.

[79] Muscas, C., et al. (2014). Effects of Measurements and Pseudo measurements Correlation in Distribution System State Estimation. *IEEE Trans. Instrumentation and Measurement*, 63(12), 2813–2823.

[80] Haughton, D. A., and Gerald, T. H. (2013). A linear state estimation formulation for smart distribution systems. *IEEE Transactions on Power Systems*, 28(2), 1187–1195.

[81] Manitsas, E., et al. (2012). Distribution system state estimation using an artificial neural network approach for pseudo measurement modelling. *IEEE Transactions on Power Systems*, 27(4), 1888–1896.

[82] Singh, R., et al. (2010). A recursive Bayesian approach for identification of network configuration changes in distribution system state estimation. *IEEE Transactions on Power Systems*, 25(3), 1329–1336.

[83] Coster, E. J., Myrzik, J. M., Kruimer, B., and Kling, W. L. (2011). Integration issues of distributed generation in distribution grids. *Proceedings of the IEEE*, 99(1), 28–39.

[84] Kim, I., and Ronald, G. H. (2016). A study on the effect of distributed generation on short-circuits current. *Power Systems Conference (PSC)*, Clemson University. IEEE.

[85] Zayandehroodi, H., Mohamed, A., Shareef, H., Mohammadjafari, M., and Farhoodnea, M. (2012). A novel protection coordination strategy using back tracking algorithm for distribution systems with high penetration of DG. In *Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia* (pp. 187–192). IEEE.

[86] Javadian, S. A. M., Haghifam, M. R., and Rezaei, N. (2009). A fault location and protection scheme for distribution systems in presence of dg using MLP neural networks. In *Power and Energy Society General Meeting*, PES'09. IEEE (pp. 1–8). IEEE.

[87] Mahat, P., et al. (2011). A Simple Adaptive Overcurrent Protection of Distribution Systems with Distributed Generation. *IEEE Trans. Smart Grid*, 2(3), 428–437.

[88] Kumar, D. S., Srinivasan, D., and Reindl, T. (2016). A fast and scalable protection scheme for distribution networks with distributed generation. *IEEE Transactions on Power Delivery*, 31(1), 67–75.

[89] Zhan, H., et al. (2016). Relay protection coordination integrated optimal placement and sizing of distributed generation sources in distribution networks. *IEEE Transactions on Smart Grid*, 7(1), 55–65.

[90] Gil, N. J., and Lopes, J. P. (2007). Hierarchical frequency control scheme for islanded multi-microgrids operation. *In Power Tech, IEEE Lausanne* (pp. 473–478). IEEE.

[91] Haj-ahmed, M. A., and Illindala, M. S. (2014). The influence of inverter-based DGs and their controllers on distribution network protection. *IEEE Transactions on Industry Applications*, 50(4), 2928–2937.

[92] Chen, Z., Lei W., and Yong F. (2012). Real-time price-based demand response management for residential appliances via stochastic optimization and robust optimization. *IEEE Transactions on Smart Grid*, 3(4), 1822–1831.

[93] Chen, Z., and Lei W. (2013). Residential appliance DR energy management with electric privacy protection by online stochastic optimization. *IEEE Transactions on Smart Grid*, 4(4),1861–1869.

[94] Mohsenian-Rad, A. H., and Leon-Garcia A. (2010). Optimal residential load control with price prediction in real-time electricity pricing environments. *IEEE Trans. Smart Grid*, 1(2), 120–133.

[95] Kondoh, J., Lu, N., and Hammerstrom, D. J. (2011). An evaluation of the water heater load potential for providing regulation service. In *Power and Energy Society General Meeting*, (pp. 1–8). IEEE.

[96] Pan, M. S., and Chen, C. J. (2016). Intuitive control on electric devices by smartphones for smart home environments. *IEEE Sensors Journal* 16(11), 4281–4294.

[97] Jiang, Q., Meidong X., and Geng, G. (2013). Energy management of microgrid in grid-connected and stand-alone modes. *IEEE Trans. Power Syst.* 28(3), 3380–3389.

[98] Bevrani, H., Mohammad, R. F., and Ataee, S. (2016). Robust Frequency Control in an Islanded Microgrid: $\{H\}\_\{\infty\}$ and μ-Synthesis Approaches. *IEEE transactions on Smart Grid*, 7(2), 706–717.

[99] Lu, L. Y., and Chu, C. C. (2015). Consensus-based secondary frequency and voltage droop control of virtual synchronous generators for isolated AC micro-grids. *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, 5(3), 443–455.

[100] Nourollah, S., Pirayesh, A., and Aminifar, F. (2016). Combinational scheme for voltage and frequency recovery in an islanded distribution system. *IET Generation, Transmission and Distribution*, 10(12), 2899–2906.

[101] Lu, L. Y., and Chu, C. C. (2015). Consensus-based secondary frequency and voltage droop control of virtual synchronous generators for isolated AC micro-grids. *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, 5(3), 443–455.

[102] Nourollah, S., Pirayesh, A., and Aminifar, F. (2016). Combinational scheme for voltage and frequency recovery in an islanded distribution system. *IET Generation, Transmission and Distribution*, 10(12), 2899–2906.

[103] Hajimiragha, A. H., Zadeh, M. R. D., and Moazeni, S. (2015). Microgrids frequency control considerations within the framework of the optimal generation scheduling problem. *IEEE Transactions on Smart Grid*, 6(2), 534–547.

[104] Lopes, J. P., et al. (2010). Identification of control and management strategies for LV unbalanced microgrids with plugged-in electric vehicles. *Electric Power Systems Research*, 80(8), 898–906.

[105] Clement-Nyns, K., Haesen, E., and Driesen, J. (2011). The impact of vehicle-to-grid on the distribution grid. *Electric Power Systems Research*, 81(1), 185–192.

[106] Jin, Z., et al. (2016). Next-generation shipboard dc power system: Introduction Smart grid and dc microgrid technologies into maritime electrical networks. *IEEE Electrification Magazine*, 4(2), 45–57.

[107] Loh, P. C., et al. (2013). Autonomous operation of hybrid microgrid with AC and DC sub grids. *IEEE Transactions on Power Electronics*, 28(5), 2214–2223.

[108] Liu, X., Wang, P. and Loh, P. C. (2011). A Hybrid AC/DC Microgrid and Its Coordination Control. *IEEE Trans. Smart Grid*, 2(2), 278–286.

[109] Che, L., et al. (2015). Hierarchical coordination of a community microgrid with AC and DC microgrids. *IEEE Transactions on Smart Grid*, 6(6), 3042–3051.

[110] Menniti, D., et al. (2014). In the future smart cities: coordination of micro Smart grids in a virtual energy district. *International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, (pp. 676–682), IEEE.

[111] Jamshidi, M. O. (2008). System of systems engineering-New challenges for the 21st century. *IEEE Aerospace and Electronic Systems Magazine*, 23(5), 4–19.

[112] Thale, S. S., and Agarwal, V. (2016). Controller area network assisted grid synchronization of a microgrid with renewable energy sources and storage. *IEEE Transactions on Smart Grid*, 7(3), 1442–1452.

[113] Hong, Y. Y., et al. (2015). Synchronisation of weak microgrid with bulk power system. *Electronics Letters*, 51(18), 1449–1451.

[114] Association internationale pour l'évaluation du rendement scolaire. Global EV outlook 2016: Beyond one million electric cars. OECD Publishing, 2016.

[115] Khushalani, S., Solanki, J. M., and Schulz, N. N. (2007). Development of three-phase unbalanced power flow using PV and PQ models for distributed generation and study of the impact of DG models. *IEEE Transactions on Power Systems*, 22(3), 1019–1025.

[116] Deilami, S., et al. (2011). Real-time coordination of plug-in electric vehicle charging in Smart grids to minimize power losses and improve voltage profile. *IEEE Transactions on Smart Grid*, 2(3), 456–467.

[117] Clement-Nyns, K., Haesen, E., and Driesen, J. (2010). The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE Transactions on Power Systems*, 25(1), 371–380.

[118] Huang, S., and Infield, D. (2010). The impact of domestic Plug-in Hybrid Electric Vehicles on power distribution system loads. *International Conference on Power System Technology (POWERCON)*, (pp. 1–7), IEEE.

[119] Padilha-Feltrin, A., Rodezno, D. A. Q., and Mantovani, J. R. S. (2015). Volt-VAR multi objective optimization to peak-load relief and energy efficiency in distribution networks. *IEEE Transactions on Power Delivery*, 30(2), 618–626.

[120] Hu, W., et al. (2013). Optimal operation of plug-in electric vehicles in power systems with high wind power penetrations. *IEEE Transactions on Sustainable Energy*, 4(3), 577–585.

[121] Vayá, M. G., and Andersson, G. (2016). Self-scheduling of plug-in electric vehicle aggregator to provide balancing services for wind power. *IEEE Transactions on Sustainable Energy*, 7(2), 886–899.

[122] Agüero, J. R., et al. (2012). Integration of plug-in electric vehicles and distributed energy resources on power distribution systems. *IEEE International Electric Vehicle Conference (IEVC)*, (pp. 1–7). IEEE.

[123] Farahani, H. F. (2017). Improving voltage unbalance of low-voltage distribution networks using plug-in electric vehicles. *Journal of Cleaner Production*, 148, 336–346.

[124] Marra, F., et al. (2013). Improvement of local voltage in feeders with photovoltaic using electric vehicles. *IEEE Transactions on Power Systems*, 28(3), 3515–3516.

[125] Alam, M. J. E., Muttaqi, K. M. and Sutanto, D. (2013). Mitigation of rooftop solar PV impacts and evening peak support by managing available capacity of distributed energy storage systems. *IEEE Transactions on Power Systems*, 28(4), 3874–3884.

[126] Tan, J., and Wang, L. (2014). Integration of plug-in hybrid electric vehicles into residential distribution grid based on two-layer intelligent optimization. *IEEE Transactions on Smart Grid*, 5(4), 1774–1784.

[127] Han, S., Han, S., and Sezaki, K. (2010). Development of an optimal vehicle-to-grid aggregator for frequency regulation. *IEEE Transactions on Smart Grid*, 1(1), 65–72.

[128] Deilami, S., et al. (2011). Real-time coordination of plug-in electric vehicle charging in Smart grids to minimize power losses and improve voltage profile. *IEEE Transactions on Smart Grid*, 2(3), 456–467.

[129] Pang, C., Dutta, P., and Kezunovic, M. (2012). BEVs/PHEVs as dispersed energy storage for V2B uses in the Smart grid. *IEEE Transactions on Smart Grid*, 3(1): 473–482.

[130] Saber, A. Y., and Kumar, G., et al. (2010). Intelligent unit commitment with vehicle-to-grid—A cost-emission optimization. *Journal of Power Sources*, 195(3), 898–911.

[131] Su, W., and Chow, M. Y. (2012). Performance evaluation of an EDA-based large-scale plug-in hybrid electric vehicle charging algorithm. *IEEE Trans. Smart Grid*, 3(1), 308–315.

[132] Darabi, Z., and Ferdowsi, M. (2011). Aggregated impact of plug-in hybrid electric vehicles on electricity demand profile. *IEEE Transactions on Sustainable Energy*, 2(4), 501–508.

[133] National travel survey (2016). Department of Transport. [Online]. Available: https://www.gov.uk/government/organizations/department-for-transport.

[134] Kempton, W., and Tomić, J. (2005). Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of Power Sources*, 144(1), 268–279.

Biographies

K. Ramakrishna Reddy received his Bachelor degree in Electrical and Electronics Engineering from Sri Venkatesaperumal College of Engineering and Technology and Master degree in Electrical Power Systems from Sree Vidyanikethan Engineering College in 2008 and 2010 respectively. He is currently an internal full time research scholar in VIT University, Vellore, India. His research interests include power system, smart grid, demand side management and Plug-In electric Vehicles.

S. Meikandasivam was received the Bachelor Degree in Electrical and Electronics Engineering in 2002 and Master Degree in Power Systems in 2005. He also worked as a Lecturer in Electrical and Electronics Engineering Department of Sri Chandra Sekharendra Saraswati Viswa Mahavidyalaya (Deemed University), Kanchipuram. He completed his PhD Degree at Maulana Azad National Institute of Technology (MANIT), Bhopal, India in 2010. Now he is working as an Associate Professor in VIT University, Vellore.