Scope of Virtual Synchronous Machine For Power Quality Improvement In Modern Power System: A Comprehensive Review

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Abstract: Recent studies on climate change warned us about the need to perform a drastic reduction in greenhouse gas (GHG) emissions. Most worrying cases are found in big cities, due to the air pollution levels, mainly provoked by the industry and vehicles' combustion engine emissions. Environmental pollution affects health very negatively, causing diseases, such as asthma, lung cancer and it is a common cause of shortened lifespan. For this reason, governments and public sector organizations are making efforts to improve the air quality and quality of life of citizens, by proposing strategies to reduce GHG emissions (i.e., CO2, CH4, as well as pollutants, such as Nitrous oxides, dust, and smoke). These strategies also include the production of electricity through the use of renewable energy sources (e.g., solar, wind, and hydroelectric energy) and encouraging the use of electric vehicles (EVs). The proposed research is intended to explore the scope of virtual synchronous machine for power quality improvement in realistic power system.
Keywords: Electric Vehicle, Power Quality Improvement, Virtual Synchronous Machine.

1. INTRODUCTION

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) have gained a growing interest in the vehicle industry. Nowadays, the commercialization of EVs and PHEVs has been possible in different applications (i.e., light duty, medium duty, and heavy duty vehicles) in energy-storage systems, power electronics converters (including DC/DC converters, DC/AC inverters, and battery charging systems), electric machines, and energy efficient power flow control strategies. This special Issue is focused on the recent advances in electric vehicles and (plug-in) hybrid vehicles that address the new power train developments and go beyond the state-of-the-art (SOTA). Plug-in hybrid electric vehicles (PHEVs) are regarded today as a promising technology, due to their excellent fuel efficiency. Energy management and component design optimization [are two significant research topics in the domain of PHEVs. Electric vehicles (EVs), hybrid electric vehicles (HEV), and most recently fuel cell hybrid electric vehicles (FCHEVs) have been widely considered as one of the most promising solutions to environmental pollution and energy crisis.

Widely used generation resources are wind, photovoltaic (PV) which can be integrated to power grid. Solar Photovoltaic (PV) is natural resource and give desirable green energy. PV systems integrated along with energy storing device like battery for improvement of quality and reliability of the power supply. Solar intensity, cell temperature, cloud/partial shading, are the major factors for proper operation of PV system. Power quality problem like power fluctuation which is due to unstable generated power and over voltage occur due to inherent characteristic of PV system and lack of inertia. Integration of PV system to Grid through inverter which convert the DC voltage to AC voltage and produce harmonics in AC voltage generated by high switching frequency.

Frequency fluctuation occur when supply & demand of power system are unbalanced. There are different power quality issue like voltage, frequency and power fluctuation, harmonic distortion, voltage sag and voltage swell of integrated PV system to grid. Occurrence of voltage sag and voltage swell caused by changed in load and environmental characteristic. The voltage and frequency fluctuation due to non-controllable variability of PV system and power grid side disturbance. The smoothing of voltage and frequency fluctuation can be achieved through the control of reactive power and real power. The power electronic inverter interface between PV system and power grid are static without any rotational energy which having negligible inertia. Therefore In power grid, Low moment of inertia degrades frequency stability because inertia is inversely proportional to the frequency. Static power electronic inverter having low moment of inertia which lead to the weakening of grid and therefore degrades its frequency stability.

For overcoming these problem and enhance power system stability, Virtual synchronous machine(VSM) method is proposed for reducing voltage and frequency fluctuation and improve power system stability in PV-Grid integrated system. The concept of Virtual Synchronous Machines (VSMs) is introduced as a flexible method for controlling power electronic converters in power system applications. VSM is emerging as flexible method for controlling power electronic converter in power system application. It is electromechanical synchronous machine which is based on static and dynamic operating properties of synchronous machine. Synchronous machine release or absorb kinetic energy when there is change in grid frequency.

VSM method used for frequency control by adding virtual inertia to control power electronic device based system. For improving the system stability VSM add the inertia into the control power electronic device to allow for higher PV penetration without losing stability. Real and reactive power flow between PV system and power grid through VSM method.VSM inject or absorb active power through three phase inverter when there is negative or positive change in frequency respectively. Good power quality term indicate the pure sinusoidal waveform of voltage and current avoiding the presence of harmonics and signal distortion.

2. REVIEW OF LITERATURES

Xu-Dong Chen et al. [1] implemented state space modelling method of virtual synchronous machine (VSM) for stability analysis. The inertia and damping characteristics of the grid are reduced due to the high permeability of distribution energy sources which may cause different type of problem. Virtual synchronous machine (VSM) [2] method is implemented for solving inertia and damping problem. Power electronics converter generate the harmonics which is difficult to analyse a time-variant system by the traditional linear time invariant based model[3]. Harmonic state-space (HSS)[1]modelling is a linear time-varying periodic model and considers different harmonics of the system for the grid connected VSM. The eigen values of system matrix based on HSS analysed the stability of the system. The traditional synchronous generator has the problem such as inertia, power oscillation and damping which is similar to VSM because of harmonics generated by power electronic converter[1].

Wenhua Wu et al.[4] investigated a virtual inertia control strategy for DC-MG through bidirectional grid-connected converters (BGCs) with virtual synchronous machine (VSM) for enhancing the inertia of the DC-MG and to maintain the dc bus voltage fluctuation[4]. Bidirectional grid connected converters (BGCs)[4][5] play an important role for controlling the energy exchange between the DC-MG and the utility grid for maintaining the dc bus voltage stability and improving the system efficiency but DC-MG having a low-inertia grid dominated by power electronic converters[6]. Efficiency and stability of the DC-MG reduced due to the frequent switching loads and intermittent DGs (e.g. PV source) which rise large volatility of the dc bus voltage. Inertia of DC-MG increased and to diminish fluctuation of the dc bus voltage and to enhance the stability of the DC-MG when introduced the virtual inertia control into the BGC.

O. O. Mohammed et al. [7] highlighted the virtual synchronous generator (VSG) control schemes for controlling the voltage and frequency fluctuation which are due to the high penetration of renewable energy (RE)[8][9] sources based on distributed generation(DG) in power system. [10]. The instability of grid occur due the inherent characteristic of renewable energy (RE) sources such as small output impedance, no inertia and damping property. In bulk power plant, stability of power system at grid dominated by using synchronous machines (SMs)[7]having in inherent rotor inertia, damping effect due to damper winding in rotor , voltage control ability and speed droop characteristic for load sharing. The renewable energy (RE) based on distributed generation(DG) is integrated to the grid through power electronics converter (PECs) [6]which employee the drrop control mechanism having no inertia and poor frequency regulation. Virtual synchronous generator (VSG) control schemes is introduced for enhancing the voltage and frequency fluctuation in order to add virtual inertia in distributed generation(DG) system[10]. VSG is used to emulate for implementing the DG system by using short-term ESS and PECs with efficient control technique. VSG is the static and dynamic operating characteristics of electromechanical SMs. The power exchange between energy storage and power system is controlled by the PEC (DC to DC and DC to AC conversion), ESS[11] and control scheme of VSG and due to this power exchange prevent the frequency fluctuation and support to power system.

Y. V. Pavan Kumar [3] designed Virtual Synchronous Motor and Synchronous Generator (VSMSG)[3] control Scheme for the inverter that can operate as a conventional electrical machines based energy converter. Static power electronic inverters having low moment of inertia which effects the system resiliency in the event of uncertainties[3]. The usage of static power electronic inverter in microgrid's [14] operation can reduce the utility grid equivalent rotational inertia. This restricts the microgrid's integration with utility grid for the grid mode of operation. Low moment of inertia leads to the weakening of microgrid's resiliency[3], which degrades its frequency-stability. Resiliency indicates the system's ability to efficiently withstand for low probability and high impact events while ensuring least possible interruption in supply and further enabling a quick restoration virtual synchronous generator (VSG)[7][1] to the normal state.

Chowdhury Andalib Bin Karim, et al.[6] highlighted power electronics based virtual synchronous machine (VSM) method for renewable energy integration modelling. VSM [15] acts as electromechanical synchronous machines[6] control the grid-connected renewable energy sources behave as conventional power generation stations from the power grid. For improving the power system stability and minimize the voltage and frequency fluctuation [15][6] of renewable energy sources, (VSM) method is proposed. Interfacing of high penetration of renewable energy sources increases to the power grid that's why power grid experiences a gradual transition from centralized traditional power generation to decentralized distributed power generation which is connected to consumer sites for reducing losses in transmission system and support the local reactive power[16].

Ujjwol Tamrakar et al.[14] investigated virtual synchronous machines which add inertia into the system to allow for higher PV penetration without losing stability. The transient stability of photovoltaic-hydro microgrid systems is poor due to lack of inertia and the intermittent nature of photovoltaic systems[14]. A PV-hydro system analyze the transient stability problems due to PV fluctuations and load. Virtual synchronous machine reduced the frequency deviations and the high rate of change of frequency due to this the transient stability of photovoltaic-hydro microgrid systems can be improved using a minimum amount of energy storage[14]. High PV penetration levels were achieved by adding virtual synchronous machine to the system. Load/generation changes and PV fluctuations in systems can cause large frequency deviations at a high rate of change of frequency (ROCOF)[14].

Pablo F. Frack et at.[17] invented control strategy based on the virtual synchronous machine(VISMA) concept to improve the incorporation of converter-coupled units. The transformation of power system from centralized generation to decentralized is undergoing and for this process Microgrid (MG) is required. Small generation technology i.e. Distributed Generation (DG)[15] is developed at consumer site for reducing the losses in transmission line and local reactive power. The system inertial response deteriorate due to the use of DG technology and MG concept. Also the reduction of short-term generation reserve fluctuate the frequency stability due to the deployment of DG to microgrid (MG) through the power electronics[4].

V. Torres-Sanz et al.[11] presented four different charging methods such as the cheapest (C), the Cheapest Starting (CS), the Low Cost (LC), and the Last Period (LP) schemes, as an alternative to the traditional Plug and Charge (P&C)[11] method. In present condition charging points are limited therefore efficient charging strategies for electric vehicles is very important because of increasing electric vehicle (EV)[18] sales. For avoiding peak power demands and promoting recharges at off-peak hours, better charging process is required such as an automatic, efficient, and scheduled electric vehicles. Therefore, for enhancing the charging process at residential homes, smart charger[5] play an important role. Objective of this paper is to enhance recharging methods for reducing the cost of recharging EVs and for this Plug & Charge [19]method is introduced but this method is not boosting efficiency. There are some issue which are improvement of vehicle battery level, the current state of the electricity grid and electricity précising for charging the EV.

Kishore Naik Mude [20] invented charging infrastructure from wired connection to on-road wireless charging for an EV. Power grid recharge the batteries for providing the electricity to electric vehicle (EV) [21]. Off-board and On-board battery chargers are the two type of battery charger which is unidirectional and bi-directional power flow. The unidirectional battery chargers(UBCs) take the power from grid and bidirectional battery chargers (BBCs)[22] work in both direction i.e. take and give the power from the utility grid. UBCs reduces the interconnection issues and battery degradation while BBCs support stabilization of power with proper power conversion. On-board chargers can be used to charge from the utility outlet at the workplace or household plug or shopping malls during the day time while Off-board charging[23] is like a gas station used for conventional vehicles and thus it is a fast charging. On-board charging require less equipment as compared to off-board charging.

Prashant Akhade et al.[24] highlighted different types of control strategies for integration of electric vehicles (EV) with power grid. The control strategy for integration of EVs are consider as portable sources of power which play an important role for enhancing the performance of power system. The integration of EV to power grid with control strategy are used for grid to vehicle (G2V) and vehicle to grid(V2G) connection which consist of Aggregated control, frequency control, multi-agent control, virtual synchronous machine (VSM)based control[2]. A grid-integrated EV (GIEV)[25] is powered by an onboard traction battery that can be charged by using a grid-connected battery charger. GIEV consist of G2V and V2G[5] connections and EVs charger may be unidirectional at G2V operation while duplex when allowing G2V and V2G operation.

Tian Mao et al.[26] implemented a generic model that can applied to the various activities of ‘Vehicle-to-anything’ (V2A) application. The penetration of massive EVs will also challenge the operation of the power system since the additional load of EV charging may potentially amplify the daily peak of power load and induce some adverse impacts including voltage drops, frequency oscillations[26]. EVs can deliver energy back to power grids or another power consumption entity or community, performing various discharging activities viz. vehicle-to-vehicle (V2V), vehicle-to-home (V2H), vehicle-to-building (V2B)[26], vehicle-to-grid (V2G). These charging scenarios can be uniformly named the ‘Vehicle-to-anything’ (V2A) charging mode.

Luis Santiago Azuara Grande et al.[28] designed off-grid Photovoltaic and Battery Energy Storage System (PV-BESS) are technically, economically viable and reliable for Charging Electric Vehicles (EVs) . OFF-grid PV-BESS which is designed by a Photovoltaic (PV) plant, Battery Energy Storage System (BESS)[29] and an Electric Vehicles (EV) charger. The BESS is used when PV power cannot satisfy the demand. The optimum technical design of Photovoltaic and Battery Energy Storage System (PV-BESS)[16] play an important role for quality, security of power supply and economic, environmental benefits which ensure the system efficiency and the reduction in emissions. Energy storage system(ESS)[14] is used because of the intermittent character of the solar radiation and to optimize the use of the PV energy through the reduction of the unused generated energy and the unmet load. Off-grid PV-BESS[28] can be considered not only a good solution for emissions reduction in industrial countries characterized by a good amount of solar radiation, but also a profitable that are economically rentable and energetically reliable.

Mahdi Soltani et al.[30] investigated the effectiveness of the hybrid energy storage system in protecting the battery from damage due to the high-power rates during charging and discharging. A potential application for this research work is the pure electric bus with energy recovery capability with the hybrid energy storage system based on Lithium-ion battery (LiB)[8] and Lithium-ion Capacitor(LiC).

Teng Liu [31] et al. proposed a genetic algorithm (GA)-based energy management strategy for the Chevrolet Volt. Vehicular Technology Society (VTS) motor vehicle challenge 2018 focused on the energy management of a range extender electric vehicle, the Chevrolet Volt**.** The energy management problem of the Chevrolet Volt[31] is the topic of the 2018 IEEE VTS motor vehicles challenge. GA-based controller[30] is introduced for this challenge. The power train includes a traction electric motor (EM), a generator (GEN), a planetary gear (PG), a battery pack, and an internal combustion engine (ICE)[32]. Design a robust energy management strategy for minimizing the fuel consumption and the battery charging cost are the challenges**.** Four traction operation modes are elaborated for the power train modeling. A genetic algorithm (GA) [33]based energy management strategy for the Chevrolet Volt is used to optimize the special parameters in the Matlab/Simulink modeling. Different driving cycles are applied to validate the adaptability of the energy management strategy. proposed method is superior to the original charge depleting/charge sustaining (CD/CS)[33] technique.

Joeri Van Mierlo [29] demonstrated an energy management strategy for a power-split plug-in hybrid electric vehicle (PHEV) based on reinforcement learning (RL)[34]. Control-oriented power-split PHEV model was built Firstly and then RL method was employed based on the Markov decision process (MDP)[35] for finding the optimal solution. The special issue in plug-in hybrid electric vehicles (PHEV)[36] are urban air quality, climate change, dependency on crude. There are many energy efficient power flow control strategies which are power electronics converters (including DC/DC converters, DC/AC inverters, battery charging systems)[4], electric machine. Q-learning (QL)[35] algorithm is the optimal control strategy and it can decide suitable energy allocation between the gasoline engine and the battery pack. The RL-based control strategy could not only limit the maximum discharge power of the battery but also fuel consumption under different driving cycles and compared with the charging depletion/charging sustaining (CD/CS)[33] method and the equivalent consumption minimization strategy (ECMS)[35].

Teng Liu et al.[37] presented energy management planning controller based on a Dyna agent of reinforcement learning (RL) technique for optimization of real-time fuel saving in plug-in hybrid electric vehicle (PHEV). The aim of this paper is to seek fuel economy improvements for a PHEV by incorporating planning strategy into the Dyna agent [34]. A model-free algorithm named Dyna-*H* algorithm is introduced through incorporating planning strategy into Dyna agent which is a model-free online reinforcement learning (RL)[34] algorithm. Chevrolet Volt[31] is built for modelling of vehicle power train where all the control components have been validated. The states of two clutches and one brake is managing for allowing four traction operation modes of Chevrolet Volt analysis and the optimal control problem is formulated where three RL algorithms, the one-step Q-learning[35]. Dyna-*H* is analysed for deriving different control actions.

Hang Zhao et al.[38] presented a consequent-pole PM magnetic-geared double-rotor machine (CPDRM)[38] that utilizes the magnetic gearing effect to transmit the power with a high efficiency for Hybrid Electric Vehicle(HEV)[39]. In HEV, Electric continuously variable transmission (e-CVT) device play an important for performing the energy transmission among the initial combustion engine, battery, and output shaft but e-CVT[38] system which suffers from friction and low efficiency. Magnetic-geared double rotor machine (MGDRMs) [38] called dc-excited consequent-pole. PM magnetic-geared double-rotor machine (CPDRM) which first introduced for solving the fixed excitation problem caused by permanent magnet (PMs). Magnetic-geared double rotor machine (MGDRM) perform as a magnetic gear, thus it has a high efficiency and needs little maintenance. HEV requires that the traction system maintains constant output power even under high speed operation[40]. MGDRMs have flux-weakening ability because of the low saliency ratio of surface-mounted permanent magnet. Therefore, for a certain speed range, the operation of MGDRM is limited which reduces the energy efficiency of the HEV that's why the internal combustion engine (ICE) cannot run under its optimal speed range[32].

Teng Liu et al.[34] created an online energy management controller for a plug-in hybrid electric vehicle (PHEV) which is based on driving conditions recognition and genetic algorithm (GA). Plug-in hybrid electric vehicle (PHEV) is the promising choice because of its remarkable energy conservation and fuel economy[29]. This goal can be realized by several significant technologies such as components design optimization and energy management. Rule-based controls are very popular in current real vehicles and decided by abundant engineering experiences and sufficient calibration effort which are not adapt to various driving conditions and vehicle configurations. Thus, the optimization-based methods are regarded as feasible alternatives to search the better controls. These approaches include global optimal ones, such as genetic algorithm (GA)[36], dynamic programming (DP)[36] [40], Pontryagin minimum principle (PMP), convex programming (CP)[19], game theory (GT), simulated annealing (SA)[19] and particle swarm optimization (PSO)[27][41], and instantaneous optimal ones, such as sliding mode control (SMC) , equivalent consumption minimization strategy (ECMS)[35], fuzzy logic control , neural network control, model predictive control (MPC)[34], stochastic dynamic programming (SDP)[40] and extremum seeking control. However, most of these optimal controls are not robust to uncertain drivers' intention and complicated driving styles.

Zheng Chen et al.[35] developed energy management strategy for a power-split plug-in hybrid electric vehicle (PHEV) based on reinforcement learning (RL). A control-oriented power-split PHEV model is built and then the RL method is employed based on the Markov Decision Process (MDP)[35] to find the optimal solution according to the built model. several different standard driving schedules are chosen and the transfer probability of the power demand is derived based on the Markov chain. The mathematical vehicle model is built after detailed power train analysis. By combining Q-learning method with MDP[35], the RL model of PHEV is constructed and the optimal result based on RL is obtained where the battery power is optimized. Proposed RL algorithm can guarantee a preferable fuel consumption and show more effectiveness than the CD/CS algorithm[35].

Daming Zhou et al.[42] performed online energy management control strategy based on a fractional-order extremum-seeking (ES) method. Electric vehicles (EVs)[22], hybrid electric vehicles (HEV)[43], and most recently fuel cell hybrid electric vehicles (FCHEVs)[42] have been widely used as a solutions to environmental pollution and energy crisis. FCHEVs have zero emission and allow braking energy recovery as they combine different power sources including fuel cells and batteries as compared with conventional vehicle. Fractional-order extremum-seeking (ES)[42] method is an online adaptive optimization algorithm, which can be effectively used in the applications of fuel cell hybrid electric vehicles (FCHEVs)[42] and compared with the traditional integer-order ES method. For FCHEVs, proton exchange membrane fuel cells (PEMFCs) can be used because of their advantages of fast fueling time, compactness, high power density, relatively low operation temperature and pressure.

Hassan Fathabadi [32] invented a renewable energy based replacement for the internal combustion engine (ICE) with a small size of PV positioned on the roof of the plug-in hybrid electric vehicle (PHEV). There is different type of EV charging in many countries such as electric vehicles (EVs)[18], hybrid electric vehicle (HEV)[29] and plug-in hybrid electric vehicle (PHEVs)[19] which is an upward trend rather than the vehicles equipped with internal combustion engines because of environmental issues and economic considerations. A PHEV is more efficient compared to a traditional HEV that mainly uses an internal combustion engine[32].

Vahid Behravesh et al. [16] explained a combined voltage control scheme for improving the voltage profile, fluctuations, and imbalance of balanced and unbalanced residential distribution networks with a high penetration level of rooftop photovoltaic-wind turbine hybrid generation systems (PVWHSs)[16] and electric vehicles (EVs). In this control scheme, there are two method such as local and central control methods[16]. In case of Local control, Inverter of EVs and PVWHSs of homes is trying to maintain their point of connection (POC)[16] voltage within the acceptable range while central controller does a complementary action for voltage improvement, by remotely controlling a battery energy storage (BES)[29] and the network on-load tap changer (OLTC)[16]. Fast responses to transients and the capability of reducing load peaks and voltage fluctuations for improving power quality, optimal energy management and voltage support has been increased by the application of battery energy storage (BESs) in low voltage (LV) distribution networks[44].

M.A. Hannana et al.[47] proposed technologies of Energy storage system(ESSs) and its classifications, characteristics, constructions, electricity conversion, and evaluation processes with advantages and disadvantages for electric vehicle (EV) applications. The electric vehicle (EV) technology addresses the issue of the reduction of carbon and greenhouse gas emissions and utilization of alternative energy resources. EV systems currently face challenges in energy storage systems (ESSs) [13]with regard to their safety, size, cost, and overall management issues. EV technologies are alternate solutions for Internal combustion engine (ICE) based transportations given that conventional vehicles with ICEs contribute low drive train efficiency and CO2 and GHGs emissions[43].

Dongqi Liu [27] presented control method for large-scale EVs connecting in grid for frequency regulation. The development of electric vehicles (EVs)[5] have the potential to become the main transportation for people to travel instead of traditional diesel locomotives. The Large-scale battery-based electric vehicles have the problem to the operation and planning of existing power grids[27]. The Large-scale battery-based electric vehicles charging increase the load of grid and reduces the efficiency of the current power system because charging behaviours occur during the peak period of the grid. Frequency regulation, reactive power support, spinning reserve, load balancing is provided by vehicle to grid (V2G)[24] system to the power grid. The frequency regulation is responsible for keeping the grid frequency stable around the rated frequency point. Thus the supply and demand balance of active power of the power system are met[23]. The current power system relies on large synchronous generators for frequency regulation by adjusting their active power output, which maintenance cost is expensive. If the electric vehicle increases then the certain strategy is used for the controlling the charging and discharging behaviour of the EVs group which can be used instead of the large synchronous generators for frequency regulation [25].

Xiangwu Yan et al.[23] introduced a three-phase virtual synchronous motor (VSM) control for providing fast-charging service from off-board chargers of electric vehicles (EVs). The electric vehicles (EVs)[27] is adopted in large scale because of energy crisis and environmental pollution. The VSM-controlled scheme introduced for the fast charging of the off-board charger[22]. The electric vehicles (EVs) charging is divided into two mode like slow charging and fast charging. Slow charging is customarily in excess of 6 h and for low-power on-board chargers while fast charging is utilized to high-power off-board chargers and have the potential to fully charge the EV in less than 1 h. In power system[23]. EVs are nonlinear loads whose frequent input and exit will provoke a negative impact on the power quality of the distribution network. For minimizing this problem VSM is used for improve stability of frequency and voltage due to the providing the inertia and damping[25].

Dongqi Liu et al.[18] implemented the idea for modelling and control of a V2G charging station (CS) for electric vehicles (EVs) by using synchronverter technology. Fuzzy controller is designed to decide the reference real power of the synchronverter by considering the grid frequency[41]. Due to the inner frequency and voltage drooping mechanisms of the synchronverter, the input and output real and reactive power of the charging station (CS) will be automatically adjusted on the basis of the reference value according to the degree of deviation from the nominal value of the grid frequency and voltage. For the safety of this operation, an adaptive frequency droop coefficient mechanism is designed to adapt the change of the total energy storage of a charging station (CS) unit[30].

Jon Are Suul et al.[22] designed a single-phase Virtual Synchronous Machine (VSM) and its application for providing Vehicle-to-Grid (V2G)[22] services from domestic battery chargers of Electric Vehicles (EVs). Power converter of VSM is controlled to emulate the inertia and the damping effect of a synchronous machine. Thus a VSM-based EV charger can contribute to the spinning reserve and the frequency regulation of the power system. In case of grid outages, the VSM can establish an islanded grid and supply local loads from the battery onboard the EV[22]. The control system for a single-phase Virtual Synchronous Machine (VSM)[45][46] has capability of providing ancillary services like participation in primary frequency control, inertia emulation for contribution to the spinning reserve and local voltage or reactive power regulation[22]. Thus, the VSM-based control approach can be a suitable option for providing Vehicle-to-Grid (V2G)[47] services from domestic single-phase battery chargers for Electric Vehicles.

Andrea Rodriguez-Calvo et al.[44] demonstrated the technical impact of integration of Electric Vehicle(EV)[27] and Photovoltaic (PV)[14] in low voltage (LV)[44] unbalanced networks. Voltage unbalance is a relevant problem that causes a less efficient operation of the system due to higher energy losses and lower hosting capacity. This work is focused on the evaluation of energy losses and voltage profiles in residential LV grids in rural and semi-rural areas. The technical analysis carried out is based on three-phase load flow analyses using the forward-backward algorithm for average hourly profiles for residential demand, PV production and EV charging during the night[44]. A wide range of scenarios has been considered to cover for different levels of demand, and penetration degrees of PV and EV[28]. The penetration of EV and PV may increase unbalance of distribution networks, as these are relatively large single-phase loads or power injections. If EV charging took place during peak demand then energy losses increase much more and arise voltage problems. The penetration of PV slightly reduces the losses in the system for low penetration degrees and mitigate the increase in losses driven by the system, but higher shares of PV produce the opposite effect[48].

4. RESEARCH FINDINGS AND SCOPE OF RESEARCH

The analysis of literature reveals that the continuous growth in the integration of distributed generations (DGs) in the power system network have little or no inertia and damping property as found in the conventional synchronous generator (SGs)[7]. The challenges that are needed to be the necessary improvement in the existing control scheme. RE of converter based has the characteristics, such as stochastic real and reactive power output, quick active and reactive power response, and small output impedance thereby causing frequency and voltage instability in the system.

- For the stability of frequency and voltage fluctuation in the system virtual synchronous machine (VSM) concept was proposed through converter control strategy of conventional SG in order to provide additional inertia virtually.
- The traditional linear time invariant based model is difficult to analyse a time-variant system and cannot analyse harmonic coupling mechanism accurately. Thus high permeability of distribution energy sources, the inertia and damping characteristics of the grid are reduced. VSM based on a small-signal modelling method is a linear-time invariant (LTI) model and linearise around a constant value which is not suitable for a grid inverter because of the time-varying characteristics of the system. All signals of linear time-varying periodic (LTP) are periodically time varying which is used to model the grid-connected inverter.
- The non-linear time varying, periodic (NLTP) system is linearised around a steady-state periodic operating trajectory. The control strategy of the VSM is superior to that of the traditional droop method in frequency stability and it is easier to cause low frequency oscillation. The LTP model is analysed in the extended harmonic domain (EHD) and the harmonic state-space (HSS) modelling approach is used to analyse the power system.
- The virtual impedance method is an important method for voltage and frequency control and for harmonic compensation based on converter control to improve system stability. The control technology based on power quality improvement including virtual synchronous machine (VSM) method and virtual impedance control method. Static synchronous compensators (STATCOMS) is usually needed to achieve reactive power compensation in the collector system lines and the point of interconnection (POI).
- Renewable energy (RE) microgrids are majorly concerned with low moment of inertia. This limits the microgrid's resiliency that may cause for the damage of electric/electronic devices in the buildings under uncertainties. Static power electronic inverters possesses low moment of inertia, which effects the system resiliency in the event of uncertainties.
- Virtual Synchronous Motor and Synchronous Generator (VSMSG) Control Scheme for the inverter that can mimic the behaviour of a conventional electrical machines based on energy converter. VSMSG control scheme to cope up and tolerate real time uncertainties such as load variations, faults by injecting the necessary virtual inertia.
- Transient stability of photovoltaic-hydro microgrid systems is poor due to lack of inertia and the intermittent nature of photovoltaic systems. The transient stability occur due to PV fluctuations and/or load or generation changes. Increased PV penetration in these PV-hydro integrated systems can have a significant impact on its dynamic performance and transient stability especially in the isolated mode of operation due to the lack of inertia and damping from conventional synchronous generators on the grid. Load/generation changes and PV fluctuations in such systems can cause large frequency deviations at a high rate of change of frequency (ROCOF).
- The stability of the systems can be improved by using virtual synchronous machines(VSM) which add inertia into the system to allow for higher PV penetration without losing stability. Virtual synchronous machine (VSM) reduced the frequency deviations and the high rate of change of frequency using a minimum amount of energy storage for the improvement the transient stability of the integrated PV-hydro microgrids.
- The system inertia is reduced because of massive deployment of power electronics . This results in a detriment of frequency stability particularly in isolated networks. The reduced inertia results in

frequency excursions in load shedding, even though the system's installed generation capacity may be enough to take over the balance between generation and demand.

- Design of a control strategy based on the virtual synchronous machine (VSM) concept to improve the incorporation of converter-coupled units. This method controls grid-connected renewable energy (RE) sources as electromechanical synchronous machines, which makes renewable energy sources behave as conventional power generation stations.
- The most common method used to recharge EVs is the well-known Plug & Charge. However, this method is not very efficient since it does not take into account any parameter for boosting efficiency. There are four different charging methods: the cheapest (C), the Cheapest Starting (CS), the Low Cost (LC), and the Last Period (LP) schemes, as an alternative to the traditional Plug and Charge (P&C) method. Objective of charging process of electric vehicles is to find better strategies for an automatic, efficient, and scheduled electric vehicles' charging process, avoiding peak power demands and promoting recharges at off-peak hours, where electricity prices are low.
- Smart charger proposed for enhancing the charging process at residential homes. Electricity pricing, the current state of the electricity grid, or vehicle's battery level would definitively improve the charging process. According to this, we propose four charging methods, namely the Cheapest, the Cheapest Starting, the Low Cost, and the Last Period. These methods seek to maximize the charge of the batteries while minimizing the cost of the electricity consumed.
- Wired charging uses metal contact between electric vehicle supply equipment (EVSE) and the charging inlet of the vehicle. Even though wired charging is popular, problems with wires and safety concerns in wet environment are major drawbacks of this system. On-road EV charging is an emerging technology where one can charge their EV batteries while vehicle is on move. Apart from their advantages such as less battery requirements, they suffer a problem of misalignment and further leads to synchronization failures. Various loading conditions, frequency mismatch, misalignment and component tolerance are the main causes for the synchronization failure.
- These problems can be overcome by charging the battery of the vehicle without wires and this technology is termed as wireless power transfer (WPT). Off-board and on-board battery chargers with unidirectional and bi-directional power flow. Most of the battery chargers take a power from the utility grid, for this reason they often termed as unidirectional battery chargers (UBCs).Unidirectional charging reduces the interconnection issues and battery degradation. On the other hand, some battery chargers work in both directions and these are called bidirectional battery chargers (BBCs). These chargers support stabilization of power with proper power conversion.
- Regarding grid connection aspects electric vehicles have some challenges such as PHEVs charging problem, the influence of charging loads on the grid, optimizing charging schedule of PHEVs [10]. Even though EVs can then be regarded as flexible performers in the smart grid, V2G comes with additional costs for battery degradation and power electronics.
- Grid-to-vehicle (G2V) and vehicle to-grid (V2G) connections are considered as essential parts of the smart grids which can considerably enhance the performance of the system in different aspects. The control strategies that are used for G2V and V2G connections include multi-agent control, frequency control, aggregated control, virtual synchronous machine-based control. VSM method can improve grid stability in terms of power system stability but it requires a complex controller design. Aggregated and Multi-agent type of control strategies prove to be a preferred choice for wide area control. V2Gs are the possible solutions for enhancing future smart grid resiliency by supporting power grid.
- The penetration of massive EVs will also challenge the operation of the power system, since the additional load of EV charging may potentially amplify the daily peak of power load curve and

induce some adverse impacts including voltage drops, frequency oscillations. EV can direct energy back into the power grid by utilizing the discharging activity of the EV battery. This technology is well known as Vehicle-to-Grid (V2G) technology. With V2G, EVs can act as moving energy banks, capable of procuring energy from the power grid and also injecting energy back when necessary. Therefore, the power flow of V2G can be unidirectional (charging only) or bidirectional.

- Analyses the technical and economic viability of an off-grid PVBESS for Charging Electric Vehicles (EVs). Economic and non-polluting charging process for EVs which ensures the system efficiency and the reduction in emissions while being technically and economically feasible. Energy storage system is used due to the intermittent character of the solar radiation.
- Off-grid PV-BESS can be considered not only a good solution for emissions reduction in industrial countries characterized by a good amount of solar radiation and that are economically rentable and energetically reliable. Therefore, a higher capacity installation must be considered, due to future growth forecasts in the electric mobility sector and new high-power chargers. The performance of the battery technologies and design control systems that allow to manage in the most efficient way the solar resource, the backup batteries and the recharges of the EVs in off-grid PV-BESS.
- EVs connected to the grid through their chargers do not only represent a load, but also a potential distributed storage system. Indeed, some of the stored energy in the EV batteries can be made available to the grid if bi-directional chargers are adopted. This can allow for additional V2G functionalities, including inertia emulation with transient power injection from the battery to the grid in case of sudden frequency transients due to loss of generation or other power system faults. The energy from the EV battery can be used to supply small local loads like individual households in islanded operation, even for several hours, in case of power outages in the main grid
- A control method for EVs participating in grid frequency regulation is proposed, which is based on the clustering algorithm and automatically adjust VSM parameters. Firstly, the K-means clustering algorithm is applied to cluster EVs with different battery SoC and with different average vehicle daily travel miles. Then according to the clustering results, a multi-objective optimization problem is proposed to optimize the set power and the droop coefficient of the VSM.
- A multi-objective optimization model considering reducing power imbalance and feeding the driving power demand for electric vehicles. The control variable of the optimization model is the initial set power and the droop control coefficient of the ”Virtual Synchronous Machine”, which is like a synchronous generator with variable capacity be driven by a prime mover with adjustable output torque. This will help the power electronic converter connected to the electric vehicle to be more compatible with the synchronous generator-dominated power system. The solution of optimization model based on Multi-Objective Particle Swarm Optimization (MOPSO) algorithm. For different electric vehicles group classes, the optimal compromise solution of the optimization model is calculated respectively, which are used as the control parameters to adjust the output power of the virtual synchronous machine of a different class of the electric vehicles.

5. CONCLUSION AND FUTURE SCOPE

Power quality is an important aspect of renewable energy integration such as Voltage and frequency fluctuations which are caused by non-controllable variability of renewable energy resources. The intermittent nature of renewable energy resources due to changing weather conditions leads to voltage and frequency fluctuations at the interconnected power grid and harmonics, which are introduced by power electronic devices utilized in renewable energy generation. Power grid operate with renewable energy sources can be very complicated. Several capacitor can be used to maintain steady-state power factor close to unity over the output range of generators. However, these generators do not have the ability to control reactive power. Hence, Virtual Synchronous machine based intelligence control strategies can be adopted for power quality improvement in realistic power system.

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