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Optimal Charging Schedule Coordination of Electric Vehicles in Smart Grid

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ABSTRACT

The increasing penetration of electric vehicle (EV) at distribution system is expected in the near future leading to rising demand for power consumption. Large scale uncoordinated charging demand of EVs will eventually threatens the safety operation of the distribution network. Therefore, a charging strategy is needed to reduce the impact of charging. This paper proposes an optimal centralized charging schedule coordination of EV to minimize active power losses while maintaining the voltage profile at the demand side. The performance of the schedule algorithm developed using particle swarm optimization (PSO) technique is evaluated at the IEEE-33 Bus radial distribution system in a set time frame of charging period. Coordinated and uncoordinated charging schedule is then compared in terms of active power losses and voltage profile at different level of EV penetration considering 24 hours of load demand profile. Results show that the proposed coordinated charging schedule is able to achieve minimum total active power losses compared to the uncoordinated charging.

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1. INTRODUCTION

Transportation sector is among the largest contributors for excessive carbon emission in the environment which lead to the deployment of electric vehicle (EV) as alternative to reduce the environmentally damaging impact from conventional vehicles. However, impact of increasing power demand due to comparatively high consumption of EV's batteries during charging grows concern on the utilities. In addition, large-scale penetration of EVs lead to a potential increase on the peak load demand of the local distribution networks especially when EV users practice the uncontrolled charging scheme [1]. Therefore, several studies have been conducted to propose smart charging control strategies of EVs by using various optimization techniques [2],[3] to reduce the mentioned impact and improve the operation of electrical grid.

Authors in [4]-[6] proposed charging schedules to minimize the charging cost of EV as well as minimizing the burden on distribution network by finding hourly optimal charging power transfer as variable. However, the proposed schedules are questionable since they lack the inclusion of power flow model and network constraints in their methodology. A centralized charging strategy is proposed where the active power of EVs charging is controlled by regulating the voltage and frequency at connection point [7]. There are many benefits of using this technique such as reducing the voltage deviation in residential distribution networks [8] and maximizing the penetration of EV with vehicle to grid (V2G) capability as a distributed energy resource (DER) in islanded grid [9]. The charging strategy is also proposed in [10],[11] to minimize the power load variance with stochastic plug-in electric vehicle (PEV) connection to grid by considering V2G and load forecasting to achieve flatten load profile in a distribution network. Rescheduling the charging of EV into multiple charging slots as proposed in [12] able to produce a more uniform load profile thus ensuring the connection of EV loads does not exceed the loading capacity at the local substation. However, an uncoordinated charging scheduling may lead to violation of voltage profile and substantially increase losses. Thus, this research proposes a coordination for EV charge scheduling in each charging slots to optimally coordinate charge scheduling for electric vehicle by considering minimum active power losses and acceptable voltage limit. The optimally coordinated and uncoordinated charging schedule is then compared for increasing penetration of EVs into the network.

The scheduling of EV charging is optimized using the Particle Swarm Optimisation (PSO) technique. The procedure of the optimization considers the technical characteristic of the charging station, users charging behavior, 24-hour load profile [13] at distribution substation and the network constraints. For case studies, the scale of the charging (CS) station is varied based on the different penetration level of EV in the test distribution system. Prior to the optimisation of EV charging, the charging characteristic of EV such as the charging profile of the batteries, charging mode and EV users charging behavior need to be identified [14],[15]. The study analysis is performed on distribution system considering daily load profile. The network model cases are developed based on the demand scenario and EV penetration level. The illustration of system analysis framework is as shown in Figure 1.

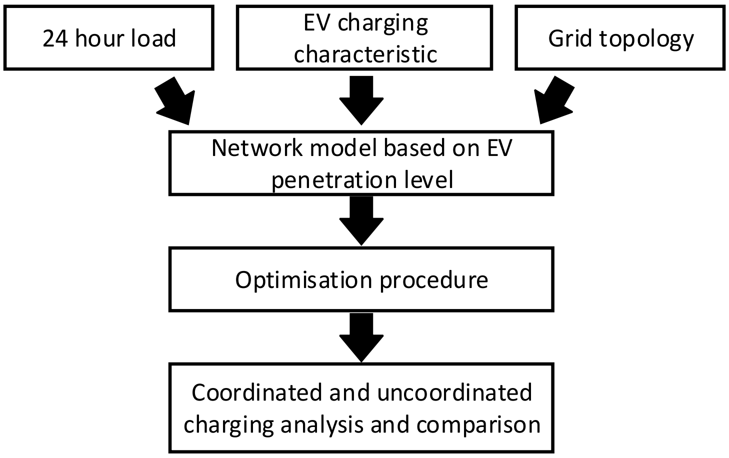

Figure 1. System Analysis Framework

2. CENTRALIZED SMART CHARGING: PROBLEM FORMULATION

This study focuses on developing an optimal EV centralized charging strategy in the smart charging schemes which is determined by an intelligent algorithm in the smart distribution network. The formulation of EV charging coordination is developed based on an objective function and subjected to a series of system constraints necessary for improving grid performance and ensuring reliability.

2.1. Objective Function.

The main objective function of this project is to minimize active power losses in the distribution network by finding the optimal schedule coordination for the charging of electric vehicle load. Therefore, the objective function is selected as follows (1):

$$\min P_{loss} = \sum_{k=1}^{ntl} |I_k|^2 . R_k \tag{1}$$

P_{loss} : Active power loss
I_k : Branch current
R_k : Branch impedance
ntl : number of lines

2.2. Constraints

There are several categories of constraints for the optimization problem which include EV charging constraints and network's technical limits.

2.2.1. Charging Constraints

The first constraint is the limit on allowable total power demand of charging station (CS) to charge EVs at bus k as shown in Equation (2). The limit depends on the number of CS that is allowed to be operated in a particular penetration level of EVs. This ensure the charging demand for EV could be satisfied based on total number of CS installed at particular buses. The limit hence is:

$$P_{CS,min} \leq P_{CS,k} \leq P_{CS,max} \tag{2}$$

The charging of EV is modelled as a constant active load. In order to ensure the effectiveness of power system operation, the addition of EV load demand, EV_D to the local load demand, P_D must not exceed the peak load demand at the local distribution transformer $T_{D,max}$. at every hour. Therefore, the ceiling limit for the total maximum power demand of the distribution system is also set as in Equation (3) to prevent overload of the local distribution transformer. P_{loss} is the line loss in the system.

$$P_D(h) + EV_D(h) + P_{loss}(h) \leq T_{D,max}(h) \tag{3}$$

2.2.2. Network's Technical Limits

The voltage constraint of the distribution system is considered by setting the upper and lower limits which correspond to grid voltage regulation limits typically set by utilities as in Equation (4). In this paper, the voltage limits are set to +/- 10% (V_{min}= 0.9pu and V_{max}=1.1pu) which is typical of many distribution network [16].

$$V_{i,min} \leq V_{i,h} \leq V_{i,max} \tag{4}$$

2.3. Distribution Network System Topology

The IEEE-33 bus radial distribution network with a total load of 3.72MW and 2.3MVAR used in this study is as shown in Figure 2. The MVA and voltage base values are 10MVA and 12.66kV respectively [14]. 10 buses in this network are randomly selected as the location for the CS installation which are bus 3, 6, 10, 14, 19, 22, 23, 25, 29 and 31. The distribution system is assumed to be occupied by 1000 population of residential consumers. Each selected bus is installed by a fix number of CS. This number is later increase based on the penetration level of EV. As the penetration level of EV increases from 20% to 80%, the number of CS installed at each bus is assumed to increase from 20 to 80 stations. This makes a total charger installed in the test networks increase from 200CS to 800CS respectively.

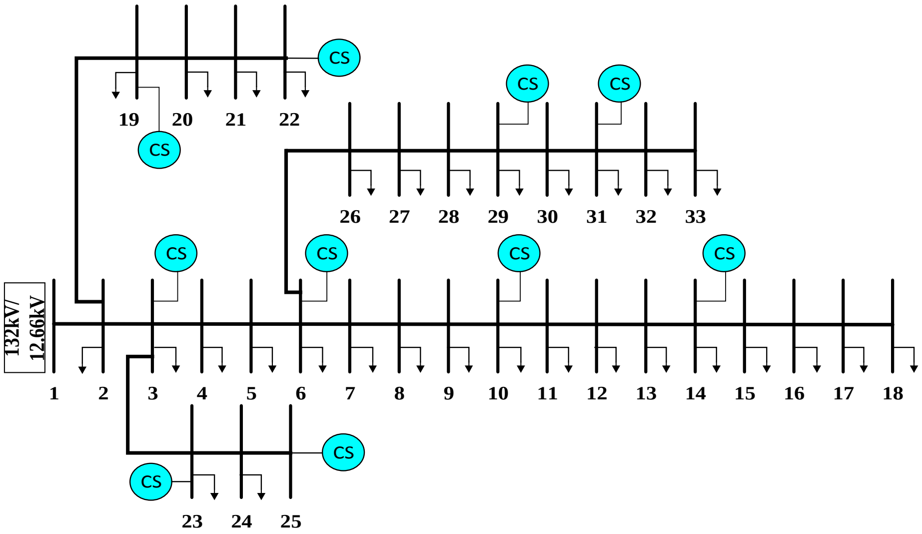

Figure 2. IEEE-33 Bus Distribution Network System Installed With Electric Vehicle Charging Station

2.4. Procedure of Optimization Algorithm

Particle Swarm Optimization (PSO) is a population-based optimization method developed by Kennedy and Eberhard to optimize the objective functions for a continuous optimization and combinatorial problems. The potential solutions called the particles (Pbest) fly through the problem space in search of the best solution called fitness. The best value obtained by any particles in the neighbourhood is called Gbest. At each time step, each particle updates its velocity and acceleration based on the weightage of a random with separate random numbers being generated for acceleration toward Pbest and Gbest location. The procedure of the PSO technique is done in MATLAB. The computational procedure to find the optimal charging schedule coordination is as shown in Figure 3. The network data which consist of the line and bus data as well as the 24 hours load profile are set as the initial inputs for the algorithm. 20 initial population of particles which represent the combination pattern of charging station operation for each particle at the selected bus in the stipulated charging slot is generated. The Newton Raphson load flow (NRLF) is performed for each initial particle and the Pbest are listed after taking into account several constraints such as voltage limit and distribution transformer peak limit to determine the feasibility of the particles current position. Gbest is the selected as the minimum fitness among the Pbest. The weight, velocity and position of each particle are updated. The new Pbest and Gbest position is updated if they are better than the previous ones. The optimal hourly EV charging pattern is achieved after the optimization process meet the stopping criteria.

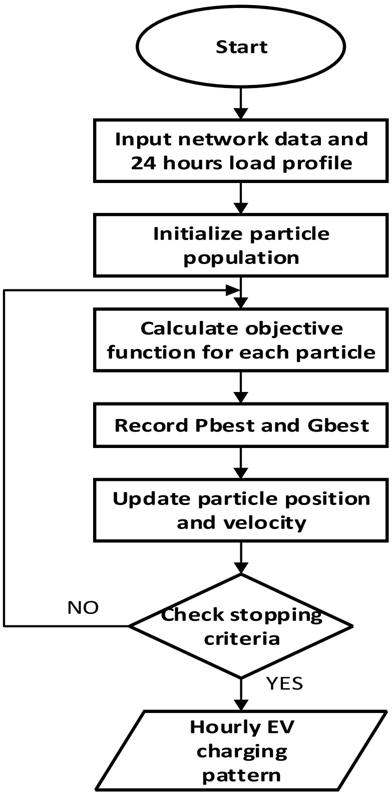

Figure 3. Flowchart of the PSO Technique

3. RESULTS AND ANALYSIS

The optimization of EV charging schedule coordination is realized by using the PSO technique. The coordinated and uncoordinated smart charging schedule are considered as the case studies. Increasing market penetration level is analyzed for every charging schedule. The impact of each charging schedule with different level of market penetration on the test system is evaluated in term of total system losses and voltage profile.

3.1. Uncoordinated charging

The charging schedule in this study consists of four charging slots. Each charging slot has a duration of 4 hours to fully charge the particular number of EV in the selected bus. In the uncoordinated charging, each charging slot is accommodated with 1/4 of the total charging load. Figure 4 shows the 24-hour active power loss of the system for this scenario.

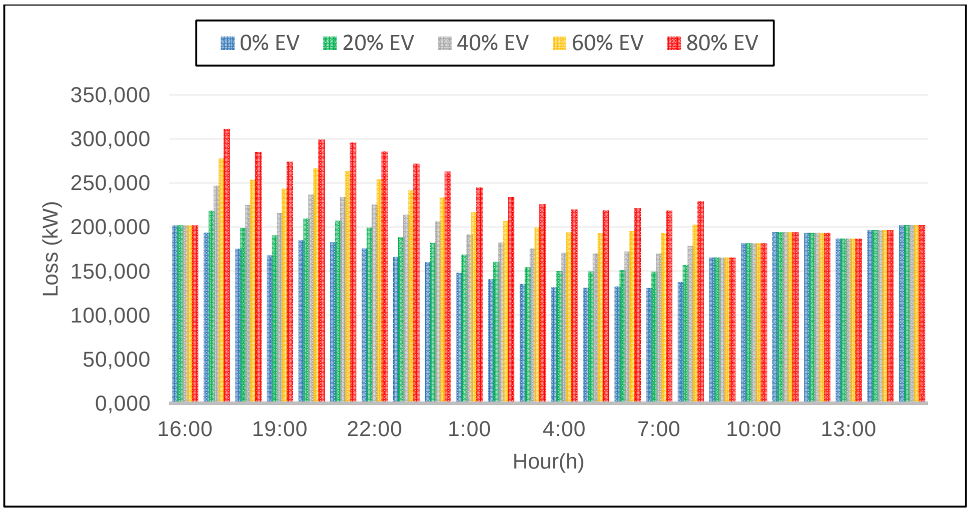

Figure 4. Uncoordinated Smart Charging 24-hour Active Power Loss

For all of the EV penetration level, the highest loss recorded is at the start of charging at 1700 which are 219.134kW, 247.233kW, 277.988kW and 311.481kW for 20%, 40%, 60% and 80% penetration level respectively. The base case loss for this particular hour is 193.911kW. The penetration of EV at 80% level shows an increase of active power losses more than 50% from the base case without EV penetration.

Since the characteristic of the test system exhibits that bus 18 have the lowest voltage in the basic case, the voltage drop due to EV loading is more significant compared to the other buses as shown in Figure 5. Therefore, the voltage drop at this bus is analyzed. There is no charging occur from 0900 to 1600, therefore the voltage is always maintained above 0.91p.u. As the charging of EV starts at 1700, it shows a drop of voltage for all cases. The voltage is maintained above 0.90p.u. at all charging time for 20% and 40% EV. Voltage drop below 0.90p.u. during the first charging hour, 1700 to 1800 and increase above 0.90p.u. after 1800 for 60%EV. However, a significant voltage drop is identified for 80% EV case by which the voltage always remains below 0.90p.u. from 1700 to 2300 before it starts to increase for the rest of the charging time. The lowest voltage magnitude is 0.892p.u. recorded at 1700 for 80% EV.

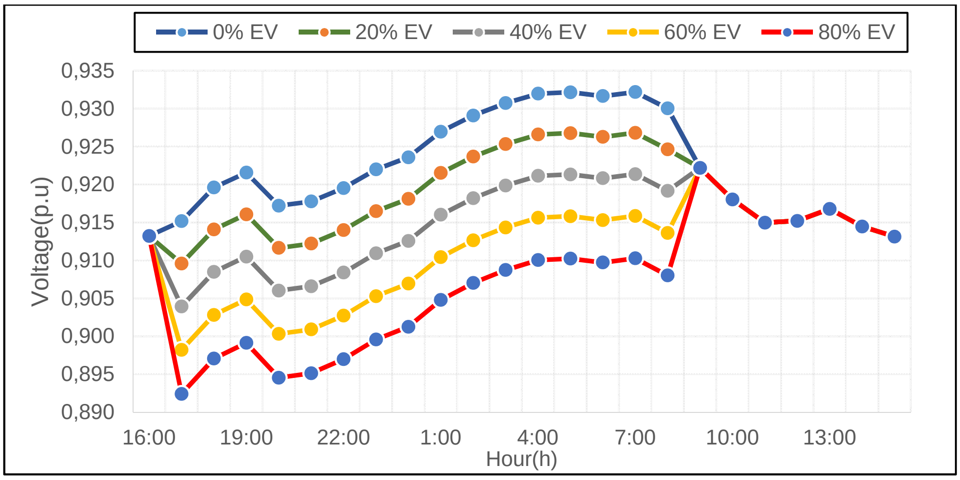

Figure 5. Uncoordinated Smart Charging 24-hour Voltage Profile at Bus 18

3.2. Coordinated Smart Charging

The coordinated smart charging means that each slot of charging will allow only a coordinated number of EV total charging load rather than allocating a fixation of 1/4 of the total charging load in every charging slot as in the uncoordinated charging. Based on Table 1, the coordination of CS is done for the 40%, 60% and 80% of EV penetration. The 20%EV have accommodate all the minimum chargers required for every charging slot. Therefore, this penetration level is not considered for coordination. The 40% until 80%EV cases show that bus 3,19 and 23 allow more CS to operate during the first and second charging slot while bus 25,29,10 and 14 allow more CS to operate during the third and the fourth charging slot. For 40%EV, bus 6,31 and 22 could accommodate more CS operation during the first and second charging slot. However, as the penetration level increase up to 80%, those buses only allow more CS to operate during the third and fourth charging slot. The charging coordination of CS is greatly influenced by the load profile. The first and second charging slot is allocated from 1700 to 0000 which is in the period of higher load demand compared to the other two slots. Therefore, as penetration of EV increase, more charging activities are shifted to the slots in between 0000 to 0900 because of lower load demand during this time interval.

Table 1. Coordinated Smart Charging Schedule for CS Operation at Selected Buses

Penetration level	Slot	Number of allowable CS operation at selected bus										
		Bus 3	Bus 5	Bus 22	Bus 29	Bus 31	Bus 6	Bus 10	Bus 19	Bus 14	Bus 23	Total CS
40%	1	16	11	6	8	7	7	6	16	6	8	91
	2	5	9	5	7	18	18	6	5	8	15	96
	3	13	9	18	11	10	7	13	9	8	5	103
	4	6	11	11	14	5	8	15	10	18	12	110
60%	1	19	9	11	8	5	14	6	12	6	25	115
	2	20	20	21	13	14	16	21	31	5	9	170
	3	12	22	6	15	12	22	6	12	16	8	131
	4	9	9	22	24	29	8	27	5	33	18	184
80%	1	38	9	11	6	6	24	18	20	5	42	179
	2	7	26	38	8	11	12	11	35	33	22	203
	3	28	24	19	36	43	16	41	14	6	7	234
	4	7	21	12	30	20	28	10	11	36	9	184

Figure 6 shows the loss profile for coordinated charging in 24 hours. The highest loss recorded for each penetration levels are 237.917kW, 258.821kW and 289.730kW for 40%, 60% and 80%EV respectively. This shows a reduction in the active power losses compared to the uncoordinated charging schedule for all the penetration levels. The comparison in total daily losses between the coordinated and uncoordinated smart charging is shown in Table 2. The coordinated charging schedule could reduce the losses by 4.797kW and 4.234kW for 40% and 60%EV respectively.

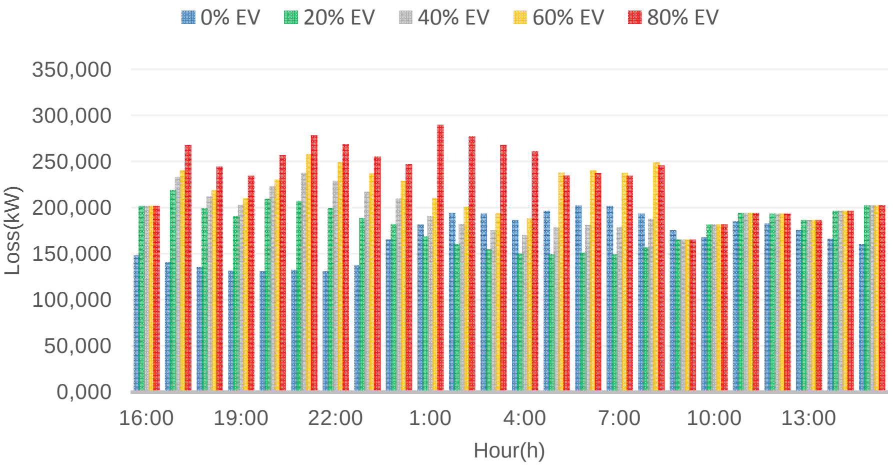

Figure 6. Coordinated smart charging 24-hour active power loss

Table 2. Comparison between uncoordinated and coordinated charging

Penetration level (%)	Total active power losses in a day(kW) Uncoordinated	Coordinated	Loss reduction(kW)
0%	4018.900	4018.900	0
40%	4740.650	4735.853	4.797
60%	5161.567	5157.333	4.234
80%	5625.893	5624.101	1.792

Figure 7 shows the voltage profile at bus 18 in the coordinated charging schedule. Both 40% and 60% EV penetration level shows that the voltage is maintained above 0.90p.u. at all hours. The lowest voltage recorded is 0.901p.u. at 0800 for 60%EV.

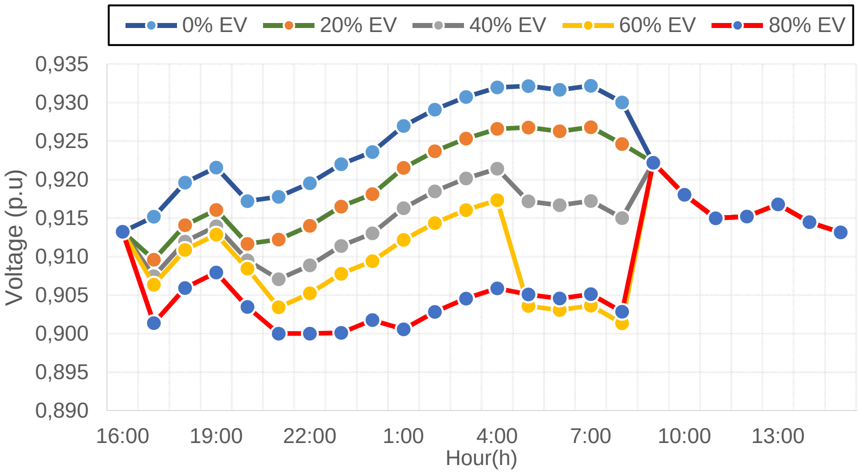

Figure 7. Coordinated 24-hour Voltage Profile at Bus 18

4. CONCLUSION

In a distribution system with high levels of EV penetration, uncoordinated vehicle battery charging may impose substantial incremental loads to distribution transformers, cause voltage regulation problems, and considerably increase system losses. This paper proposes an optimal EV charging schedule coordination using PSO algorithms. The simulation results for IEEE-33 Bus distribution system are presented and compared with uncoordinated and coordinated charging schedule. The proposed PSO algorithm approach is validated by comparing its solutions at different EV penetration levels. The PSO algorithm schedule the charging activities by determining the best combination of CS operation for 10 selected buses for each timeslot. The results indicate that the total daily power losses are greatly affected by the combination of different charging demand at different buses. Therefore, it is very important to consider the charging coordination of the grid for maintaining the electrical system security. Results show that the active power losses are reduced when an optimal charging coordination of CS is proposed compared to the uncoordinated charging scenario for every case of EV penetration. The future work for this research should focus on the new approach of optimizing the schedule coordination for the EV charging demand. Problem formulation should be focusing on the decentralized charging which consider several aspects such as random connection of EV to the grid and variable pricing scheme for the charging schedule optimization. In addition, random connection of EV to the grid and the decentralized charging should be considered in the problem formulation when optimizing the schedule.

REFERENCES

[1] Mukherjee J. C. and Gupta A., “A Review of Charge Scheduling of Electric Vehicles in Smart Grid,” *IEEE Systems Journal,* vol/issue: 9(4), pp. 1541-1553, 2015.

[2] Tan K. M. and Ramachandaramurthy V. K., “Integration of electric vehicles in smart grid: A review onvehicle to grid technologies and optimization techniques,” *Renewable and Sustainable Energy Reviews,* vol. 53, pp. 720-732, 2016.

[3] Gong X. and Lin T., "Optimal Decision-making on Charging of Electric Vehicles," *TELKOMNIKA Indonesian Journal of Electrical Engineering,* vol/issue: 12(4), pp. 2431-2438, 2014.

[4] Ahmad M. R. and Othman M. M., "Optimal Charging Strategy for Plug-in Hybrid Electric Vehicle Using Evolutionary Algorithm," *IEEE 8th International Power Engineering and Optimization Conference (PEOCO). Langkawi*, pp. 557-562, 2014.

[5] Celli G. and Ghiani E., "Particle Swarm Optimization for minimizing the burden of electric vehicles in active distribution networks," *IEEE Power and Energy Society General Meeting*, pp. 1-7, 2012.

[6] Sortomme E. and E. Sharkawi M. A., "Optimal charging strategies for unidirectional vehicle-to-grid," *IEEE Transactions on Smart Grid*, vol/issue: 2(1), pp. 119-126, 2011.

[7] Marra F. and Yang G. Y., "Improvement of local voltage in feeders with photovoltaic using electric vehicles," *IEEE Transactions on Power System,* vol/issue: 28(3), pp. 3515-3516, 2013.

[8] Knezović K. and Marinelli M., "Phase-wise enhanced voltage support from electric vehicles in a Danish low-voltage distribution grid," *Electric Power System Research,* vol. 140, pp. 274-283, 2016.

[9] Pillai J. R. and B. Jensen B., "Vehicle-to-Grid for islanded power system operation in Bornholm," *IEEE Power and Energy Society General Meeting. Providence,* pp. 1-8, 2010.

[10] Jian L. and Zheng Y., "Optimal scheduling for vehicle-to-grid operation with stochastic connection of plug-in electric vehicles to smart grid," *Applied Energy,* vol. 146, pp. 150-161, 2015.

[11] Tan K. M. and Ramachandaramurthy V. K., "Minimization of Load Variance in Power Grids-Investigation on Optimal Vehicle-to-Grid Scheduling," *Energies,* vol/issue: 10(11), pp. 1-21, 2017.

[12] Putrus G. A. and Suwanapingkarl P., "Impact of electric vehicles on power distribution networks," *IEEE Vehicle Power and Propulsion Conference. Dearborn*, pp. 827-831, 2009.

[13] Fofana G. H. and Zhang Y., "Electric Vehicle Lithium Ion Batteries Thermal Management," *TELKOMNIKA Indonesian Journal of Electrical Engineering,* vol/issue: 12(3), pp. 2414-2421, 2014.

[14] Luo H. and Li F., "A Method for Electric Vehicle Ownership Forecast Considering Different Economic Factors," *TELKOMNIKA Telecommunication Computing Electronics and Control,* vol/issue: 11(4), pp. 2239-2246, 2013.

[15] Gia I. K. and Jamian J. J., "Optimum distribution network operation considering distributed generation mode of operations and safety margin," *IET Renewable Power Generation Power Generation,* vol/issue: 10(8), pp. 1049-1058, 2016.

[16] Deilami S. and Masoum A. S., "Real-Time Coordination of Plug-In Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile," *IEEE Transaction Smart Grid,* vol/issue: 2(3), pp. 456-467, 2011.