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The Electrical Vehicle to Grid, it's likely Impact on Future of Power System – A Review Paper

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Vehicles running on oil have to change over in next few decades to alternatives which could be hydrogen, electricity. World over, almost all the major players in the automobile industry have introduced electric vehicles (EV) or Plug-in Hybrid Electric vehicle (PHEV) in the market. This is rather in response to their commitment to a green environment, reducing carbon footprints and reducing the emission rates. With the unveiling of the National Electric Mobility Mission Plan 2020, by the government of India manufacturers areurged to adopt electric vehicles in an attempt to reduce our dependence on imported oil. The ambitious plan aims to produce 6–7 million electric vehicles by 2020 with an estimated fuel saving of 2.2–2.5 million tonnes of oil. Electric vehicles when utilized for feeding back the energy to the grid play a very important role in Demand response in Smart grid environment. This will play a major role in the Power sector scenario. Though this technology is yet to pick up in India, it has become popular in the western countries. Lot of Research work has been carried out and research work has been published, which is reviewed in this paper.

Keywords: *Plug-in hybrid electric vehicle (PHEV), Battery chargers, Vehicle to grid integration (V2G) and Grid to vehicle (G2V).*

1.0 INTRODUCTION

Recent technological advances in electricity distribution and load management that make use of information and communications technologies, referred to as 'Smart Grids', promise to facilitate the integration of EVs into existing distribution network. Smart Grid technology can enable EV charging (grid-to-vehicle or G2V) load to be shifted to off-peak periods taking power from EV during peak load period, thereby flattening the daily load curve and significantly reducing both generation and network investment needs. In the longer term, there may be potential for smart-grid technology to enable EVs to be used as distributed storage devices i.e. supplying electricity stored in their batteries back into the grid whenever the demand is more (vehicle-to-grid or V2G).

V2G is a technology that makes clean and efficient electric-powered transportation possible by allowing electric vehicles to power and be powered by the grid. With Time of Day metering (ToD) concept, it may be possible to earn money by deciding when to take power from grid or when to sell the power to the grid. V2G concept opens up the research in different fields. This paper presents review of different technical papers and the issues like reliability, power quality, charging optimization, testing, power electronics, communication and EVs with Renewable etc. are elaborated.

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2.0 IMPACT OF PLUG-IN HYBRID VEHICLES ON DISTRIBUTION SYSTEMS

A Plug-in Hybrid Electric Vehicle (PHEV) is a hybrid vehicle which utilizes rechargeable batteries that can be restored to full charge by connecting a plug to an external electric power source (usually a normal electric wall socket). A PHEV shares the characteristics of both a conventional hybrid electric vehicle and of an all-electric vehicle.

The literature available discuss about the analysis, design and evaluation, charging of PHEVs and Electric Vehicles (EV) in the future smart grid environment and their impact on the grid when they are plugged in for charging to the already loaded grid. The impact of PHEVs on the distribution network depends on PHEVs battery and its charging and discharging characteristics. The simulated results by Sheng Lin [1] show that high penetration of PHEVs connected the grid will increase the feeder currents and the fault currents. And any impact could be ignored if there are few PHEVs connected to the grid.

Christophe Guille et al. [2] focuses on the design of a conceptual framework to integrate electric vehicles into the grid. In an electrical grid the electric vehicle acts as a demand- side or supply-side resource. Demand side resource is one in which during more load on the system, the customers need to turn off their appliances such as washing machine, TV etc. In order to avoid overload on the system, the electric vehicles are charged in the night, when the load demand is at low peak. Electric vehicle as a supply side resource means that the energy stored in the batteries during night can be supplied to the grid when demand is more and the price is high. With this generation resources are utilized to maximum extent and the load-time curve is flattened. PHEVs form an integral part of the smart grid in the nearest future. Several studies have been carried out in order to find the impact of different PEV battery charging profiles that affects the performance of the grid distribution system. Uncontrolled charging of PHEVs has some disadvantages such as, increase in distribution transformer losses, over loading on the distribution transformer which reduces the transformer life and increase in voltage deviation and harmonic distortions.

Amir S Masoum et al. [3] have the comparison between the charging rates i.e. slow, medium and fast charging. The studied system consists of a 23 kV distribution system with industrial feeders and several attached low voltage 415 V residential networks with high penetration of PEVs. Based on load flow analysis, the impacts of three different charging rates were studied. This paper also discusses the effects of large scale introduction of EVs in the power system. The impact on performance in terms of Voltage profile, Power losses, Peak demand and transformer loading is investigated. It is shown that EV charging rate have a significant impact on the system load curve and the distribution system efficiency can be significantly impacted by EV charging.

M. Musio et al. [4] have analyzed the economical benefits offered to a Virtual Power Plant (VPP) structure by a distributed storage system, composed of EVs connected to the grid using two scenarios. In the first scenario the VPP without EVs was analyzed, while in the second scenario EVs work as distributed energy storage system and as electric loads. Also the aim of the study was to evaluate the optimal number of EVs required to minimize the total costs of the VPP.

The impact of PHEV charging using a case study based on a small residential distribution network for two different charging rates i.e. level-I and level-II (level-I charging use 120 VAC and level-II charging uses 240 VAC circuit) and charging times (night and evening charging) is analyzed by Seshadri Srinivasa Raghavan et al. [5]. Four scenarios of level charging are considered and for each of these scenarios, distribution system specific metric such as demand factor, utilization factor, diversity factor and load factor are evaluated. The impacts of PHEV charging on load factor, Diversity Factor (DF) and Utilization Factor (UF) are considered. The Paper shows the impact of PHEV charging on distribution network with respect to load factor and demand factor is that charging the PHEVs in the evening not only under utilizes the distribution system but also potentially increases the electricity cost by consuming more electricity during peak times, when the price of electricity is usually higher than off peak period. Similarly the impact of charging the PHEVs based on the diversity factor and utilization factor show that level-II evening charging stresses the distribution transformer the most compared to all other scenarios.

The economics of PHEV charging are presented by calculating the electricity cost under each scenario using different pricing schemes like TOU, flat rate and Real Time Pricing (RTP). It is observed that RTP is economical compared to flat rate and TOU rates. Results indicate that charging PHEVs in the night time benefits the distribution system as well as the PHEV owner and avoids negative impact of PHEV penetration into the system when the demand is more. Also by charging the PHEVs during night the consumers will be benefited by low electricity cost which directly reduces the PHEV charging cost as well as it more economical.

Traditional Demand side management technique can be tapped to charge the Electric Vehicle in the so called Valley filling approach. The concept of E2G comes in as Demand Response. Along with the above, the concept of Distributed Generation of Renewable energy and Advanced Metering Infrastructure (AMI) in smart grid is widely discussed by W. Shireen [6].

3.0 RELIABILITY

Over the years the electric power system has seen an exponential growth in terms of size and technology. Pramod et al. [7] has developed a distribution test system with integration of EVs into the distribution network. Extensions to an existing distribution test system (RBTS, Bus-2) are presented and the proposed extensions are kept simple and flexible to be suitable for a large variety of applications from probabilistic reliability to power system economics. The presented extensions make the test system easily modifiable. A reliability study has been carried out on the extended system as a sample study and the results of the same are presented.

Wenxia et al. [8] has established the charging and discharging power model of electric vehicles and proposed the time-varying distribution system reliability model. The reliability of a distribution system with electric vehicles can be evaluated accurately by using Monte Carlo time sequential simulation. Also, by using the proposed sequential Monte Carlo method reliability indexes of a main feeder of IEEE-RBTS (Roy Billinton L-Test System) BUS6 test system with electric vehicles is calculated. The reliability simulation results under different electric vehicle types, penetrations and access points are analyzed.

4.0 POWER QUALITY

Power Quality (PQ) is one of the issues which will be of great importance when many EVs are plugged to the grid either for charging or giving back to the grid, since the charges and associated electronics are non-linear electronic devices. Paul S. Moses et al. [9] has studied the impact of PEV charge rate on voltage profile, fundamental and harmonic losses, transformer loading and total harmonic distortions. Figure 1 illustrates the smart grid distribution system topology investigated.

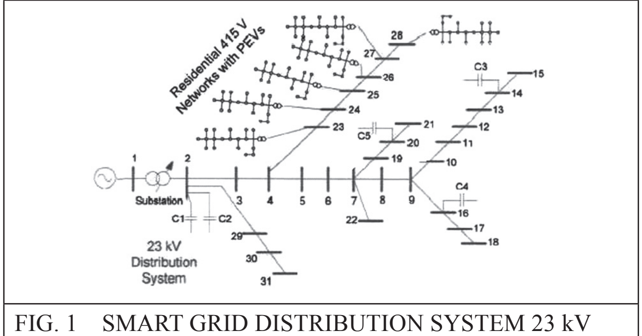

FIG. 1 SMART GRID DISTRIBUTION SYSTEM 23 kV DISTRIBUTION FEEDER WITH 415 V RESIDENTIAL NETWORKS AND HIGH PENETRATION OF PEVs.

The HV distribution feeder and LV residential networks are considered by expanding the IEEE 30 bus system to include several LV 415 (240) V sections. The LV networks represent different residential zones and are based on realistic data for a local neighborhood. Each LV network consists of 19 nodes representing customer households, and potentially high penetrations of PEV charging have been included. Six LV sections of this type, each with 19 nodes, are implemented and are supplied from main buses 23 through 28 via 23 kV/415 V, 100 kVA distribution transformers. The remaining 23 kV buses have active and reactive power loads based on the IEEE 30 bus system data which represents the lumped loads from other residential, commercial and industrial load centers. The total number of nodes of this system is 145.

Conclusions have shown that with high penetration of PEVs will cause unchangeable and severe voltage harmonics power loss etc. The findings being relevant for design and implementation of smart grids consisting of power quality issues.

5.0 CHARGING OPTIMIZATION, ECONOMICAL ISSUES

Olle Sundstrom et al. [10] have shown by minimizing the charging costs, achieving satisfactory state-of-energy levels and optimal power balancing, the electric vehicle battery charging performance can be improved. Two methods for charging schedule optimization are compared. The first formulation uses a linear approximation of the battery whereas the second uses a quadratic approximation. This paper also shows the impact of using a linear versus a quadratic approximation.

Chris Hutson et al. [11] have proposed an intelligent method for scheduling usage of available energy storage capacity from PHEVs and EVs. Figure 2 shows a typical parking lot setup.

At each vehicle's departure time the battery State of Charge (SoC) is expected to be at a certain desirable level. For the study, every vehicle is assumed to have the same desired departure SoC of 60%. Once a vehicle reaches this desired departure SoC it can never be discharged below this level. In order to figure out the appropriate charge and discharge times throughout the day Binary Particle Swarm Optimization method is proposed.

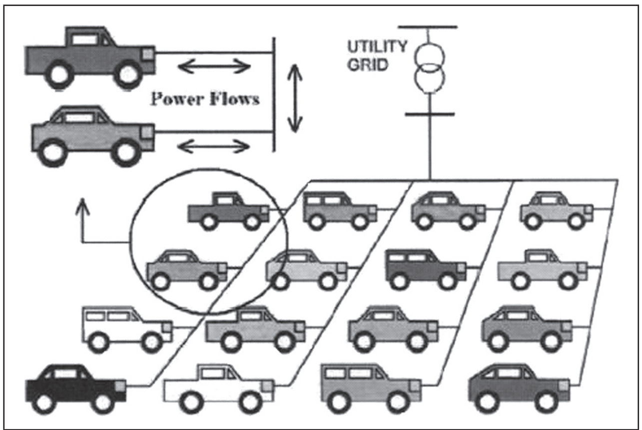

FIG. 2 EXAMPLE OF A PARKING LOT DIAGRAM.

A techno-economical evaluation of EVs parking lot construction by distribution companies is presented by Hamid Reza ESMAEILIAN et. al. [12]. The optimization procedure in order to find the maximum profit of the distribution company is performed using genetic algorithm. The profit can be an incentive for distribution companies to invest in the construction of parking lots of EVs to smooth load profile and shave peak load in order to improve load management. It is also shown that a mutual agreement between EV owners and the distribution company as the owner of the parking lot can be profitable for EV owners as well as the distribution company. The optimum number of EVs available in the parking lot should satisfy this agreement.

A Mathematical model for simulating EVs participation in load response through the method of charging and discharging is implemented by Junqiu Yang et al. [13]. An adaptive mutation PSO algorithm is presented to optimize the control strategy of the electric vehicle fleets.

Also for a given case the feasibility and effectiveness of the algorithm is proved.

A mathematical model is developed by Sumit Paudyal et. al. [14] to study the impacts of uncoordinated and coordinated charging of the PHEVs on distribution system operations considering a 15-node distribution feeder with 10%, 20% and 50% PHEV penetrations in residential loads.

Figure 3 depicts a distribution feeder with PHEVs connected to it, to illustrate the concept of uncoordinated PHEV charging. Uncoordinated charging is one in which the PHEV owners define their own optimal charging schedules that are independent of other PHEV owners.

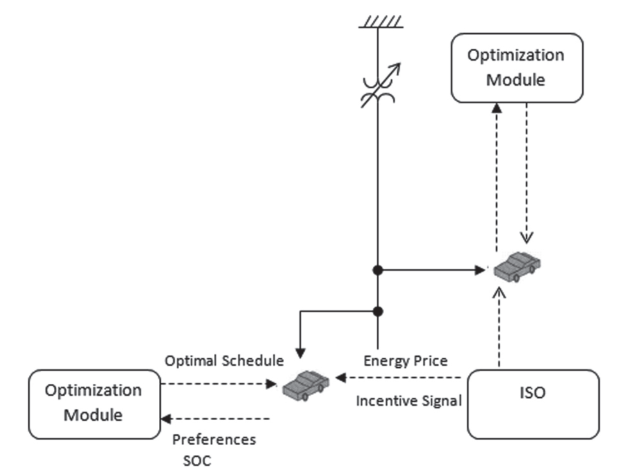

FIG. 3 UNCOORDINATED CHARGING OF PHEVs.

An energy cost function is considered an optimization objective for uncoordinated charging of PHEVs, and defined as,

$$F_1 = E_{max}(j,n)\sum_{h=H_i}^{H_f-1} p(h)\big(C(J,n,h+1)-C(j,n,h)\big) \quad .... (1)$$

Where,

E_{max}: maximum energy storage capacity

ρ: Energy price

H_i: time when vehicle is connected to the grid

H_f: time when vehicle is off the grid

h: represents the intervals in optimization horizon

n: vehicle number

$C(j,n,h)$: SOC of PHEV connected to the grid at any time instance.

Figure 4 shows a distribution feeder with PHEVs connected depicting the information exchange between various entities involved in coordinating charging of PHEVs. Coordinated charging is one in which a PHEV aggregator (offers services to aggregate energy production from different sources and acts towards the grid as one entity) defines optimal charging schedules for various PHEVs.

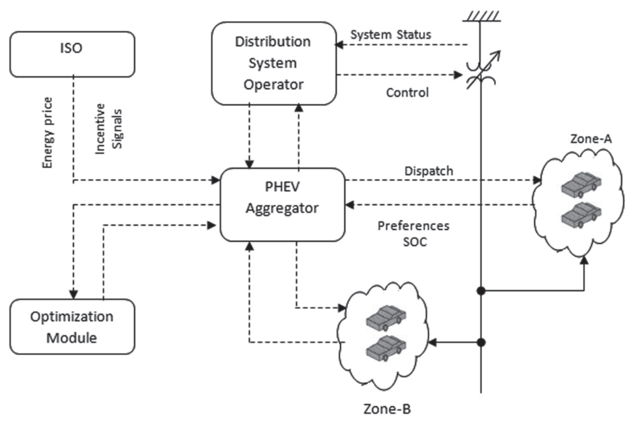

FIG. 4 COORDINATED CHARGING OF PHEVs SHOWING INFORMATION EXCHANGE AMONG VARIOUS ENTITIES.

In coordinated charging two objectives are considered:

(a) Distribution loss minimization objective, defined as the difference between grid power and demand

$$F_2 = \sum_h (PG(h) - \sum_j \Big(PL(j,h) + \sum_n \big(PEV(j,n,h)\big)\Big) \quad .... (2)$$

(b) Maximization of distribution load factor, defined as the average demand over the peak demand,

$$F_3 = \frac{\sum_h PG(h)}{hmaxMAX[PG(h)]} \quad .... (3)$$

Where,

h: intervals in optimization horizon

h_{max}: total number of time intervals in optimization horizon

P_{EV}: active power demand of PHEV

n: vehicle number

h: represents the intervals in optimization horizon

$P_G(h)$: Grid power

The results show that uncoordinated charging leads to more losses and increased peak load even though it produces optimized energy costs for the PHEV owners, while the coordinated charging is beneficial for the Distribution system operators (DSOs) – [DSO is responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing] to decrease distribution losses and to increase voltage profiles and load factor.

Plug-in Hybrid Electric Vehicles (PHEVs) in a power network are considered as price elastic loads. To optimally schedule the charging of the PHEVs, a dynamic Optimal Power Flow (OPF) problem is solved by Somayeh Sojoudi et al. [15]. The OPF is associated with both elastic and inelastic loads. The results provide an efficient way to globally optimize a fundamental optimization problem for smart grids.

6.0 TESTING

Testing the capabilities of EV for smart grid applications requires the development of adequate evaluation platforms. EVs can potentially operate under a number of coordination schemes, including the participation in regulating power reserves. While this was extensively presented by simulation scenarios, F. Marra et al. [16] have presented a real implementation of regulating power reserve performed by a full scale EV test bed. The implemented EV test bed architecture is shown in Figure 5.

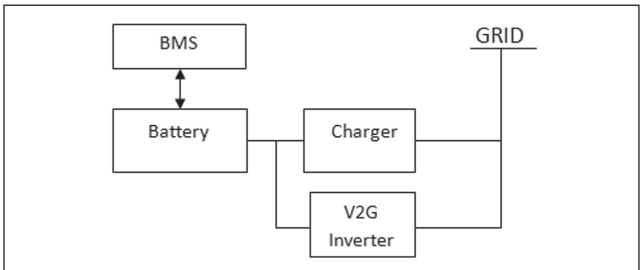

FIG. 5 EV TEST BED ARCHITECTURE.

The battery pack is interfaced to a Battery Management System (BMS), which monitors its status. The charger is designed as an AC/DC converter and is directly connected to the main grid. The V2G unit is made of a single-phase DC/AC inverter.

The test bed is designed to flexibly interact in real time with an EV coordinator and the electricity grid, under different coordination concepts. The implementation of an EV test bed from scratch enabled the management of the single components involved in the EV system: charging/discharging units and BMS. With the implemented communication and control architecture it is possible to establish a stable communication between the EV the test bed and the Virtual power plant. The potential offered by the EV for regulating power was demonstrated by testing the EV test bed hardware and software interfaces. A case study on the regulating power requests sent by Danish TSO was studied. The test results revealed the potential capability of EV to respond in real time to different charging/discharging requests based on different coordination plans.

The demand flexibility inherent in the energy storage capability of a large, highly distributed PHEV fleet can only be realized if the supporting communication and control architecture is well designed. Ian Beil et al. [17] have reviewed past research on communication and control architectures for PHEV charging and proposed a novel test bed to test the effectiveness of using the AIMD (Additive Increase and Multiplicative Decrease) algorithm to control a set of constant-current, constant voltage chargers.

7.0 POWER ELECTRONICS

The important requirement to demonstrate the concept of vehicle to grid needs an interface between the electric vehicle and the grid. Duleepa J Thrimawithana et al. [18] describes about the novel wireless and bidirectional power interface suitable for the grid integration of Electric Vehicles (EVs) or for V2G applications. The proposed interface is based on the IPT (Inductive Power Transfer) technology, and comprises a high frequency IPT system to control the wireless charging and discharging of the EV and a low frequency converter to facilitate the grid integration. A DQ controller has been proposed and implemented for the grid converter while typical voltage control has been employed to control the IPT system at unity power factor. The viability of the proposed system has been demonstrated through both simulations and experimental results of a 1 kW prototype system.

8.0 COMMUNICATION

An EV must have three or more elements in order to provide G2V or V2G type of service. First of all, it must have a bidirectional power interface in order to supply or absorb energy. The second fundamental element is an Energy Management System (EMS). Such an element has to control and measure the energy flows from/ to the battery pack and finally, a communication protocol between grid operator and EV owner to transfer all the information useful to the EMS and to evaluate the cost and the revenues associated with the services.

A V2G system comprising of a plug-in hybrid vehicle, called Blue-Angel III and a wireless power interface for grid integration is presented by Vinzenz V. Haerri et al. [19]. The wireless interface is based on IPT technology and facilitates the power exchange between the grid and Blue-Angel III. The paper discusses briefly about the design aspects of the 2 kW bi-directional IPT power interface and the structure, control, energy storage and management, and communication protocols of the hybrid Blue-Angel III. Simulation results under various conditions are presented to show that the proposed wireless and bi-directional IPT interface is ideal for the grid integration of Blue-Angel III and EVs.

9.0 RENEWABLE INTEGRATION

Power management problem in the smart grid network is studied by Yifan Li et al. [20], with multiple energy resources, including both the conventional thermal power plants and the renewable energy resources such as wind turbines. The power management solution for both the case of with and without integration of PHEVs is obtained by the integration of PHEVs and formulation of stochastic programming frameworks. Numerical results show that energy generation by conventional thermal power plants can be apparently reduced by integrating PHEVs and also the cost to generate overall energy to satisfy the load can be effectively reduced. Renewable energy like wind and solar reduce emission from the electrical industry i.e. from power plants. Like wise in the next generation plug in vehicles such as electric vehicles can be used to reduce emissions from the transportation industry. The maximum utilization of Renewable energy sources (RES) using Grid Vehicles (GV) is presented by Ahmed Yousuf Saber et al. [21] to illustrate the cost and emission reductions for a sustainable integrated electricity and transportation infrastructure. Load-leveling model and smart grid model are studied for GV applications. The PSO (Particle Swarm Optimization) method is used to generate the successful schedule and control of GVs in a smart grid.

Design of a unique charging station has been proposed by G. Preetham et al. [22], in which the rate of charging of the PHEVs is controlled in such a way that the impact of charging during peak load is not felt on the grid and it uses a combination of PV system and smart charging strategies. The PVs can be installed on the rooftop of the parking lot for charging PHEVs during peak time. The charging station consists of a PV array (acting as a source), PHEVs (acting as a load), Energy Storage Unit (ESU) consisting of a battery bank to store energy during off peak hours which can be used during emergencies to charge the PHEVs.

An algorithm is proposed to monitor and control the power flow in the system. The algorithm consists of four modes of operation. A set of variables I_{grid}, $I_{grid.max}$, $V_{DC.min}$, $V_{DC.max}$, $V_{DC.bus}$, T_{soc} and $T_{soc\text{-}max}$ are used to describe each of the modes. I_{grid} represents the grid load and $I_{grid.max}$ represents the peak load condition. $V_{DC.bus}$ is the voltage at the DC bus. $V_{DC.min}$ and $V_{DC.max}$ are the minimum and maximum limits of the DC bus voltage. T_{soc} is the state of charge of the battery pack in the PHEV which decides whether the PHEV should be charged or not. Finally $T_{soc\text{-}max}$ is the maximum value of the state of charge. The charging of the PHEV should be terminated once the state-of-charge is equal to $T_{soc\text{-}max.}$ Figure 6 describes the various modes of the charging station.

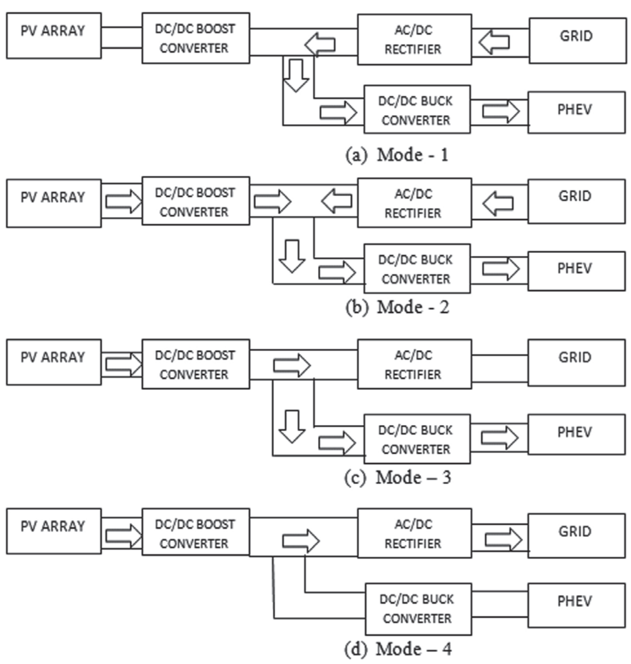

FIG. 6 OPERATION MODES OF THE PROPOSED ARCHITECTURE.

MODE I: $V_{DC.bus} < V_{DC.min}$: Grid connected rectification.

In the first mode the PV system does not generate any power due to bad weather conditions and the power required to charge the PHEVs is completely provided by the grid but whenever there is increase in local demand, the charging of PHEV is stopped temporarily and the PHEVs are charged by the ESU. Once the grid is back to off peak condition the charging of PHEV is restored.

MODE II: $V_{DC.min} < V_{DC.bus} < V_{DC.max}$: PV charging and grid connected rectification.

In the second mode the power generated by the PV system is less than power required to charge the PHEV therefore all the power generated by the PV system is transferred to PHEVs and if any shortage, is supplied by the grid.

MODE III: $V_{DC.bus} = V_{DC.max}$: PV charging mode

In the third mode the PV system generates all the power required to charge the PHEV. Once the PHEV is completely charged the PV supplies power to charge the battery bank in the ESU.

MODE IV: $V_{DC.bus} > V_{DC.max}$: Grid inversion mode

In the fourth mode the PV delivers power more than that required to charge the PHEV and the excess power is sent to the grid.

10.0 CONCLUSIONS

- In this review paper, effect of PHEV on eight different aspects has been categorized. Disadvantages of PHEV are brought out clearly.
- Studies on impact of PHEV on distribution system has shown that high penetration increases feeder currents and fault currents.
- Uncontrolled charging of PHEVs may lead to increase in distribution transformer losses, over loading and harmonic distortion.
- Proper methodology needs to be worked out to overcome these likely drawbacks. System load curves and distribution efficiency can be significantly impacted by EV charging.
- Studies show that EVs charging in the evening (at peak times) not only puts the pressure on the distribution system but also potentially increases the cost by charging during peak load.
- Demand response techniques using the popular Valley filling technique have been discussed. EVs are set to play a very significant role in Demand Response in Smart Grid environment.
- Some of the other issues discussed are Distribution System Reliability,

Power quality issues due to charging, optimization techniques of whole operation and related economical issues.

- The use of Renewable like Photovoltaic for charging stations in urban as well as rural areas are set to change the future of deep penetration of EVs.
- Communication issues in case of Bi-directional transfer of power and testing aspects of EVs will be also important.

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