

Security of Supply in Active Distribution Networks with PHEV-Based Strategic Microgrids

Dilan Jayaweera and Syed Islam

1 Introduction

Renewable power is a strong resource of green energy for the future of electricity generation. Among renewable energy sources, wind energy is the world's fastest growing energy source with an average annual growth rate of 29% over the last 10 years. It is estimated that worldwide installed capacity of wind will reach 460 GW by 2015. Unlike conventional power plant sites, wind plants are geographically constrained and operated as geographically constrained intermittent power generating units that randomly suffer from network constraint issues in transporting electricity to destinations. Such problems can be mitigated by strategically placing the units that compensate for intermittent power outputs. One of such units is the plug-in hybrid electric vehicle (PHEV) reserve-based microgrid. Strategically placing PHEV reserve-based microgrids can potentially mitigate severity of network problems and they can also improve the security of supply if they are appropriately located in an active distribution network. Such a provision can also improve the active network performance by reducing power losses, by improving voltage profiles, by reducing the network congestion, and by improving power transfer margins. However, the challenging issue in this context is how to determine the locations of PHEV reserve-based strategic microgrids and how to quantify their capacities with the presence of increased renewable power generation. The challenge and the complexity of the problem are further increased when the overall objective is to improve the security of supply or at least to maintain the acceptable level of security of supply to consumers.

The integration capacity of distributed generation (DG) on existing distribution networks are limited and high penetration of DG can also harm the security of power supply to consumers unless the high penetration is made through strategi-

D. Jayaweera (✉) · S. Islam

Department of Electrical and Computer Engineering, Curtin University, Perth, Australia

e-mail: d.jayaweera@curtin.edu.au

S. Islam

e-mail: s.islam@curtin.edu.au

cally gifted locations. The intermittent power output characteristics of centrally integrated DG units such as wind and photo voltaic (PV) units have caused problems to the security of power supply at some of the penetration levels and the literature addresses these issues in detail [1–3]. Reference [4] proposes a linearized technique to quantify the risk-based index for the assessment of dynamic security. DG impacts can be viewed through many avenues. Reference [5] proposes a successive elimination algorithm to assess impacts of DG on investment deferral through the security of supply provision. Reference [6] presents an investment deferral approach based on demand growth and investigates the associated influence of the investment on security of supply. Impacts of large scale integration of wind power on network security through contingency analysis are explored in [7]. Optimal power flow and active management techniques-based approach is proposed in [8] for the economical assessment of wind-diesel connected systems. Reference [9] proposes a technique to assess impacts of location of wind farms. A method to determine the accommodation capacity of DG with the objective of minimizing the power losses with smart control switches is explored in [10]. The reference [11] investigates the PHEV applications in the deregulated electricity market and applies dynamic programming to optimize the charge control. Reference [12] assesses electric energy and power consumption with light duty plug in hybrid vehicles. Impacts of PHEV charging patterns are studied in [13] in the context of stochastic unit commitment.

This chapter investigates the role of PHEV-based microgrids for improving the security of supply to customers with the increased penetration of intermittent DG as the form of remote microgrids. The chapter also proposes a methodology to determine locations of the PHEV-based strategic microgrids and their capacities taking into account the mobility advantage of PHEV-based microgrids. The chapter focuses on what power the PHEV and remote microgrids deliver to an active distribution network and not the inside operation of microgrids. The steady state security is the focus of the approach which incorporates Monte Carlo simulation (MCS) to estimate the parameters.

The chapter is organized as follows. Section 2 presents the approach of the chapter. Section 3 describes the case study in detail and critically scrutinizes the results. Section 4 concludes findings.

2 The Approach

Outages in a distribution network can stress the nominal operating characteristics of equipment. Some of the active networks are congested with increased penetration of DG. In those circumstances, although the electricity can be generated at remote stations they may not always be able to transfer to the load centers. The severity of the situation can also be increased with the increased penetration of intermittent DG. Thus, identifying PHEV-based strategic microgrids and then penetrating renewable power through remote microgrids can be a potential solution to mitigate network congestion at stressed operating conditions. In addition, the PHEV-based strategic

microgrids help reducing power losses as well as reduce the need for reactive power due to intermediate supply of active power. The most important aspect of a PHEV-based microgrid is the ability to vary its capacity dynamically taking into account the advantage of PHEV capacity mobilization.

The proposed approach incorporates sequential MCS to capture uncertainties in active distribution network operating conditions. Sequential MCS is used because the successor sample operating condition of MCS depends on the predecessor sample operating condition. In an active distribution network, most uncertainties are due to random outages of network components, intermittent power outputs from stochastic DG plants, and significant demand level variations. The severity of outages can also be increased with different weather conditions.

The proposed approach treats the wind and PV plants as generating sources of remote microgrids. Thus, the strategic PHEV-based microgrids are able to provide standing reserve supports for the intermittent outputs of remote microgrids and help reducing the network stress due to outages and congestion.

The first step of the approach is to model the base case operating condition without incorporating PHEV-based microgrids. Adopting this philosophy enables to differentiate the impacts of intermittent DG-based microgrids from PHEV-based microgrids. The base case should be selected in such a way that it does not carry constraint violations. Constraints in this assessment include thermal limits of branches and voltage limits of buses.

Next, remote microgrids with wind and PV generating units are identified and they are connected to the active distribution network. These microgrids can inject power to the active distribution network. Then, the network component outages are modeled by generating random numbers and comparing with probability of failure of network components. For example, if a component has a probability of failure of α and the generated random number corresponding to the network component is β then satisfying the condition $\alpha > \beta$ sets the component status as in service. If this inequality condition is not satisfied then the state is considered as out of service.

In this way, the network topological arrangement is determined for the sample and the system equilibrium is assessed by running A/C power flow algorithm. Convergence of power flow can also result constraint violations. Any violation is rectified by applying active network management (ANM) controls. ANM controls include dispatching of flexible generation, on load tap changing (OLTC) of transformers, shunt compensation, and load shedding. The load shedding is applied only if other ANM controls failed to rectify the constraint violations or the resulting state following the application of power flow algorithms results an unstable operating condition. The order of the application of ANM control is followed as re-dispatching of flexible generation, OLTC of transformers, shunt compensation, and at last load shedding if that option is compulsory and appropriate. These control actions are sequentially applied and the sensitivity of the ANM control to reduce the constraint violations is determined. In this way, one or more ANM is applied to rectify any constraint violation. Upon rectifying all violations, the energy not supplied (ENS) of the sample of MCS is calculated using the amount of shed load and time to restore it. ENS is defined as the product of the amount of shed load and restoration time of the shed load.

Next, the PHEV-based microgrids are connected to the distribution network through feasible PHEV sites. PHEV microgrid reserve of each site is quantitatively injected to the network and the sensitivity of each PHEV-based microgrid reserve to reduce the ENS value (resulted through the disturbances of the sample) is assessed. At this stage two options are proposed. The first option considers simultaneous but proportional injection of active power from PHEV-based microgrids to reduce the ENS and calculates the active power capacity of necessary PHEV from each PHEV microgrid site when they are operated simultaneously.

The second option considers stand-alone injection of active power to the distribution grid or in other words, PHEV-based microgrids inject active power into the distribution network on one at a time basis and calculates the active power capacity of necessary PHEV if the PHEV microgrids are to operate as stand-alone microgrids. Both options can have benefits depending on the probability of failure of components surrounding the PHEV-based microgrids in the active distribution network. For example, given that no outage affects the availability of any PHEV microgrid then option 1 can give most beneficial PHEV dispatch. The option 2 is beneficial if one concerns of out of service of any PHEV microgrid that affects the duty of PHEV-based microgrids to reduce ENS. In this way, the ENS of a sample of MCS is calculated and the level of reduction in ENS obtained through PHEV-based microgrid deployment is determined.

The process described above occurs in a sample of MCS. The process continues until the MCS meets the convergence criteria [14]. Three conditions are set to meet the convergence criteria. It should first run trials that can at least capture the time series profiles of intermittent DG and demand level variations in a year. Then, the parameter to be estimated (curtailed load) is used to check if it meets the degree of confidence within an acceptable confidence interval, which is also called as tolerance criterion. It can mathematically be interpreted as in Eq. (1).

$$\sigma \leq \frac{E \times L}{\alpha} \quad (1)$$

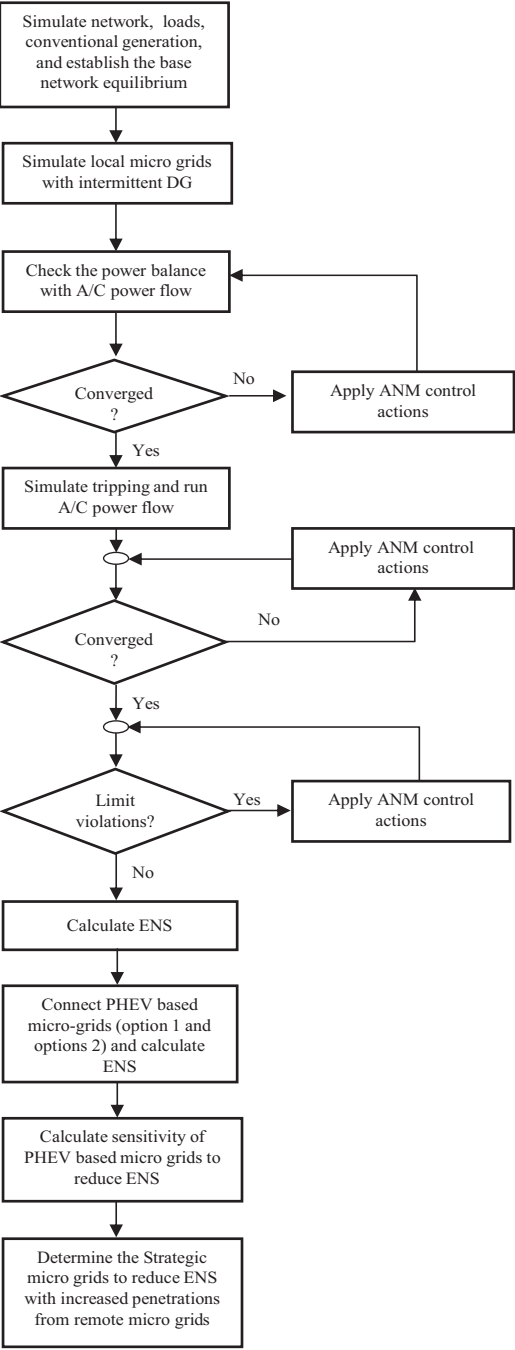
where, E , L , σ , and α are estimated sample mean, confidence interval, estimated sample standard deviation, and the factor that represent postulated normal distribution for the accepted degree of confidence respectively. If both of above criteria were not met, then MCS is stopped by meeting the maximum number of trials. With the convergence of the MCS the expected energy not served (EENS) is calculated using Eq. (2).

$$EENS = \frac{1}{n} \sum_{i=1}^n P_i \times T_i \quad (2)$$

where n = number of samples processed, P_i = the magnitude of curtailed load at the sample i , and T_i = time to restore P_i . Figure 1 shows the basic steps of the approach in a sample of the MCS that is used to determine the strategic microgrids.

The ENS in a sample can also be interpreted with the cost of outage using value of lost load functions [15]. With the convergence of the MCS, the expected cost of outage (ECO) can be estimated using Eq. (3).

Fig. 1 Determination of PHEV-based strategic microgrids in a sample in MCS



$$ECO = \frac{1}{n} \sum_{i=1}^n (VoLL_i^t \times ENS_i) \quad (3)$$

where $VoLL_i^t$ and ENS_i respectively referred to value of lost load for the interruption duration t and ENS for the sample i .

2.1 *Ranking Remote Microgrids*

The remote microgrids are used to increase the intermittent DG penetration. They are connected to the active distribution network on the basis of one at a time. The process described above is repeated and the EENS is calculated for each of the penetration level. In this way, all the remote microgrids can be ranked in ascending order of reducing EENS with high penetration of intermittent DG. The most favorable remote microgrid can be identified as the microgrid that reduces EENS most while increasing the penetration level of intermittent DG.

2.2 *Strategic PHEV Microgrids*

The active power capacities of PHEV-based microgrids are determined as follows. At each sample of the MCS the net MW import/export from each PHEV-based microgrid is calculated. In some samples, it can be seen as the exporting active power as the favorable option to reduce ENS whereas in other samples it can be seen as the importing MW as the favorable option to reduce ENS. Here, exporting and importing respectively referred to discharging and charging of all PHEVs in a microgrid. In this way, the exporting/importing of net active power through PHEV-based microgrids are calculated and recorded. Upon convergence of the MCS, the required net active power capacities of PHEV-based microgrids are determined by identifying the capacity that would fulfill all the net MW import and export of samples of MCS. The term “required active power” is used in this chapter to describe the useful or effective capacity of a PHEV-based microgrid because there is a threshold capacity level of PHEVs that is useful in exporting/importing powers. As the one of the objectives of the chapter is to assess the level of security with the presence of remote and PHEV-based microgrids, the chapter considers what PHEV-based microgrids deliver and what PHEV-based microgrids absorb from an active distribution network or in other words net in and out of microgrids.

The PHEV-based microgrids that reduce or at least maintain the base case level of EENS (i.e., resulting EENS value without the connection of intermittent DG and PHEV-based microgrids) by responding to increased penetrations of intermittent DG can be identified as strategic microgrids of the active distribution network.

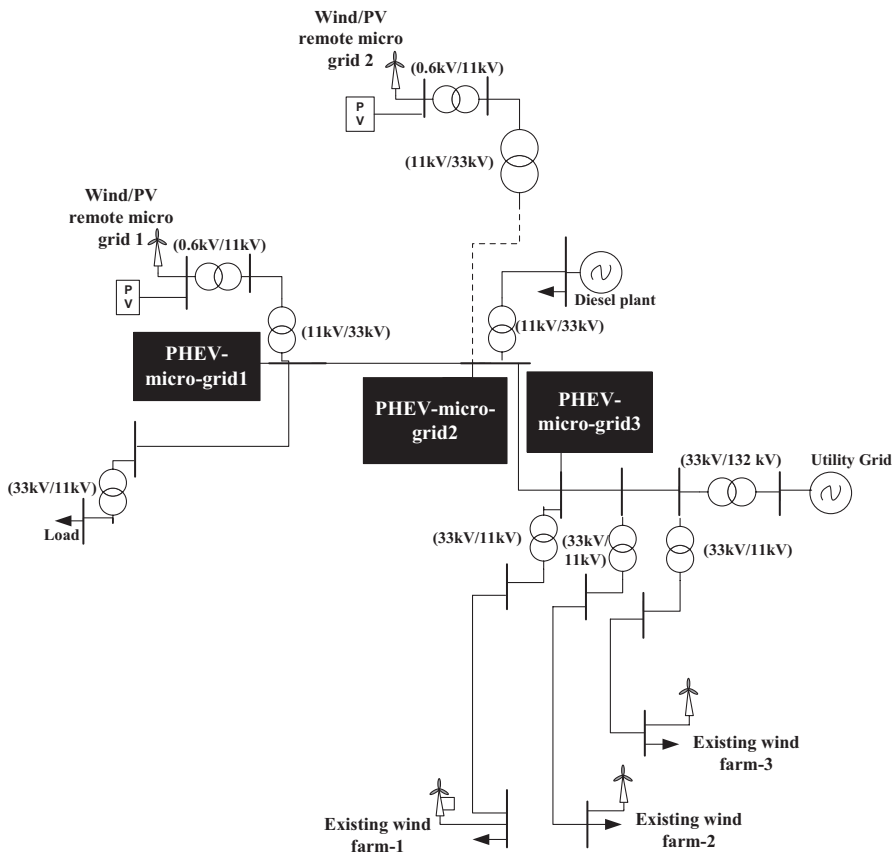


Fig. 2 Schematic diagram of a model of an active distribution network

3 Case Studies

3.1 Network Details

Figure 2 shows an active distribution network model that is used for the case studies. The network has 17 buses, 8 transformers, and 8 lines.

The 132/33 kV transformer connected at the utility bus has the OLTC operation. Remote microgrids shown in Fig. 2 represent only the power export operation under the grid connected mode. The microgrids supplying their own local demands are not simulated. Similarly the PHEV-based microgrids supplying their own local demands are not simulated. PHEV charging and discharging operations are simulated as net import and export of active power. For example if PHEV charging cycle or discharging cycle reduces the ENS of a sample of MCS then corresponding cycle is taken into account as a component of sizing the net capacity of PHEV-based microgrids.

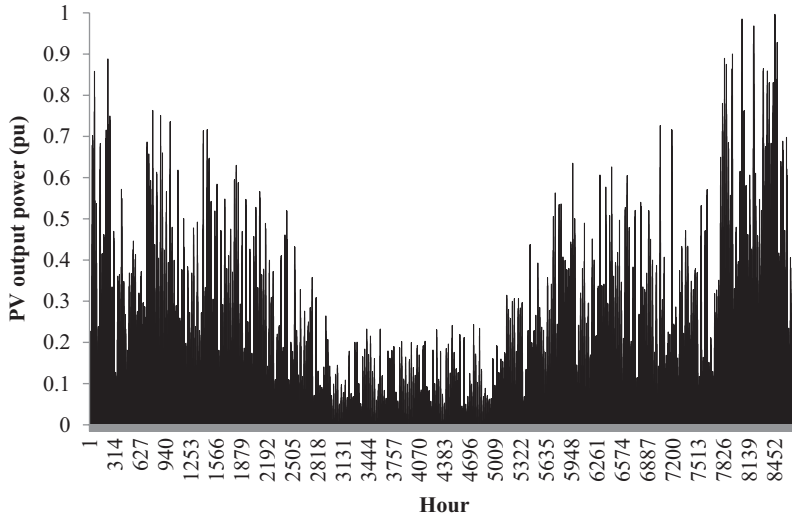


Fig. 3 Photo-voltaic (PV) output characteristics in a year

The total peak active and reactive power demands of the base case of the network are 15.2 MW and 5 MVar respectively. There are two remote microgrid sites that can be connected to the active distribution network. There are also three proposed PHEV-based microgrids that are shown in Fig. 2 as PHEV microgrid 1, PHEV microgrid 2, and PHEV microgrid 3. Installed capacity of wind and PV units of each of the remote microgrid are 2 MW and 0.6 MW respectively. Each of the existing wind farm installed capacity is 0.7 MW. Intermittency of wind and PV units are modeled using hourly wind and PV power generation profiles. Figure 3 and 4 respectively show the PV and Wind data for a year respectively. There are three types of customers simulated for the assessment. They are residential, industrial, and commercial. The wind farm capacity factor accounts for 0.27 whereas PV system capacity factor accounts for 0.12.

3.2 Scenarios

A set of scenarios are developed to study the performance of the proposed approach and to determine the PHEV-based microgrid capacity that can increase the integration capacity of intermittent DG without compromising the security of supply to customers. Each scenario used for the study is described below.

Scenario 1 Base case which does not have remote or PHEV-based microgrids. Thus, intermittent wind and PV generating units and PHEV reserves are not present in the active distribution network in Scenario 1.

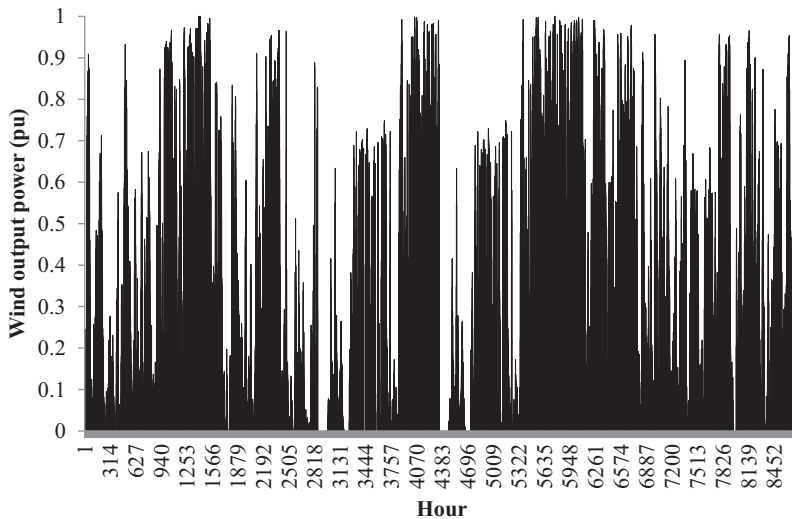


Fig. 4 Wind generation output characteristics in a year

Scenario 2 Base case with remote microgrids but without the integration of PHEV-based microgrids. Thus, the active distribution network is integrated with intermittent wind and PV power generation without PHEV-based microgrid supports.

Scenario 3 Base case with PHEV-based microgrids are connected at three locations in the active distribution network. These locations are shown in Fig. 2 as PHEV microgrid 1, PHEV microgrid 2, and PHEV microgrid 3. Network is also connected with remote microgrids as described in scenario 3(a) and 3(b).

Scenario 3(a) Remote microgrid 1 which has wind and PV generating units.

Scenario 3(b) Remote microgrid 2 which has wind and PV generating units.

3.3 Results and Analysis

Figure 5 shows EENS values of the base case with and without incorporating remote microgrid1 that exports intermittent renewable power to the active distribution network. The results depict that the component outages and existing 2 MW wind farm combinatorial impacts result an EENS of 10.3 MWh annually whereas injecting a further renewable power of 2.7 MW reduces the EENS value to 9.6 MWh annually. Thus, the reduction of 0.7 MWh is directly a result of the influence of 2.7 MW renewable power injection from the remote microgrid 1.

Figure 6 shows the required active power capacity of PHEV-based microgrid1, 2, and 3 to have the EENS values shown in Fig. 7. In other words, the required ac-

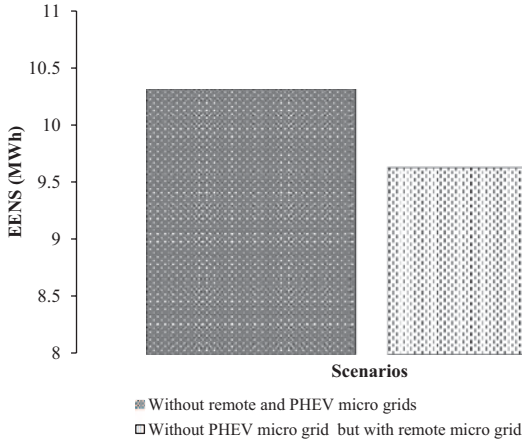


Fig. 5 EENS values with base case operating conditions and incorporating remote microgrid 1

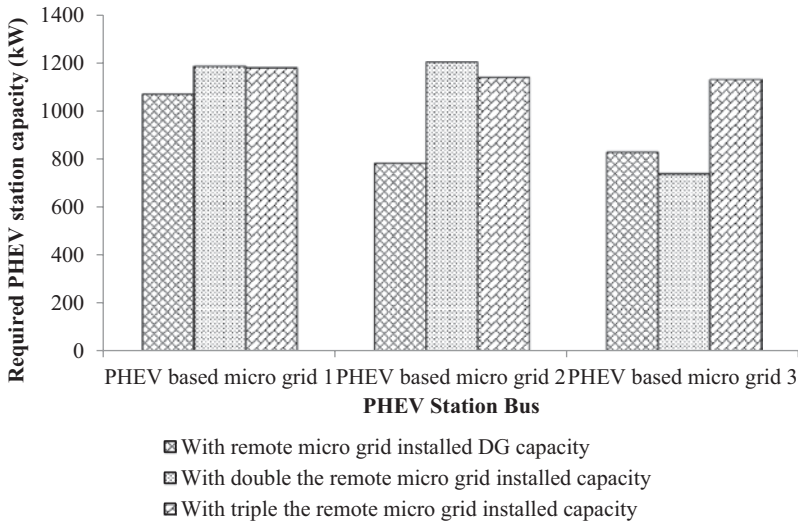


Fig. 6 Required PHEV supports from respective PHEV-based microgrids in response to increased penetration levels of wind and PV generation from remote microgrid 1

tive power capacity represents the necessary installed capacity of the PHEV-based microgrids to meet the net active power import/export of all MCS samples. When the remote microgrid 1 injects power to the distribution network with three times the remote microgrid installed capacity, all PHEV-based microgrids have similar sensitivity in reducing EENS values although the PHEV microgrid 3 can mostly reduce the EENS. However, when the required active power capacity of PHEV-based microgrid and penetrating renewable generation is compared with the initially in-

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