

Optimal DG Sizing and Location in Modern Power Grids using PEVs Load Demand Probability

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ABSTRACT

The integration of plug-in electric vehicles (PEVs) to the conventional distribution system has had a major impact upon consumption of energy in the past year. This paper presents optimal distributed generator (DG) sizing and location in the power system using PEVs load demand probability. The MATLAB m-file scripts and OpenDSS were applied to solve the proposed study by varying the percentage penetration level of PEVs. A genetic algorithm optimization technique was used to find the best solution of DG installation. The simulation results showed that the PEVs were directly connected to the power grid with 100 PEVs (13.84%), 200 PEVs (27.68%) and 500 PEVs (69.19%), respectively. It was found that the DG sizing also varied with 1.773 MW, 1.663 MW and 1.996 MW, respectively. While the position of the DG also changes according to the sizing of DG. The position of DG was installed at bus No.738, bus No.741 and bus No.711, respectively. Therefore, the optimal DG placement helped to improve and reduce the total line loss and total energy demand from the power grid. The grid increased the power system stability and reduced the impact from the large scale of PEV penetration.

Keywords: Genetic Algorithm, G2V, PEVs, OpenDSS, Optimal DG Placement, Power Flow

1. INTRODUCTION

Recently, the modern electric load has had an impact on the power system and increased the level of power consumed. Plug-in electric vehicles (PEVs) have a role in modern life, and represent an emerging load for the grid given their power consumptions [1]. Energy sources (ES) or renewable energy sources

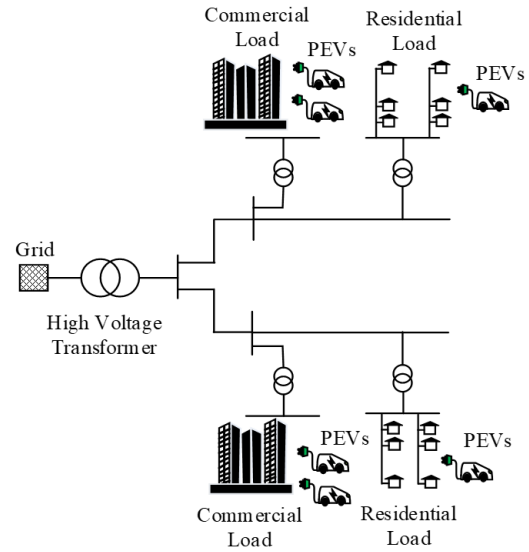


Fig.1: Plug-in electric vehicles (PEVs) load when connected to the modern power grid.

(RES) are becoming key issues for providing and supporting energy to the power grid [2]. Thus, multi-types of distributed generator (DG) have been used to represent each energy source and to solve the problems of the proposed system [3]. Therefore, the impact of the emergence of PEVs has created interest in the study of ways to reduce the impact and provide optimal conditions to the power system networks [4-5]. Many researchers have studied the impact of PEVs on the power system networks. The increasing number of PEVs was expressed to affect the power system stability in terms of the low power/frequency oscillation when considered in the fast charging station as presented in [6]. The increasing of power transformer loading and high power system loss from a high penetration level of PEVs are presented with the power system impacts in [7-9]. Meanwhile, PEVs were defined based on population density data and number of charging station [10]. The PEVs were presented as the load voltage dependent on the exponential indices variation. This confirmed that the low impact of PEVs can consider each PEV one by one when compared with the conventional load [11].

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This revealed the problems from DG placement when connected with the large number of PEVs in commercial and residential areas as shown in Fig. 1. The PEVs may be charged at charging stations that are installed between the houses and work places under different charging conditions (normal charging mode, fast charging mode, and special mode) depending on the social life conditions [11]. Therefore, this paper aims to contribute the DG placement under PEV panatration by increasing load profiles, commercial load profiles and residential load profiles. The voltage unbalance factor (VUF) and energy demand are also used to consider the objective function for this proposed study.

The rest of this paper is organized as follows: Section 2 describes the problem formulation for this proposed study; the proposed method algorithm is introduced in Section 3; the energy demand profiles and optimal DG placement are presented Section 4 which summaries of the case studies and simulation results. Finally, conclusion and discussion are given in Section 5.

2. PROBLEM FORMULATION

The optimization of DG power is one of the problems to be solved with regard to the sizing and position of DG placement. The importance of DG placement is its benefit towards the operating condition of power grids. Therefore, the optimal condition of DG should be managed and provided by supporting energy demand from each load type on the power grid. The energy support from the DG was defined from each load to consume energy from the power grid. This section shows each parameter and the tools that are used to solve in the proposed methodology.

2.1 Probability of PEVs Load in Modern Power Grid

Driving behaviour is used to determine the characteristics of the PEV load into the power grids. It consists of daily starting time, daily travel frequency, driving mileage (in km) and driving duration (in minutes). However, the electricity consumption was calculated based on driving mileage to consume energy from the battery. State of charge (SOC) of the battery was used to calculate charging power per PEV based on rated 3.4 kW and pf. 0.85 of the battery charger [12-13]. The probability of charging can be calculated as shown in Eq. (1).

$$F_A = (t, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t-\mu)/2\sigma^2}; 0 < t < 24 \quad (1)$$

where F_A is the probability of charging at a given arrival time, t is time in a day, μ is the mean value, σ is the standard deviation of the normal distribution.

The battery is used to store energy by charging

with an AC to DC power converter or battery charger. The battery-charging mode is relevant to the time of charging; thus, the time at which charging ends is defined by the SOC level after accounting for the energy used for driving. The charging duration can therefore be defined as expressed in Eq. (2).

$$t_{End} = \left(1 - \frac{SOC}{100}\right) \times \left(\frac{24}{3.4}\right) \quad (2)$$

where t_{End} is charging duration time (hrs) and SOC is the state of charge of the battery (%). 24 is hours in a day and 3.4 is charging power per PEV in kilowatts.

The scale of PEV used was defined based on the ratio of the total capacity of PEVs to the total capacity of the general load on the grid. The penetration level was used to indicate the level of energy consumed from the grid, which can be expressed as shown in Eq. (3).

$$\text{Penetration Level (\%)} = \frac{\sum_{i=1}^{N_{PEV}} P_{PEV}(i)}{\sum_{n=1}^{N_{Load}} P_{Load}(n)} \times 100 \quad (3)$$

where N_{PEV} is the total number of the PEVs in the power grid. P_{PEV} is power consumption of the battery charger. N_{Load} is the total number of loads in the power grid. P_{Load} is power consumption of the load n in the power grid.

Meanwhile, PEV charge profiles were individually calculated based on arrival time, state of battery charging and charging method. The purpose of battery charging in this work was defined in normal charging condition. The PEV represents low power consumption when connected to the grid. Thus, the charging profiles each day can be expressed as in Eq. (4).

$$\text{Total Charge Profiles}_{hr} = \sum_{i=1}^{\# \text{ of } PEV} P_{PEV}(i, hr) \quad (4)$$

where $\#$ of PEV is the total number of PEVs, and hr is the time for charging of PEVs in any given day (24 hrs).

However, the high penetration level of PEVs has a direct effect on the grid. The optimal charging of the battery charger needs to be able to manage and provide energy sources in order to provide energy peak shaving. The peak shaving from energy consumption of the PEVs affects the power grid, the impact of which needs to be managed charging time in this case.

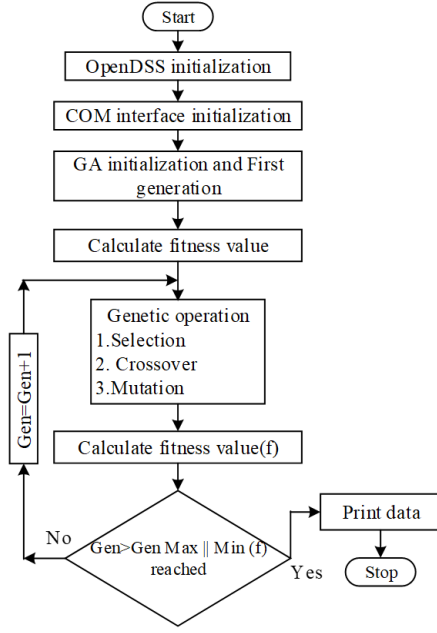


Fig.2: Flowchart of GA Optimization Techniques.

2.2 Genetic Algorithm (GA) Optimization Technique

The GA is one of the optimization techniques that performs a heuristic method based on a natural evolution. The GA begins by selecting a specific number of chromosomes from an initial population. Each chromosome characterizes a solution to the problem and the performance is evaluated by the fitness function [14]. The GA operation was used to find new populations based on a random selection from the chromosomes of the previous population, and consisted of a selection process, a crossover process, and a mutation process. Therefore, the process is related to the stages of the DG placement presented in Fig. 2.

This approach was applied to find the optimal solution to the problem in a single objective or to modify in a multi-objective scenario. Many studies have applied the GA to solve the optimal solution of the power grid such as optimal capacitor placement, optimal DG placement, and optimal reconfiguration of the transmission line [15-17]. This work also considers the GA application to solve the optimal condition for placing the DG in modern power grids under widespread use of PEVs installation.

2.3 Application of Open Distribution System Simulator (OpenDSS)

OpenDSS is a free software used to solve the power system, which can interface with m-files of MATLAB [18]. It has many built-in solution capabilities including snapshot and time mode power flow, fault current study, harmonics, dynamics, parametric and probabilistic studies. OpenDSS can be used to solve the electrical power distribution and to analyze the con-

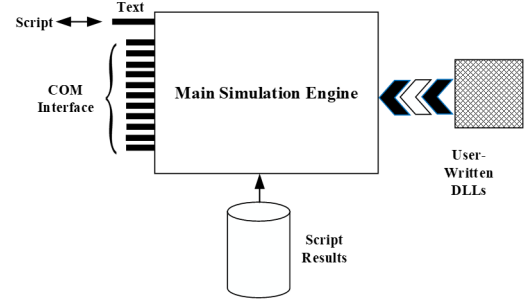


Fig.3: Component Object Model (COM) interface.

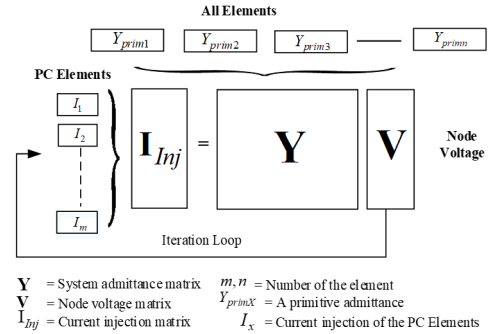


Fig.4: Nonlinear equation set of nodal voltage analysis.

ditions of the multi-phase AC circuit model and any other equipment such as models for renewable energy resources, energy storage devices and transformers.

The application of OpenDSS can be interfaced with the main simulation engine through the connection of the Component Object Model (COM) interface method whose script was used to control and simulate. The MATLAB m-files were used to link between OpenDSS and MATLAB to cover data, control command and exchange of data. The advantage of the COM interface was its ability to analyze the power system network test and to use each methodology to analyze the problem.

Therefore, the interfaced structure is defined in the COM interface by using scripts of the environmental structure as shown in Fig. 3 [18]. The distribution system simulator (DSS) executive is relevant to the circuit of the electrical power system. The element and component consists of PDElement, PCElement, controls, meter and general. Direct connection shared libraries (DLL) is an OpenDSS COM interface that consists of classes, properties and methods. Meanwhile, the power flow solution of OpenDSS is defined based on the nodal admittance formulation in the nonlinear system admittance equation, as shown in Eq. (5).

$$I_{PC}(V) = Y_{System} \cdot V \quad (5)$$

where Y_{System} is the admittance matrix of the system,

I_{PC} is the compensation current from PCElement in the circuits and V is nodal voltage. Therefore, the set of nonlinear equations can be shown in each iteration for solving the converged solution as shown in Fig. 4.

2.4 Voltage unbalance factor (VUF)

Generally, the voltage effect of electricity load has an impact on the direct voltage profiles from the power grid. Therefore, the voltage unbalance analysis is selected to solve the voltage unbalance impact when the unbalanced loads were connected into the power system. The VUF defines a ratio from the negative sequence voltage component to the positive sequence voltage component, as described in Eq. (6) [19].

$$VUF(\%) = \frac{V_2}{V_1} \times 100 \approx \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}} \quad (6)$$

where $\beta = \frac{V_{ab}^4 + V_{bc}^4 + V_{ca}^4}{(V_{ab}^2 + V_{bc}^2 + V_{ca}^2)^2}$, V_1 and V_2 represent positive and negative sequence voltage components. V_{ab} , V_{bc} and V_{ca} represent line - line voltage bus.

Meanwhile, the voltage unbalance can be evaluated and calculated by using the symmetrical component method, as described in Eq. (8). The voltage phasors are written as the sum of three symmetrical components and can be shown to be related to the symmetrical sequence systems [20]. Accordingly, the VUF can be formulated using the following definition as shown in Eq. (7).

$$\begin{bmatrix} V_+ \\ V_- \\ V_0 \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

where V_0 , V_- and V_+ represent zero sequence voltage, negative sequence voltage and positive sequence voltage. V_a , V_b and V_c represent phasor voltage of phase A,B and C. Meanwhile, a represents $e^{j\frac{2}{3}\pi}$.

$$VUF(\%) = \sqrt{\frac{|V_-|^2 + |V_0|^2}{|V_+|^2}} \times 100 \quad (8)$$

2.5 Distributed Generation (DG)

Generally, DGs have many different power sources, such as gas turbines, internal combustion engines, storage devices and renewable energy device. DG types can be classified into four types; type I: the DG injects real power and is operated at unity power factor; type II: injected reactive power; type III: injected real and reactive power; and type IV: consumes reactive power but injects real power [21]. This paper applies DG type I in the balance of injected power when installing and generating active power only. The injection of active power can improve the capability of

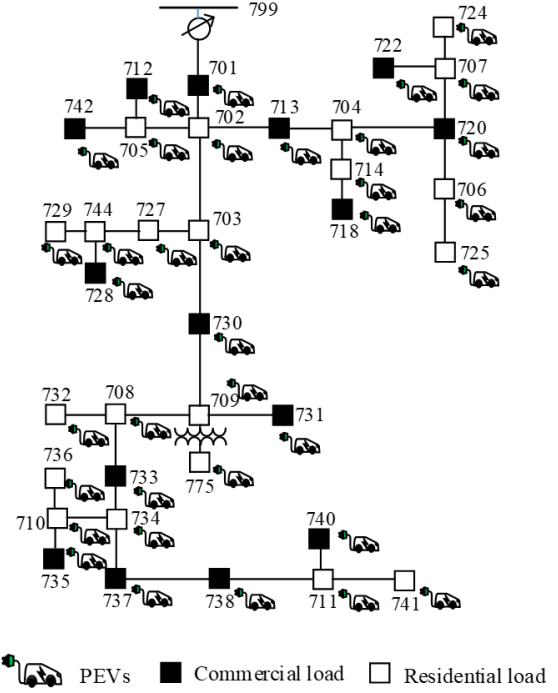


Fig.5: IEEE37 bus test system when connected with large scale of PEVs.

the grid and increase the power system stability.

3. PROPOSED METHODOLOGY

The optimal DG placement was used in an unbalanced load system based on the IEEE37 test feeder, which consisted of three phase underground cables, operating at a nominal voltage of 4.8 kV. The conventional load consisted of constant power, constant current and constant impedance. The IEEE37 bus can be seen in Fig.5 [22]. The daily starting time of charging the battery was calculated based on Eqs. (1) and (2) with $\sigma=2$ and $\mu=10, 20$ by determining working place and house charging time from 500 PEVs as shown in Fig. 6. The energy demand of the commercial and residential load was intended to be based on the load factor (LF) from Fig. 7. Meanwhile, the PEV load profiles were formulated based on probability and calculating the energy consumed to charge the battery per day. Therefore, the PEV load factor is shown in Fig. 7 (star line). The energy demand of the PEVs was calculated by using power at 3.4 kW of the battery chargers. The penetration levels of PEVs are defined in three cases by using base power from the total power of each load in the grid to calculate the percentages that consist of 100PEVs (13.84%), 200PEVs (27.68%) and 500PEVs (69.19%). The objective function for finding the optimal DG placement was demonstrated from the three related equations as shown in Eqs. (9) to (12).

$$\min(f) = f_1 \times f_2 + f_3 \times \text{penalty} \quad (9)$$

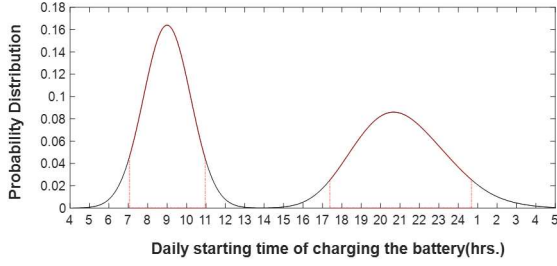


Fig.6: Probability distribution of daily starting time of charging in a day.

$$f_1(x) = \max(VUF) \quad (10)$$

$$f_2(x) = \sum_{t=1}^{24hr} P_{SystemDemand,t} \quad (11)$$

$$f_3(x) = \sum_t \sum_{l=1}^{NL} R_{l,t} \left(\frac{P_{l,t}^2 + Q_{l,t}^2}{V_{l,t}^2} \right); l \in NL \quad (12)$$

where $P_{SystemDemand}$ represents the energy demand of the load at any point in time in a day. NL is the total number of transmission line. R_l is the resistance of the l transmission line. V_l is the voltage of the l transmission line. P_l and Q_l are active and reactive power of the l transmission line. t is time period in a day.

The objective function consisted of the maximum voltage unbalance factor (f_1), the total energy demand (f_2), the total energy transmission line loss (f_3) and the penalty. Meanwhile, the constraints are shown in Eqs. (13) and (14) and the penalty is shown in Eq. (15). The voltage limits and the injected power limit of the DG were controlled and maintained in the optimal condition of the grid.

$$V_{\min} \leq V_{Bus,i} \leq V_{\max} \quad (13)$$

$$P^{\min} \leq P_{DG,i} \leq P^{\max} \quad (14)$$

where $V_{Bus,i}$ is bus voltage of the bus i . $V_{\min}$ and $V_{\max}$ represent the voltage limit 0.95 and 1.05 p.u.. P_{DG} is active power injected to the grid from the DG. $P^{\min}$ and $P^{\max}$ represent the active power limits of the DG. The penalty condition was used to control the injected active power of the DG to the grid. The injected active power does not generate power more than the load consumption. This can be illustrated as shown in Eq. (5).

$$P_{inj} = P_{DG} - P_{TotalLoad}$$

$$Penalty = \begin{cases} P_{inj} < 0; Penalty = 10,000 \\ P_{inj} > 0; Penalty = 1 \end{cases} \quad (15)$$

where P_{DG} is active power injected to the grid from the DG. $P_{TotalLoad}$ is total energy load demand of the grid. P_{inj} is energy balance from active power injected by the DG and total energy load demand.

The steps in identifying the optimal DG placement using GA by interfacing OpenDSS are as follows:

Step 1: OpenDSS initialization

- 1.1) Design test system in *.DSS.
- 1.2) Initial load shape of commercial load, residential load and PEVs.

Step 2: COM interface initialization

- 2.1) Initial COM interface between m-files and OpenDSS.
- 2.2) Formulation of the objective function by using Eq. (9) under data analysis from the COM interface of OpenDSS.

Step 3: GA process initialization

- 3.1) Initial parameters
 - Population size = 300
 - Max. number of generations = 200
 - Number of Variables = 2
 - Crossover = 0.8
 - Mutation = 0.1
 - Defined Max. and Min. of DG size in 3 phases = [5000 70,000] kW.
 - Defined Max. and Min. of DG position = [2 35].
- 3.2) Randomly generate an initial population of chromosomes and input data of the DG size and position to the IEEE37 bus test system through the COM interface.
- 3.3) Initialize the first fitness evaluation by computing the objective function based on data from the COM interface.

Step 4: Generate a new population by using the GA operation consisting of the selection process, crossover process, mutation process and obtain a new population for the next generation.

Step 5: Compute the fitness evaluation of the new population.

Step 6: Check condition and termination criteria consisting of reaching the max. generation. If neither criterion is satisfied, go to Step 4. Otherwise, proceed to Step 7.

Step 7: Terminate the algorithm and present the output results.

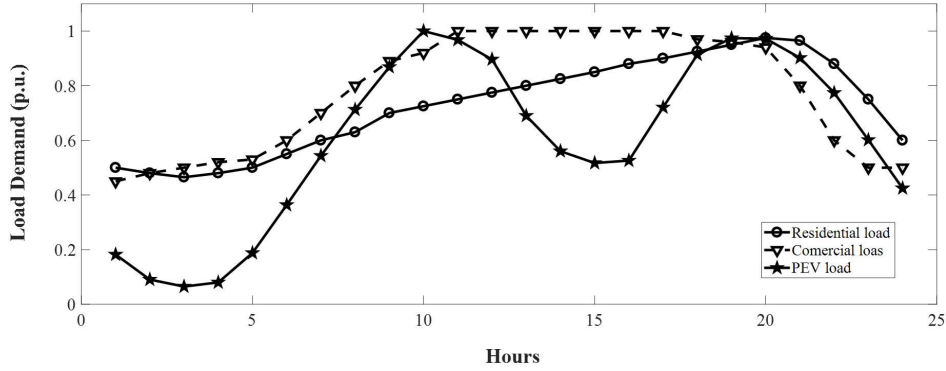


Fig.7: Daily load factor of different loads.

4. SIMULATION RESULTS

In this study, a combination of genetic algorithm and OpenDSS is designed to find the optimal DG placement of the grid. Unbalanced propagation in a primary distribution network was investigated in an asymmetric three-phase load that realistically simulated the electrical power system. The simulation results showed the optimal DG placement when the percentage of PEV penetration was set at 13.84%, 27.68% and 69.19%. Table 1 shows data comparisons in each scenario of the DG placement whose data consisted of max.VUF, total line loss, total energy demand, objective function, DG sizing and installation position. The maximum of the VUF showed differences when the penetration level of the PEVs and DG were changed. However, the effect from DG installation may cause an increase of VUF value, while the total energy demand and total line loss were reduced. Generally, the load increase in the grid was affected by voltage fluctuation, the total energy demand and the total line loss, which can be reduced by finding the active power source to support the grid. The DG placement was changed from this case. With 100 PEVs in the grid, the optimal DG was at Bus No. 738 with 42.568 MW. Meanwhile, with 200 PEVs in the grid, the optimal DG was at Bus No 741 with 39.935 MW. However, with 500 PEVs in the grid, the optimal DG was at Bus No. 711 with 47.907 MW. Interestingly, when comparing the DGs installed before and after, both the total line losses and the total energy demand were reduced.

As shown in Fig. 8, the comparison of 100 PEVs shows the impact of PEVs connected to the grid. The grid can reduce the power demand when the DG installed is 1.773 MW at Bus No. 738. The optimal DG sizing and location (diamond line) reduced the energy demand from the grid and can decrease total line losses of the system. Meanwhile, the power system network increased load ability in terms of the energy demand and supported the energy consumed from each load in the grid. The penetration level of PEVs was reduced by installing the DG.

The results for 200 PEVs are shown in Fig. 9.

The power demand profiles of the grid were compared between the base case (square line) and connected to PEVs. It also shows the DG placement whose power demand increased from the base case (triangle line) while the energy demand from the grid reduced after DG installation of 1.663 MW at Bus No. 741. The energy demand can be reduced after DG placement from the grid, which can be seen as the diamond line in Fig. 9. However, the DG sizing was less than the case of 100 PEVs because of the change of position of the DG.

Fig. 10 shows the comparisons of 500 PEVs when connected to the grid and the DG placement. The power demand of the system increased compared to the base-case (square line). Therefore, the energy demand of the grid was moderately impacted by the installation of the DG sizing of 1.996 MW at Bus No. 711. Thus, the fixed type of the DG in this application was considered to select the optimal sizing and absorb power demand from each load of the grid. In this case, the total energy demand was reduced along with the total line loss, but the total line loss was effected by the amount of 500 PEVs connected to the grid.

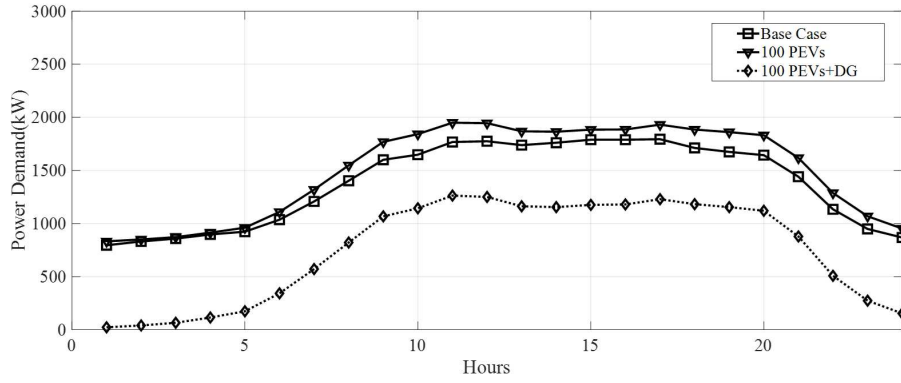
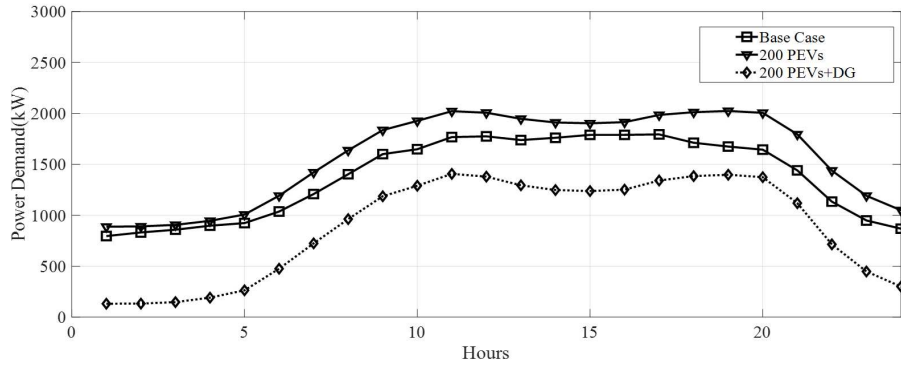
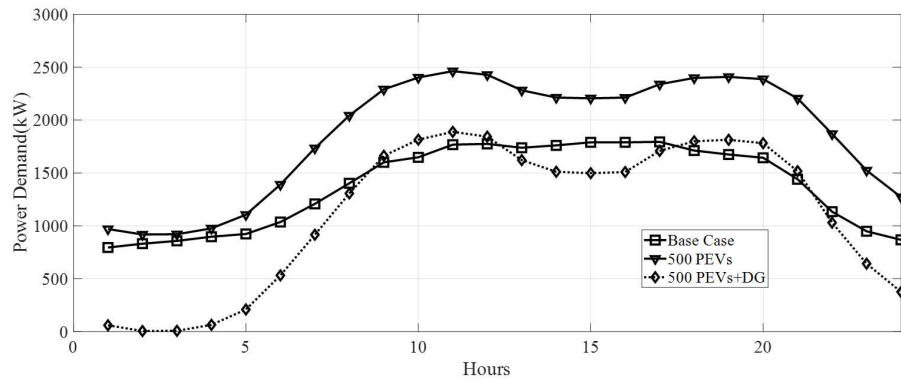
However, the sizing of the DG could be controlled and designed to limit the power demand of the load on the grid. If the active power generated from the DG was more than the consumption of the loads from the grid, the active energy from the DG may cause a power reverse to the external grid at the point of common coupling (PCC). Therefore, the active energy from the DG source should be controlled so that it would not exceed the demand of the system indicated before installation.

5. CONCLUSION

The performance of the optimal DG placement was used to solve the problem when a large number of PEVs are connected to the grid. The purpose was to use DG type I to find the optimal DG placement. The genetic algorithm and OpenDSS were applied to solve this problem. The PEV penetration level was defined based on the probability from the daily start-

Table 1: Performance comparison of base case and different PEVs penetrations under with/without DG installation.

	Scenario	Penetration level (%)	Max. VUF	Total line loss (kW)	Total energy demand (MW)	Objective function ($\times 1000$)	DG sizing (MW)	DG posi.
Before	Base case	0%	1.234	964.364	47.140	-	-	-
	100 PEVs	13.84%	1.482	1182.400	51.090	-	-	-
	200 PEVs	27.68%	1.598	1412.300	54.774	-	-	-
	500 PEVs	69.19%	2.539	2292.700	65.465	-	-	-
After (+DG)	Base case + DG	0%	1.559	481.160	20.137	31.280	1.646	740
	100 PEVs + DG	13.84%	1.533	594.200	22.628	34.511	1.773	738
	200 PEVs + DG	27.68%	1.057	828.660	28.251	29.720	1.663	741
	500 PEVs + DG	69.19%	1.745	1921.900	36.266	39.871	1.996	711

**Fig.8:** Comparison of the power demand from base case, 100 PEVs with/without DG installation.**Fig.9:** Comparison of the power demand from base case, 200 PEVs with/without DG installation.**Fig.10:** Comparison of the power demand from base case, 500 PEVs with/without DG installation.

ing time for charging the PEV charger. The simulation results showed the optimal sizing and location when the penetration level of PEVs varied. The optimal of DG sizing and position showed 1.773 MW at Bus No.738 (100 PEVs), 1.663 MW at Bus No. 741 (200 PEVs) and 1.996 MW at Bus No. 711 (500 PEVs). The key point of the optimal DG placement was used to reduce the total line losses and the total energy demand on the grid. However, the VUF showed more variability from the large scale of PEVs when connected to the electrical power system. In particular, the optimal DG placement in the condition of the low penetration level may result in the increase of the VUF, but in the case of large scale PEVs, the penetration level can be improved. However, the sizing of the DG must be limited so that it will not exceed the demand from the grid. Therefore, future research could assess the impact of installing multi-type DGs in the grid, with performance analysis undertaken and controlled in time series.

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