A Literature Survey on Control Strategies in a Microgrid

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***Abstract*—Due to the rapid increase in global energy consumption and the diminishing of fossil fuels, the customer demand for new generation capacities and efficient energy production, delivery and utilization keeps rising. The micro grid concept has the potential to solve major problems arising from large penetration of distributed generation in distribution systems. Although the inertia energy in power sources can partly cover power unbalances caused by load disturbance or renewable energy fluctuation, it is still hard to maintain the frequency deviation within acceptable ranges. However, electric vehicles (EVs) can act as mobile energy storage units, which could be a solution for load frequency control (LFC) in an isolated grid.**

In this paper, the major issues and challenges in microgrid control are discussed, and a review of control strategies and trends is presented.

***Keywords*—*Electric Vehicles(EVs), Load Fequency control(LFC), Distributed Generation(DG)*.**

I. INTRODUCTION

One of the biggest problems that mankind has to deal with is global warming and all the consequences related to it. Carbon dioxide emissions (CDE) have to be avoided as much as possible for which purpose drastic changes are urgently needed in the way fossil fuels are used. An important contribution in this field is being done by the increasingly use of renewable energy sources (RES) within power systems.

It is therefore important to contribute in topics associated to energy efficiency, which is linked with the concept of the smart grids (SGs), which incorporates bidirectional telecommunication networks, distributed and centralized controllers, distributed generators and manageable loads, in order to offer an increased reliability, security, energy efficiency and a reduced rate of CDE.

Microgrids are vital components of SG architectures, which are defined as low voltage (LV) and medium voltage(MV) systems with distributed energy resources (DER), storage devices (SD) and controllable loads (CL), connected to the main power system or isolated. During grid-connected operation of a microgrid it is possible to dispatch DERs active power considering an economic criterion since voltage and frequency regulation is performed at the main grid.

In isolated mode is necessary to control DERs to ensure voltage and frequency stability within the microgrid.

In order to successfully integrate renewable Distributed Energy Resources (DER), many technical challenges must yet be overcome to ensure that the present levels of reliability are not significantly affected, and the potential benefits of distributed generation are fully harnessed. In this sense, the main issues include [1]:

• Schedule and dispatch of units under supply and demand uncertainty, and determination of appropriate levels of reserves.

• Reliable and economical operation of microgrids with high penetration levels of intermittent generation in standalone mode of operation.

• Design of appropriate Demand Side Management (DSM) schemes to allow customers to react to the grid's needs.

• Design of new market models that allow competitive participation of intermittent energy sources, and provide appropriate incentives for investment.

• Reengineering of the protection schemes at the distribution level to account for bidirectional power flows.

• Development of new voltage and frequency control techniques to account for the increase in power electronics interfaced distributed generation.

• Develop market and control mechanisms that exhibit a plug-and-play feature to allow for seamless integration over time.

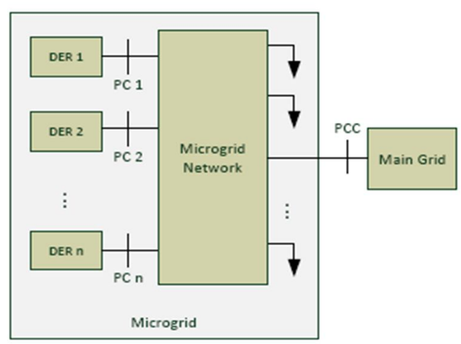

Fig.1: Schematic diagram of a generic multiple-DER microgrid

II. MICROGRID DEFINITIONS

The concept of microgrid was first introduced in the technical literature in [2] and [3] as a solution for the reliable integration of DERs, including Energy Storage Systems (ESSs) and controllable loads. Such microgrid would be perceived by the main grid as a single element responding to appropriate control signals. Although a detailed definition of microgrids is still under discussion in technical forums, a microgrid can be described as a cluster of loads, Distributed Generation (DG) units and ESSs operated in coordination to reliably supply electricity, connected to the host power system at the distribution level at a single point of connection, the Point of Common Coupling (PCC). The adoption of microgrids as the paradigm for the massive integration of distributed generation will allow technical problems to be solved in a decentralized fashion, reducing complex central coordination and facilitating the realization of the Smart Grid. In general, a microgrid can have any arbitrary configuration, as illustrated in Fig.1; however, some entities, such as the Consortium for Electric Reliability Technology Solutions (CERTS), promote a configuration in which loads are connected to the feeders with existing generation [10]. In some cases, where a strong coupling between the operation of different energy carrier systems (heating, hot water, etc.) exists, microgrids can integrate and operate all these energy carriers in coordination.

A Microgrid and its various evolved forms, such as Active Distribution System (ADS), cognitive microgrid, and Virtual Power Plant (VPP) [4]–[8], can be considered and exploited as a main building block of the Smart Grid. An ADS is a microgrid equipped with power management and supervisory control for DG units, ESSs and loads [9]. A cognitive microgrid is an intelligent microgrid that features an adaptive approach for the control of the microgrid components. Thus, in the context of VPP [6], the cognitive microgrid is presented to the host grid at the PCC as a single market agent with a prespecified performance; the internal mechanisms and composition of the VPP are hidden from the host power system. It is important to note that the VPP is not limited to a microgrid scope; in fact, the coordination of multiple DG units throughout a bulk power system is also considered as a VPP solution. A microgrid is capable of operating in grid-connected and stand-alone modes, and handling the transitions between these two modes [10], [11]. In the grid-connected mode, the power deficit can be supplied by the main grid and excess power generated in the microgrid can be traded with the main grid and can provide ancillary services. In the islanded mode of operation, the real and reactive power generated within the microgrid, including the temporary power transfer from/to storage units, should be in balance with the demand of local loads. IEEE Standard 1547 includes guidelines for interconnection of DER units [12]. Islanding, i.e., disconnection of the microgrid from the host grid, can be either intentional (scheduled) or unintentional. Intentional islanding can occur in situations such as scheduled maintenance, or when degraded power quality of the host grid can endanger microgrid operation. Unintentional islanding can occur due to faults and other unscheduled events that are unknown to the microgrid; proper detection of such a disconnection is imperative for safety of personnel, proper operation of the microgrid, and implementation of changes required in the control strategy. The technical literature offers a wealth of islanding detection algorithms, which operate based on frequency/voltage measurements (pasive) or disturbance injection (active) (e.g., [13], [14]). Microgrids that do not have a PCC are called isolated microgrids. This is the case of remote sites (e.g., remote communities or remote industrial sites) where an interconnection with the main grid is not feasible due to either technical and/or economic constraints; therefore, isolated microgrids operate permanently in stand-alone mode.

III. Control and Protection Requirements

Microgrids, and integration of DER units in general, introduce a number of operational challenges that need to be addressed in the design of control and protection systems in order to ensure that the present levels of reliability are not significantly affected and the potential benefits of DG are fully harnessed. Some of these challenges arise from invalid assumptions typically applied to conventional distribution systems, while others are the result of stability issues formerly observed only at a transmission system level.

The most relevant challenges in microgrid protection and control include:

(i) Bidirectional power flows: While distribution feeders were initially designed for unidirectional power flow, integration of DG units at low voltage levels can cause reverse power flows and lead to complications in protection coordination, undesirable power flow patterns, fault current distribution, and voltage control.

(ii) Stability issues: Local oscillations may emerge from the interaction of the control systems of DG units, requiring a small-disturbance stability analysis. Transient stability analyses are required to ensure seamless transition between the grid-connected and stand-alone modes of operation in a microgrid.

(iii) Modeling: Prevalence of three-phase balanced conditions, primarily inductive transmission lines, and constant power loads are typically valid assumptions when modeling conventional power systems at a transmission level; however, these do not necessarily hold valid for microgrids, and consequently models need to be revised.

(iv) Low inertia: Unlike bulk power systems where high number of synchronous generators ensures a relatively large inertia, microgrids might show a low-inertia characteristic, especially if there is a significant share of power electronic-interfaced DG units. Although such an interface can enhance the system dynamic performance, the low inertia in the system can lead to severe frequency deviations in stand-alone operation if a proper control mechanism is not implemented.

(v) Uncertainty: The economical and reliable operation of microgrids requires a certain level of coordination among different DERs. This coordination becomes more challenging in isolated microgrids, where the critical demand supply balance and typically higher component failure rates require solving a strongly coupled problem over an extended horizon, taking into account the uncertainty of parameters such as load profile and weather forecast. This uncertainty is higher than those in bulk power systems, due to the reduced number of loads and highly correlated variations of available energy resources (limited averaging effect).

The microgrid's control system must be able to ensure the reliable and economical operation of the microgrid, while overcoming the aforementioned challenges. In particular, desirable features of the control system include:

(i) Output control: Output voltages and currents of the various DER units must track their reference values and ensure oscillations are properly damped.
(ii) Power balance: DER units in the microgrid must be able to accommodate sudden active power imbalances, either excess or shortage, keeping frequency and voltage deviations within acceptable ranges.
(iii) DSM: Where applicable, proper DSM mechanisms must be designed in order to incorporate the ability to control a portion of the load. Additionally, for the electrification of remote communities with abundant local renewable resources, the active participation of the local community may be beneficial in order to design cost-effective DSM strategies that enhance load-frequency control [15][16].
(iv) Economic dispatch: An appropriate dispatch of DER units participating in the operation of a microgrid can significantly reduce the operating costs, or increase the profit. Reliability considerations must also be taken into account in the dispatch of units, especially in stand-alone operation.
(v) Transition between modes of operation: A desirable feature of microgrids is the ability to work in both gridconnected and stand-alone modes of operation, including a smooth transition between them. Different control strategies might be defined for each mode of operation and, therefore, a high-speed islanding detection algorithm is very important in order to adjust the control strategy accordingly [17].

Components involved for Control and protections are:

A. Controlled Variables

The main variables used to control the operation of a microgrid are voltage, frequency, and active and reactive power. In the grid-connected mode of operation, the frequency of the microgrid and the voltage at the PCC are dominantly determined by the host grid. The main role of the microgrid control in this case is to accommodate the active and reactive power generated by the DER units, and the load demand.

Reactive power injection by a DER unit can be used for power factor correction, reactive power supply, or voltage control at the corresponding Point of Connection (PC). In this mode, the host utility may not allow regulation or control of the voltage by DER units in proximity of the PCC (determined by the electrical distance and Short Circuit MVA of the grid) to avoid interaction with the same functionality provided by the grid [12].

In stand-alone mode of operation, the microgrid operates as an independent entity. This mode of operation is significantly more challenging than the grid connected mode, because the critical demand-supply equilibrium requires the implementation of accurate load sharing mechanisms to balance sudden active power mismatches. Voltages and frequency of the microgrid are no longer supported by a host grid, and thus they must be controlled by different DER units. Power balance is ensured either directly by local controllers utilizing local measurements, or by a central controller that communicates appropriate set points to local controllers of different DER units and controllable loads. The main objective of such a

mechanism is to ensure that all units contribute to supplying the load in a pre-specified manner. A minute mismatch in the amplitude, phase angle or frequency of the output voltage of any unit in the group can lead to a relatively high circulating current. This problem is extensively investigated in the literature

and different control schemes are proposed to overcome the issue [18]–[22]. One possible approach is to have one inverter operate as a master unit that regulates the voltage of the microgrid [23]. The same unit can also control the frequency in open loop through an internal crystal oscillator.

This DER unit can be operated similar to a synchronous generator with a reactive power-voltage droop characteristic, while the remaining DER units inject active and reactive power according to the set points determined by the secondary controller [24]. A similar strategy can also be applied to the control of DC microgrids, where a master DER unit can be assigned to control the voltage level of the microgrid, compensating for instantaneous active power mismatches. Alternatively, several units can share active power mismatches using active power voltage droop characteristics [25].

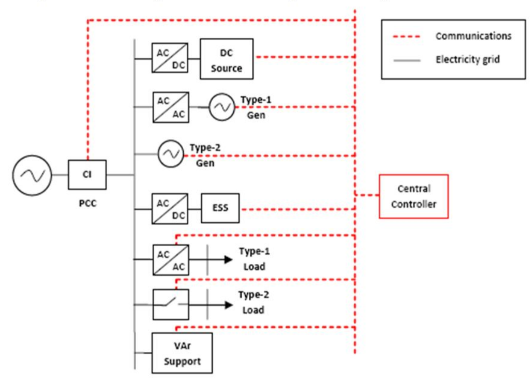

Fig. 2: Microgrid general components

B. Types of DER Units

The DER units present in a particular microgrid are very problem-specific and depend on a variety of factors, including whether the microgrid is designed to operate in grid-connected or stand-alone mode, the different generation technologies deployed, and the topology of the system [26]. In general, the components that can be found in a purely-electrical microgrid are illustrated in Fig. 2.

Microgrids are characterized by a single point of connection with the host grid. The Connection Interface (CI) at the PCC can be realized using electro-mechanical circuit breakers, solid state switches or even back-to-back converters.

The connection of DC-type energy sources such as PV panels, fuel cells and energy storage technologies (batteries and ultracapacitors) requires the use of a DC-to-AC power converter interface. While some conventional generators can be connected directly to the microgrid and operate at 50/60 Hz, variable-speed generators such as wind turbines using synchronous machines, and high-speed microturbines require the use of AC-to-AC power converters to match the constant frequency and voltage of the microgrid. Wind turbines can also operate with low flexibility using induction generators directly connected to the system, or use the more flexible doubly-fed induction generator. Loads within the microgrid can be controlled using either a conventional circuit breaker or a more sophisticated AC-to-AC power electronic interface to allow more flexible control. Reactive power support can be provided by capacitor banks, SVCs or STATCOMs.

DER units can also be categorized based on their dispatchability. Dispatchable units (e.g., diesel generators) can be fully controlled; however, nondispatchable units cannot, and are typically operated to extract the maximum possible power. DER units based on renewable energy sources (e.g., a wind turbine or photovoltaic units) are generally intermittent and their output is not controllable.

C. Energy Storage Systems

Integrated storage can decrease losses and increase reliability. Energy storage enables large-scale integration of intermittent renewable energy sources [27]. The benefits of storage in the latter application are of particular interest, because while renewable energy resources are a pillar of the microgrids, without storage, their generation cannot improve the system reliability and has to be duplicated by other means of generation. A storage unit can provide a functionality similar to that of the inertia of a synchronous generator by absorbing temporary mismatches between power generation and demand, especially in a low inertia power electronic-based microgrid. Therefore, system stabilization can be improved by providing voltage/frequency control in a droop-based scheme. Despite its benefits, energy storage has not been fully utilized. Among the limiting factors is, besides the cost, the lack of appropriate control and management strategies [28].

Several contribution is going on to investigate and develop control methodologies for the following different energy storage technologies, with different energy and power ratings and efficiencies and in different applications (e.g., diurnal renewable resources levelizing, reserve augmentation, voltage support, and reliability enhancement) [29]–[33]: Battery Energy Storage System (BESS), Compressed Air Energy Storage (CAES) systems, flywheels, thermal energy storage, pumped hydro, Superconducting Magnetic Energy Storage (SMES) and vehicle-to-grid (V2G) technologies [34].

Energy storage has applications in transmission capability improvement, power quality enhancement, microgrid islanded operation, active distribution systems, and electric vehicle technologies, and may improve dynamic stability, transient stability, voltage support, and frequency regulation [31], [35], [36]. The power grid can substantially benefit from the availability of stored energy in generation, transmission, distribution, and consumption [37]. For example, storage can eliminate or delay expansion of the transmission infrastructure or generation capacity. Storage can be combined with nondispatchable DER units such as wind and solar energy to turn them into dispatchable units. On the consumers' side, storage can be employed for peak-shaving by storing the locally generated energy until it is needed. An extensive list of applications for energy storage in transmission, distribution, and generation is presented in [38].

IV. Control Strategies In A Microgrid

Several contributions on control strategies of microgrids have been made.

[39] proposed Model of the *Benchmark Micro-Grid and with LFC Controller* as shown in Fig3, and Fig4 respectively a micro-grid is composed of a single bus-bar, a wind turbine, a diesel generator, EVs and loads. The power grid is managed by a distribution management system (DMS), and the micro-grid operation is controlled by a micro-grid dispatch system (MGDS). Phasor measurement units (PMUs) are installed in this micro-grid to measure the real-time information of circuit breakers, distributed generation sources, EVs, and loads. With the same model, the micro-grid can be operated in two alternative modes, *i.e.*, the isolated mode and the grid-connected mode.

By controlling the circuit breaker "Breaker1" in Fig3, the micro-grid can switch from one mode to the other mode. If the micro-grid is grid-connected, the majority of loads can be supplied by the connected electrical power system. Otherwise, in the isolated mode, the loads will be supplied by coordinated control of EVs and the diesel generator.

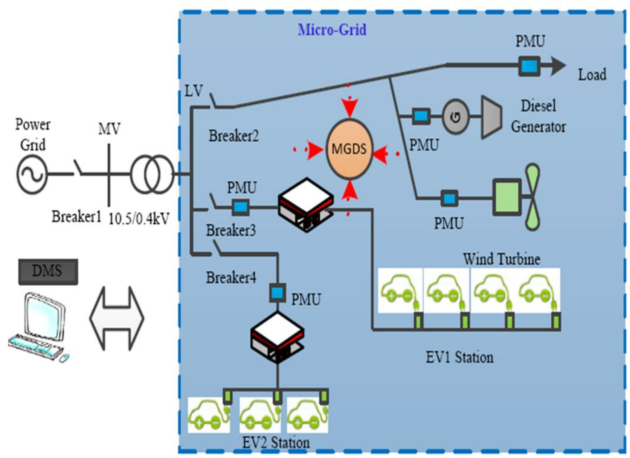

Fig.3: The model of the benchmark micro-grid

Fig4 shows the framework of the proposed LFC controller in an isolated micro-gird, which consists of a DG, two equivalent EVs (*i.e.*, EV1 and EV2), and power disturbance ΔP_D .where ΔP_D consists of load disturbance ΔP_L and the fluctuation of wind power generation ΔP_W. Also, in the Fig4 H_t represents the equivalent inertia constant of the isolated micro-grid, which consists of inertias for all the directly connected generators and motor loads.

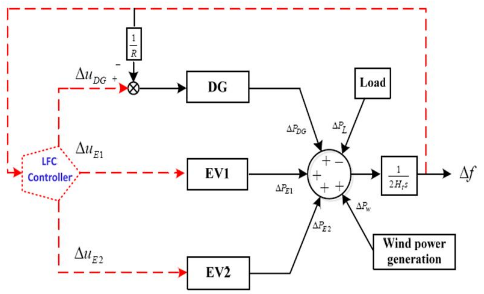

Fig.4: The control model of the micro-grid including LFC controller

[39] proposed The Coordinated LFC Controller Based on Multivariable Generalized Predictive Control. When the isolated grid suffers from a power disturbance, the goal of LFC is to regulate the frequency deviation to zero as soon as possible by controlling the input signal of DG and EVs. According to system state and disturbance characteristic, an online closed-loop control system can be established considering the constraints of DG and EVs. As shown in Fig5, this controller is composed of two layers: a coordinated control layer and a local frequency control layer. Based on frequency deviation and active power deviation, the coordinated control layer first provides the real time LFC signal to the local frequency control layer; then the local frequency control layer controls the DG and the EVs to quickly damp the system frequency oscillation.

The operation flow of the proposed controller can be divided into following three steps:

Step 1: State monitoring. The real-time state information measured by PMUs, including Δf, ΔP_{E1},

ΔP_{E2}, ΔP_{DG}, and ΔP_D, is collected by MGDS, and then sent to the proposed coordinated controller.

Step 2: *Future prediction*. Based on the real time state information from MGDS, the coordinated controller will predict the dynamic trajectory of Δf using the controlled auto-regressive and integrated moving average (CARIMA) model [40]. Then the relationship between control variables Δu_{E1}, Δu_{E2}, Δu_{DG} and the predicted variable Δf is established.

Step 3: *Optimal control*. Based on the result from step 2, the coordinated controller will calculate Δu_{E1}, Δu_{E2} and Δu_{DG} according to the objective function considering the constraints of EVs and DG.

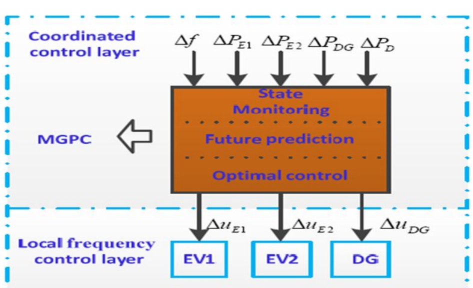

Fig. 5: The structure of the proposed coordinated LFC controller based on MGPC

[41] proposed an energy management scheme for ESS in micro-grid applications to extend ESS life expectancy as well as to improve ESS energy efficiency while complying with constraints of energy storage modules in ESS. A model of battery lifetime based on the workload of the battery using Peukert Lifetime Energy Throughput has been developed. For operating conditions of ESS where the constraint such as SOC cannot be achieved, there should be some trade-offs of lifetime reduction or efficiency reduction. These trade-offs also can be partly determined and it is easy to extend energy capacity of the ESS by installing new energy storage devices into the current ESS to avoid further constraint violation

[42] proposed an interactive DG interface for flexible micro-grid operation in the smart distribution system environment. The proposed control scheme utilizes a fixed power–voltage–current cascaded control structure with robust internal model voltage controller to maximize the disturbance rejection performance within the DG interface, and to minimize control function switching. The control scheme has a simple and linear control structure that facilitates flexible DG operation in the grid-connected mode and autonomous micro-grids, yields robust transition between grid-connected and islanded modes either in PQ or PV operational modes, and provides robustness against islanding detection delays due to the fixed control structure under different modes of operation.

[43] proposed design of a micro-grid with a centralized renewable hybrid generation system based on solar photovoltaic and wind energies. The innovations introduced in this kind of system are related to the requirements imposed and adequately fulfilled, i.e., reliability of the service, adaptability to the climate conditions, and high level of robust automation in order to reduce maintenance needs. It was shown that part of these requirements can be fulfilled with parallel operations of inverters specially designed for these applications. The system described here definitely helps to bring energy to isolated islands and to decrease the CO2 emissions.

[44] proposed a fuzzy based frequency control approach by the grid-connected MW class PV generators and EVs. From the simulation results, it is seen that it works efficiently in the case of insolation and load variations.fuzzy controls are effective when mathematical expressions are difficult by the inherent complexity or nonlinearity or uncertainty. Load and insolation variations are the causes for the problems like frequency deviations, tie-line power fluctuations, and bus voltage fluctuations in a utility grid. These problems need to be solved for the large penetration of distributed PV power. So, the fuzzy control of PV inverters can be an intelligent solution to address those problems in the formation of the future smart grid.

[45] proposed a broad comparison of two immense energy conversion systems, finding them surprisingly complementary. The electric grid has high capital costs and low production costs; the automobile fleet is the reverse. Electric generators are in use 57% of the time, automobiles only 4%. The electric grid has no storage; the automobile fleet inherently must have storage to meet its transportation function. Based on the contrasts between these systems, management strategies, business models, and three steps for a transition to V2G are lay out.In the short-term, electric-drive vehicles should be tapped for high-value, time critical services—regulation and spinning reserves—which can be served by about 3% of the fleet. As those markets are saturated, V2G can begin to serve markets for peak power and storage for renewable electric generation.

[46] proposed a new technique that allows the specification of the weighting matrices *Q* and *R to solve* The frequency control problem of a large power system (a multi-area electric energy system). the optimal output state feedback, together with the proposed algorithm for specifying *Q* and *R*, yields results that are robust, and according to the desired performance.

[47] proposed the V2G concept through simulation of a typical distribution system of Guwahati city. The concept of a charging station has been introduced where all EVs from a particular area will charge or discharge their energy to the grid from the same location. V2G controller and a charging station controller have been designed using fuzzy logic. These controllers have been used to control the flow of energy between EVs and the grid. FLC has been implemented to achieve V2G operation and the impact of this V2G operation, in terms of voltage stability and peak demand management, has been analyzed for two different scenarios. Simulation results reveal that charging and discharging of EVs can be easily controlled using an FLC. Power leveling and peak saving can be achieved by charging of EVs during off-peak hours and discharging the EVs energy during peak hours.

[48]proposed two battery control methods to suppress frequency variations caused by wind power generation while considering battery SOC. One method controls signal distribution using LPF to consider response speed differences between generators and storage batteries. The other method determines storage battery output while considering SOC to maintain proper SOC levels. Furthermore, H_∞ control theory is applied to achieve robust control that considers parameter fluctuation generated by state variation of power systems. Finally, proposed a control system that combines these two methods, and carried out simulations to verify the effectiveness of the proposed method. Those simulations confirmed that the proposed method is valid when a large amount of wind power generation is connected to the power system.

[49] proposed the feasibility of using PV electricity to charge PHEVs, from a system performance perspective. Results reveal that this practice is feasible in short-term, as PV arrays can meet part of the PHEV charging demand and lessen the loading of distribution system equipment, thus reducing the necessity for costly system upgrades. However, in the long-term, PV arrays will not be able to meet the much-increased demand projected with higher PHEV penetration, and so system upgrades will be necessary. These findings are attributed to the weak chronological coincidence between PV array production and PHEV demand. The authors suggest using storage devices to increase the synergy between these two technologies and thus lessen the impacts of uncontrolled PHEV charging on distribution transformers.

[50] proposed an enhancement of a stochastic EV charging model based on the Non homogeneous Poisson process to be incorporated in the SMCS method in order to analyze the EV impact on the probabilistic evaluation of the generating system adequacy studies. The use of the NHPP model in SMCS allows the analysis of the EV impact in the same time basis of the generating unit transition and makes it possible to monitor the battery SOC of each vehicle as well as the ramp of EV load events.

[51] proposed DVC to suppress system frequency fluctuation while simultaneously achieve charging demand. With adaptive frequency droop control, a V2G control strategy, called BSH, is designed based on the initial SOC to maintain the residual battery energy. It is flexible for the BSH to hold different initial SOC levels altogether with frequency regulation. In order to achieve charging demand of the EV customer, another V2G control strategy, called CFR, is developed on the basis of the actual plug-in duration and the expected SOC. The CFR is designed considering the specific charging demand of each EV, so it is flexible.

[52] proposed a TDMLP neural network load frequency control to improve the performance and stability of the power system. This control strategy was chosen because the power systems involve many parametric uncertainties with varying operating conditions. Transient behavior of the frequency of each area and tie-line power deviations in the power system with two areas is considered under any load perturbations in any area. The simulation results show that proposed controller is effective and can ensure that the overall system will be stable for all admissible uncertainties and load disturbances, also The TDMLP controller can achieve good performance even in the presence of GRC, especially when the system parameters are changing.

[53] proposed Coordinated control of blade pitch angle and PHEV power output using MPCs in order to reduce fluctuation of frequency in microgrid system .The MPC for blade pitch angle control is employed for smoothing wind power production of WTG. In addition, the MPC for PHEVs controller is employed in order to control load frequency of the microgrid system. Simulation results show that the proposed coordinated control of MPC-Pitch-PHEVs has better performance than MPC-Pitch and MPC-PHEVs. The results imply that the proposed MPC based coordinated control method not only reduces frequency fluctuation of the system but also reduces the number of PHEVs. Moreover, the proposed MPC-based pitch angle and PHEV control is robust to the system parameter variation when compared with PID controller.

[54] Proposed A transient performance study of the isolated wind Diesel hybrid power system with load frequency controller installed on the Diesel unit and the wind turbine unit equipped with a blade pitch control mechanism and shows that, for change in input wind power, the transient performance of the system is better when it is equipped with a blade pitch control mechanism, but for change in load, the transient performance of the system remains unaffected, as it is accomplished by the load frequency controller installed on the Diesel unit.

[55] Proposed The investigation of V2G regulation capabilities in the West Denmark power system using a simplified load frequency control model. From the simulation results for two typical days with high and low wind power production, the power exchange deviations are significantly reduced between the West Denmark—UCTE interconnections with the use of faster V2G regulation power. The regulation power requirements from conventional generators are also greatly reduced with the integration of a V2G system participating in load frequency control.

V. Conclusions

The development of microgrids comes as a necessity for the integration of renewable energy sources into remote communities, and as an intermediate milestone towards the realization of the Smart Grid. This paper presented an overview of current developments on microgrid control.The paper reviewed the requirements and desirable traits of the control systems, its different architectures and remaining challenges; emerging approaches applied to microgrid control (e.g., MPC, MAS) were also discussed. ESS is identified as a key technology for the integration of intermittent renewable energy sources. This, in turn, introduces major challenges to the control system for the appropriate management of this resource. According to review results, a coordinated controller based on MGPC theory for LFC in an isolated micro-grid with V2G technique can obtain better robust performance on LFC with complex operation situations, namely, random renewable energy generation and continuous load disturbances.

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