https://doi.org/10.24191/jeesr.v22i1.004

Electric Vehicle Smart Charging Coordination on a Residential Distribution Grid

Norhasniza Md Razali, Hasmaini Mohamad* and Zaipatimah Ali

***Abstract*—The future grid with high plug-in electric vehicles (PEVs) penetration poses great challenges to the stability of the distribution system. Power quality degradation and transformer overload are some of the critical issues that need to be addressed. To alleviate the effect, smart charging coordination has been introduced using various optimization techniques and considerations on PEV penetration, charging parameters as well as grid operation limits. This study presents smart charging coordination of PEVs in a residential distribution network considering a daily residential load demand profile in Malaysia using a particle swarm optimization (PSO) algorithm. The proposed optimization is operated within several operating constraints such as power demand and bus voltage constraints while achieving the objective function of load optimization and minimum power loss. The performance of the proposed method is evaluated using a 415V IEEE 33-bus radial distribution network system with each bus connected to a residential feeder populated with PEVs. Results are compared between uncoordinated and coordinated charging considering four different PEV penetration levels. The proposed coordinated charging manages to optimize the load with PEV charging and gives a promising reduction in the network's power losses compared to uncoordinated charging.**

***Index Terms*—Charging coordination, Distribution network system, Electric vehicle (EV), Minimize power loss, Particle Swarm Optimization (PSO)**

I. INTRODUCTION

THE transportation sector which mainly uses traditional combustion engine vehicles (ICEV) is reported to be the top consumer of oil resources. The sector is expected to experience shortages by 2038 [1]. The introduction of electric vehicles (EVs) is an initiative towards sustainable technology and significantly contributes to a cleaner environment. A series of commercial EVs have been produced by leading manufacturers such as Tesla, Nissan, Mitsubishi, and Renault. Hybrid EVs (HEVs) are the first widespread EVs on the market. However, EVs which can be plugged into the grid namely plug-in EVs (PEVs) offer better performance and reliability [2].

With the increasing penetration of PEVs expected soon, PEV charging would consume a large amount of power, particularly during peak loading time. The demand from a PEV is usually larger than common household appliances. The Nissan Leaf, for example, requires a 3.3kW charger [3] and this demand is double the hourly average household demand during daily residential activity [4]. PEVs such as the Tesla Roadster require a much higher charging demand of at least 10kW [3]. Additionally, PEV owners are more likely to start charging as soon as they arrive home. Overnight charging would be the best and optimal time for utility providers due to the current low household demand during this period. Base-load power plant operations will be more effective and smoother with optimum use throughout the day [5]. However, simultaneous PEV charging demand is risky and has to be addressed. Uncoordinated PEV charging is a concern for utilities as the charging would cause overloading, voltage profile degradation, and increased power losses [4], [6]. To avoid power interruption during the connection of massive numbers of PEVs to the power system network in a short period, load management in terms of PEV charging coordination needs to be carried out.

Charging coordination of PEVs can be performed using different optimization techniques to achieve various objectives such as peak load shaving, minimizing energy losses, improving voltage deviation, and cost-saving [7]. Investigations in [8] have shown that with the application of a smart charging coordination strategy, the integration of PEVs into electrical networks is five times greater than uncoordinated or dumb charging. Among the numerous optimization techniques, three metaheuristic algorithms are commonly used namely Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Simulated Annealing (SA) [9], [10]. Most PEV charging coordination studies on residential distribution systems are based on a load profile reference which emphasizes the grid operational requirements and preferences of PEV owners.

EV charging scheduling on allocated buses of an IEEE 33-bus distribution network via the PSO method is proposed in [10]. The work focused on minimizing active power losses while maintaining the voltage profile on the demand side. A PEV charging study based on Evolutionary Programming (EP) techniques is conducted in [11]. This study focused on

This manuscript is submitted on 19 July 2022 and accepted on 8 February 2023. This work was supported by the Malaysian Government and Universiti Teknologi MARA under Fundamental Research Grant Scheme (600-IRMI/FRGS 5/3(090/2019)).

Norhasniza Md Razali and Hasmaini Mohamad are with the School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor (e-mail: hasmaini@uitm.edu.my).

Zaipatimah Ali is with the Department of Electrical and Electronics Engineering, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor (e-mail: zaipatimah@uniten.edu.my).

*Corresponding author
Email address: hasmaini@uitm.edu.my

minimizing and stabilizing the voltage level of distribution network buses. The flowchart and methodology are discussed only in general. Optimal scheduling of PEV charging based on meta-heuristic methods and random arrival of PEVs is proposed in [12] to minimize power loss and voltage deviation with the inclusion of time-of-use electrical tariff to minimize the charging cost in the residential distribution system. Reference [13] proposed an EV coordinated charging employing the sliding recursive algorithm to achieve load shifting and valley filling in a residential area in Henan Province of China. To overcome the effect of distribution transformer overloading due to EV uncoordinated charging, a study in [14] has developed a coordinated control strategy of 10 EV charging station piles with a real-time distribution transformer load control integration. If the transformer is overloaded, the control system will send a control command to reduce the output power of the charging station piles. The study is conducted in residential areas in dense urban areas. The impacts of EV charging during workday and holidays in three types of different residential districts namely ordinary, mid-level and high-level residential districts have been studied in [15]. Through peak-valley pricing strategy, the proposed EV charging coordination has improved the capability of ordinary residential districts to accommodate the EV charging load.

Centralized and decentralized control are the two main schemes in PEV charging coordination strategy [16]. In a centralized charging scheme, the PEV charging scheduling is controlled centrally by an aggregator. Information such as PEV maximum battery capacity, state of charge, and charging rate is collected from each connected PEV in the system. All the previous reviewed studies in [10], [15], [16] are based on centralized control charging. In a decentralized charging scheme, each PEV is given preferences to charge or not and can share its energy requirements to the aggregator [16]. Some studies also focused on decentralized control charging due to its advantages such as minimal computational requirements for EV controllers, protection of user privacy, enhanced security features, and fast convergence [17]. A decentralized EV charging control strategy in a residential distribution system is proposed in [18] by applying Augmented Lagrangian alternating direction multiplier methods. An EV aggregator as an intermediary between the power grid and the individual EV coordinates the EV charging while meeting individual EV charging requirements. Reference [19] developed a fully decentralized cooperative approach to maximize user satisfaction. The proposed decentralized approach is shown to be comparable with the centralized approach.

From the reviews of EV charging optimization on residential distribution systems, most of the developed algorithms are based on diverse daily residential load demand profiles. However, none considered a local load variation. The main contribution of this paper is to propose a centralized smart PEV charging coordination via PSO with a consideration of a daily load profile representing patterns of electricity consumption for typical residential buildings in Malaysia. The developed algorithm is tested on an IEEE 33-bus radial distribution network while considering the system technical constraints. The focused objectives are to optimize load demand with PEV charging and minimize power losses of the distribution system network.

The rest of the paper is structured as follows. Section II introduces the distribution network and load profile models. Section III presents the related problem and objective function formulations. Section IV explains the details of the PSO algorithm and the proposed algorithm framework. Simulation results and analysis are discussed in Section V.

II. SYSTEM MODELS

A. Network Topology

The IEEE 33-bus radial distribution system as illustrated in Fig. 1 is used to evaluate the effectiveness of the proposed algorithm. This system has a base voltage of 12.66kV, and total loads of 3715kW and 2290kVAR. A total of 32 buses are connected to low voltage 415V residential feeders populated with PEVs. There are a maximum of eight houses equipped with PEV home charging outlets on every residential feeder. This results in a total of 256 PEVs that can be plugged in at the same time in the distribution system. System data including lines and load parameters are given in [20].

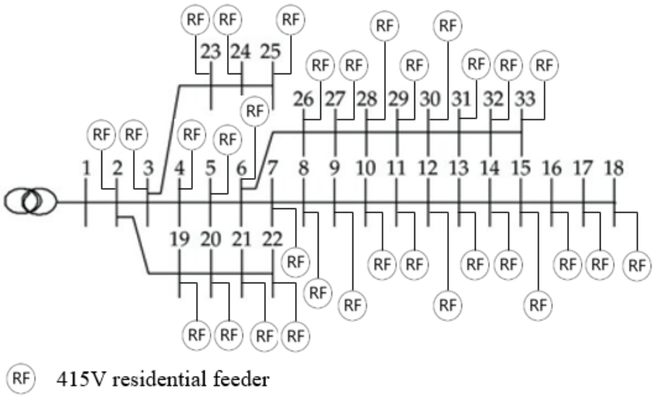

Fig. 1. IEEE 33-bus radial distribution system.

B. Residential Daily Load Profiles

A daily load demand curve for typical residential buildings in Malaysia shown in Fig. 2 is used to model the domestic load variations within 24 hours without PEV charging [21]. Off-peak hours occur between 09:00h to 18:00h which are working hours and most residents are not at home during this time. After 18:00h, a sudden increase of load is observed until it reaches a peak load at 21:00h. This is the active period when residents are already at home and start using their electrical appliances. Among appliances that consume the most electricity are air conditioner, rice cooker, water heater, refrigerator, oven, microwave and flat iron [22].

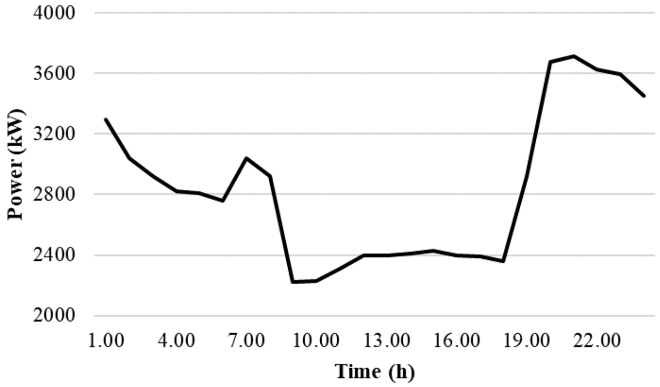

Fig. 2. Daily residential load demand in Malaysia.

C. Assumptions

The storage capacity of each PEV battery is set at 16kWh. For every timeslot, PEV charging will consume 4kW considering the energy flow is unidirectional only. The batteries can only be charged and not discharged. All PEVs are assumed to be charged at home. Each PEV will complete the charging process within 4 hours depending on the power available during each timeslot. The maximum power output of a standard single-phase 230V home outlet is 4.6kW. Therefore, a standard home charger of 4kW is suitable for the application.

III. PROBLEM FORMULATION

The design of PEV charging coordination of PEVs in a power distribution system employs a smart and fast optimization algorithm with consideration of an objective function necessary to improve grid performance. Based on different PEV penetration levels, the charging coordination in this study aims to achieve load optimization and minimum power losses while taking into account several system constraints throughout the process.

A. System Constraints

Distribution systems are designed so that all consumers along the feeder will experience voltage within a specified range due to variation of load. The voltage range of a distribution system is limited by minimum voltage, $V_{\min}$ and maximum voltage, $V_{\max}$ values which correspond to the grid voltage regulations set by the utility company as shown in (1). In this study, the voltage limits are considered at ±10% ($V_{\min}$= 0.9 pu and $V_{\max}$ = 1.1 pu)

$$V_{\min} \le V_i \le V_{\max} \qquad \text{for } i = 1,........,n \tag{1}$$

where i is the node of branches and n represents the total number of branches. The second constraint is to prevent overload of the local substation transformer. The ceiling limit of total maximum power demand, P_{demand} for the distribution system which includes the household load, P_{load}, PEV power consumption, P_{PEV} and line loss in the power system, P_{loss} is set as in (2).

$$P_{\text{demand}} \ge \sum\nolimits_{i=2}^{n} (P_{\text{load}} + P_{\text{PEV}})i + P_{\text{loss}} \tag{2}$$

B. Objective Function

The power loss equation of the distribution system is presented by (3),

$$\min f = \sum\nolimits_{k=1}^{n-1} | I_k |^2 \times R_k \tag{3}$$

where I_k and R_k are current and impedance at line k.

IV. OPTIMIZATION ALGORITHM

The charging profiles of PEVs have major effects on the distribution system. The main contribution of this study is performing a smart PEV charging coordination to achieve load optimization and minimum power losses considering the daily residential load profile in Malaysia. This study employs the well-known metaheuristic optimization algorithm of Particle Swarm Optimization (PSO). This method was introduced in 1995 by James Kennedy and Russell Eberhart [23]. PSO is a swarm intelligence-based search algorithm inspired by the social behavior of bird flocks and schooling fish. A particle is a "bird" in the search space. All particles have fitness values that are evaluated based on the fitness function and velocities which direct the movement of the particles. The algorithm is initialized with a group or population of random particles, and the search for the optimum solution is performed by updating generations of particles. Two 'best' values namely P_{best} and G_{best} are updated for each particle in every iteration. P_{best} is the best solution or fitness achieved by the particle so far while G_{best} is the best value obtained by any particle in the population or also known as the global best. Both values are stored in the program. Each of the particles will update its position and velocity over the iterations based on (4) and (5) until a global minimum is reached.

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{4}$$

where

$$\begin{aligned} V_i(t+1) = wV_i(t) + C1r1(P_{\text{best},i} - X_i(t)) + \\ C2r2(G_{\text{best}} - X_i(t)) \end{aligned} \tag{5}$$

$X_i(t)$ and $V_i(t)$ are the current particle position and velocity, respectively. $r1$ and $r2$ are random numbers between 0 to 1. Constants w, $C1$ and $C2$ are parameters to the PSO algorithm. PSO is chosen for this study because it is simple and has a fast convergence compared to other global optimization algorithms like GA, SA and many more [24]. The computational procedure of the proposed technique is summarized in Fig. 3.

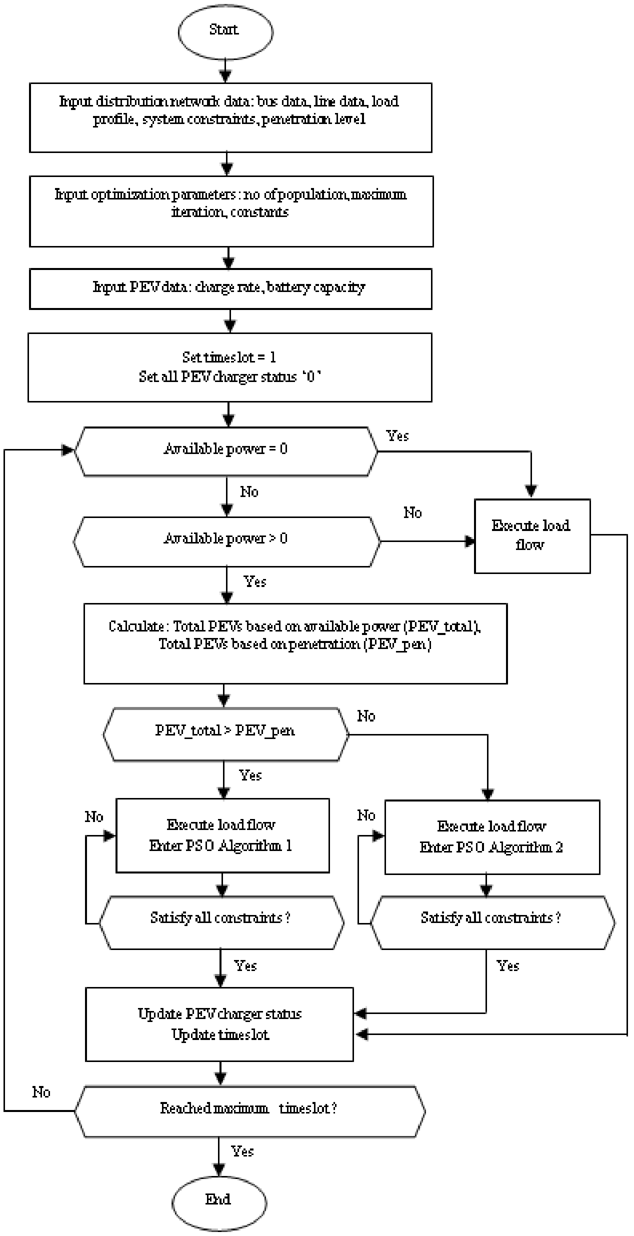

Fig. 3. Proposed smart PEV charging coordination flowchart.

The distribution system's load flow and proposed charging strategy are developed using MATLAB software. A load flow analysis based on the Newton-Raphson method is performed to assess voltage deviations and power losses in the distribution grid. Random PEV arrivals are considered. However, only several PEV charging outlets are programmed to operate based on available power demand on each network bus and penetration level set for each timeslot. For timeslots that require optimization, the initial population of PSO is randomly generated from the network bus numbers required to supply PEV charging. The population number is set at 20. Thus, 20 values of initial power loss are generated. P_{best} and G_{best} values are searched and stored in the program. Each population is then updated based on (4) and (5). In the next iteration, new values of P_{best} and G_{best} will be stored. The population is then updated again and this process repeats until the iteration is completed or the converge condition is met. The peak load and voltage are monitored and controlled to not exceed their limits throughout the optimization process. Overnight charging mode is chosen for this study taking into account PEV users' convenience and their availability at home being much longer during night hours.

V. RESULTS AND ANALYSIS

The impacts of the proposed study on the IEEE 33-bus distribution system performance are investigated and compared between uncoordinated and coordinated charging schemes. Results for both charging schemes are evaluated in terms of power consumption, power losses, and voltage profiles and summarized at four different levels of PEV penetration which are 25%, 50%, 75%, and 88%. For overnight PEV charging, the charging time frame is selected from 19:00h until 06:00h the next morning.

A. Uncoordinated Charging

Uncoordinated charging indicates that there is no control over the PEV charging time and frequency. PEV batteries either start charging immediately upon being plugged in or after a user-adjustable fixed start delay. Each timeslot is equipped with several PEVs based on the penetration level and the same PEVs will continue charging for 4 hours to fully charged. Fig. 4 shows the daily load profile variation due to increased power consumption from uncoordinated charging of PEVs.

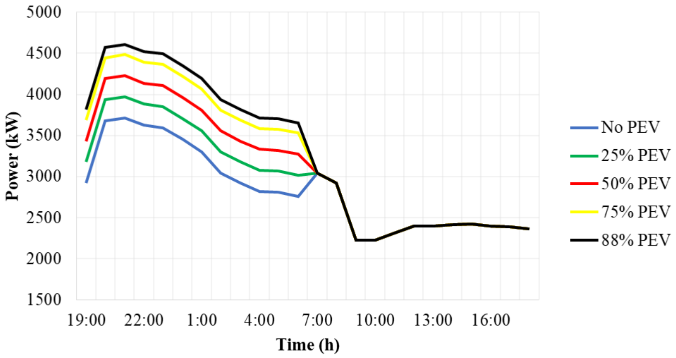

Fig. 4. Impact of uncoordinated charging on 24-hour power consumption.

Based on the tested IEEE 33-bus distribution system, the maximum power capacity is rated at 3715kW. Exceeding this limit would cause overloading and degradation to the distribution transformer. We observed that at 25%, 50%, and 75% PEV penetration levels, overloading conditions have occurred starting from 20:00h until 23:00h. This condition continues for the next 2 hours and 3 hours at 50% and 75% penetration levels, respectively. At 88% PEV penetration level, overloading occurs as soon as charging starts at 17:00h and continues until 04:00h. The highest power consumption occurs at 21:00h for all PEV penetration levels. The values recorded are 3971kW, 4227kW, 4483kW, and 4611kW at 25%, 50%, 75%, and 88% penetration levels, respectively. Increased power consumption also leads to higher power losses and alarming voltage deviations in the distribution system as shown in Figs. 5 and 6.

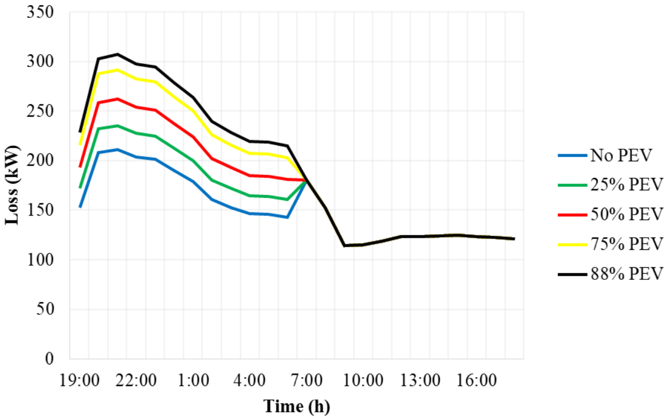

Fig. 5. Impact of uncoordinated charging on 24-hour power losses.

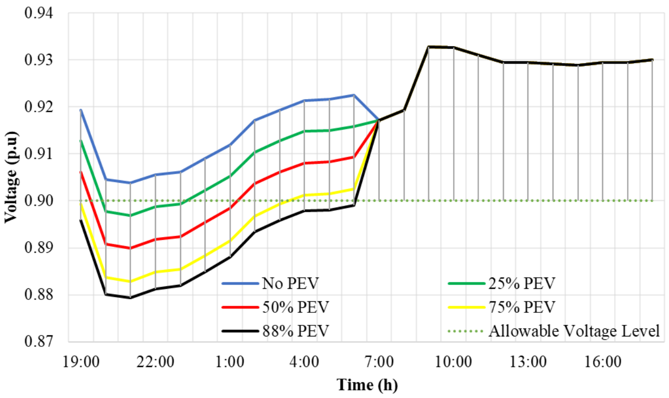

Fig. 6. Impact of uncoordinated charging on 24-hour voltage profile at bus 18.

For all PEV penetration levels, the highest power loss also occurs at 21:00h. The values recorded are 235.55kW, 262.43kW, 291.70kW, and 307.26kW at 25%, 50%, 75%, and 88% penetration levels, respectively. Power loss without any PEV charging at this particular hour is 210.99kW.

The voltage profile is analyzed at the weakest node of the distribution system which is bus 18. Without any PEV charging, bus 18 records the lowest voltage drop compared to other end node buses. At 25% penetration level, we observed that the voltage has experienced a drop below its minimum limit of 0.9 pu starting from 20:00h until 23:00h. Voltage drop continues for the next 2 hours and 4 hours at 50% and 75% penetration levels, respectively. At 88% PEV penetration level, all voltages are affected and remain below 0.9 pu throughout the whole charging time frame. The lowest voltage recorded is 0.879 pu at 21:00h for 88% PEV penetration. In conclusion, we observed that even with low PEV penetrations, uncoordinated charging would adversely affect the stability of the distribution system.

B. *Coordinated Charging*

A smart PEV charging coordination strategy via PSO algorithm is proposed to achieve load optimization and minimum power losses, taking into account the distribution system constraints and residential load profile. Similar to uncoordinated PEV charging, the results of coordinated charging are evaluated at four different PEV penetration levels as shown in Figs. 7, 8, and 9 for 24-hour power consumption, power losses, and voltage profile, respectively.

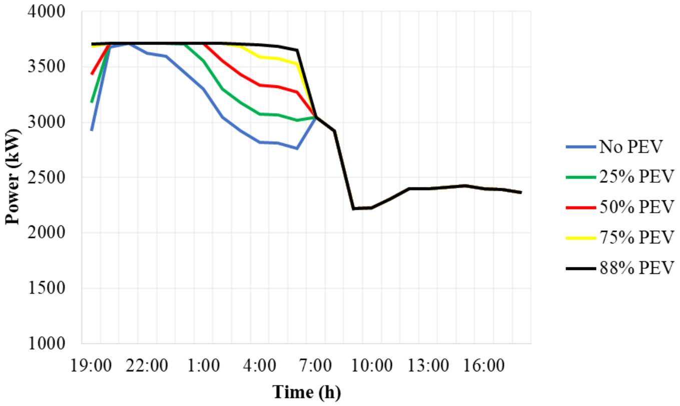

Fig. 7. Impact of coordinated charging on 24-hour power consumption.

Coordinated PEV charging only allows several PEVs to charge in every timeslot. Based on the load curve without any PEV charging, the maximum power consumption of 3715kW from household appliances is recorded at 21:00h. Thus, no PEVs are allowed to charge during this timeslot. The PEV charging is managed accordingly via the coordinated charging algorithm. Throughout the charging time frame, power consumption with the additional load from PEV charging is successfully maintained below 3715kW at all PEV penetration levels. Power consumption at each timeslot is also optimized based on the available power and allowable number of PEVs that can be charged on each residential feeder. At 88% PEV penetration, we observed that power consumption is near maximum at all timeslots with PEV charging.

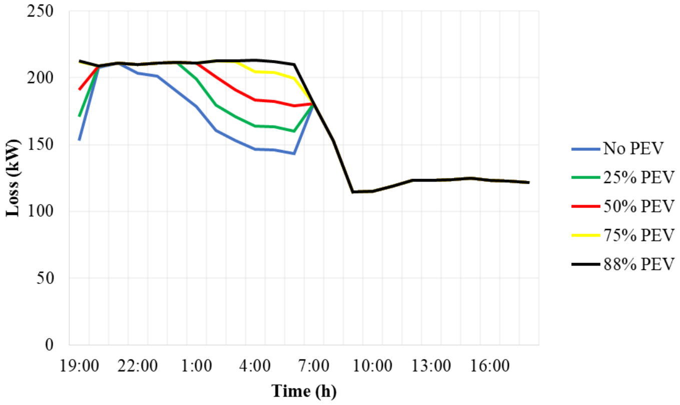

Fig. 8. Impact of coordinated charging on 24-hour power losses.

Power losses during the PEV charging time frame are also reduced significantly for all penetration levels as shown in Fig. 8. For coordinated charging, the highest power loss for each penetration level is now varied at different timeslots with reference to the PEV charging load variation in every residential feeder. The values recorded are 211.60kW, 211.63kW, 212.79kW, and 213.11kW at 25%, 50%, 75%, and 88% penetration levels, respectively. The highest power loss at 88% penetration level has only a difference of 2.12kW from the nominal value of power loss without any PEV charging. The reduction of total power loss in 24 hours at all PEV penetration levels is summarized in Table I.

TABLE I
SUMMARY OF REDUCTION IN TOTAL POWER LOSSES OVER 24-HOURS

Penetration level (%)	Total power loss in 24 hours (kW)		Total power loss reduction (kW)
	Uncoordinated charging	Coordinated charging	
0	3639.41	3639.41	0
25	3891.51	3805.17	86.34
50	4169.91	3935.40	234.51
75	4475.53	4053.73	421.80
88	4638.87	4081.34	557.53

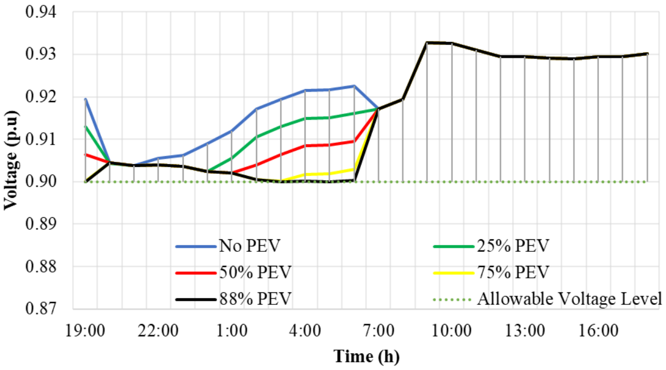

Fig. 9. Impact of coordinated charging on 24-hour voltage profile at bus 18.

From Fig. 9, the voltages at the weakest node of bus 18 are successfully regulated within limits even under large PEV penetrations. In conclusion, the proposed smart PEV charging coordination strategy has improved the distribution system performance compared to uncoordinated charging.

VI. CONCLUSION

This study has presented a smart PEV charging coordination based on the PSO method to achieve minimum power losses and load optimization with consideration of daily residential load variations in Malaysia while maintaining voltage profiles and peak demand limits. The proposed PEV charging coordination only allows several PEVs to be charged on each residential feeder based on available power demand. As expected, the distribution system is facing problems of overloading, high power losses and voltage regulation due to uncoordinated PEV charging. The improvements of the proposed algorithm versus uncoordinated PEV charging are compared with simulation results in MATLAB software. The results are demonstrated at different penetration levels of PEV. Coordinated PEV charging is proven to be beneficial in reducing system overloads by maintaining the power demand below its maximum limit, reducing the system's total power losses and maintaining the voltage profile. The load with PEV charging is optimized on every residential feeder where the algorithm will allocate as many PEV as possible to be charged based on the penetration level. The minimum power losses are obtained by searching the best combination of PEV charging and bus location in the system. The proposed PEV charging coordination strategy has successfully achieved the targeted objectives following the satisfying results of total daily power loss reduction. Further study will focus on improving the PEV charging algorithm with consideration of PEV users' preferences and satisfaction.

ACKNOWLEDGMENT

The authors would like to thank the College of Engineering, Universiti Teknologi MARA (UiTM) Shah Alam campus for the support given to this study.

REFERENCES

[1] M. Ehsani, Y. Gao, S. Longo, and K. Ebrahimi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*. CRC Press, 2018. [Online]. Available: https://books.google.com.my/books?id=o8JKDwAAQBAJ

[2] D. Alfonso, G. Gianluca, M. Ignazio, P. Mario, and S. Alessandro, "Vehicle-to-grid technology: State-of-the-art and future scenarios," *Journal of Energy and Power Engineering*, vol. 8, no. 1, Jan. 2014, doi: 10.17265/1934-8975/2014.01.018.

[3] M. Yilmaz and P. T. Krein, "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles," *IEEE Transactions on Power Electronics*, vol. 28, no. 5. pp. 2151–2169, 2013. doi: 10.1109/TPEL.2012.2212917.

[4] A. R. Abul'Wafa, A. E'Garablyl, and W. A. F. Mohamed, "Uncoordinated vs coordinated charging of electric vehicles in distribution systems performance," *International Journal of Engineering and Information Systems*, vol. 1, no. 6, pp. 54–65, 2017.

[5] P. Denholm and W. Short, "Evaluation of utility system impacts and benefits of optimally dispatched plug-in hybrid electric vehicles (Revised)," National Renewable Energy Lab.(NREL), Golden, CO (United States), 2006.

[6] S. Chadha, V. Jain, and H. R. Singh, "A review on smart charging impacts of electric vehicles on grid," *Materials Today: Proceedings*, May 2022, doi: 10.1016/j.matpr.2022.05.122.

[7] M. T. Rahman, N. B. A. Rahim, M. Othman, and H. Mokhlis, "Plug-in electric vehicle charging coordination considering distribution protection system," in *2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, 2018, pp. 51–55. doi: 10.1109/APPEEC.2018.8566658.

[8] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of electric vehicles in the electric power system," *Proceedings of the IEEE*, vol. 99, no. 1, pp. 168–183, Jan. 2011, doi: 10.1109/JPROC.2010.2066250.

[9] S. M. Arif, T. T. Lie, B. C. Seet, S. Ayyadi, and K. Jensen, "Review of electric vehicle technologies, charging methods, standards and optimization techniques," *Electronics (Switzerland)*, vol. 10, no. 16. MDPI AG, Aug. 02, 2021. doi: 10.3390/electronics10161910.

[10] W. I. F. W. Zalnidzam, H. Mohamad, N. A. Salim, H. Mokhlis, and Z. M. Yasin, "Optimal charging schedule coordination of electric vehicles in smart grid," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 11, no. 1, pp. 82–89, 2018, doi: 10.11591/ijeecs.v11.i1.pp82-89.

[11] J. Ahmad *et al.*, "Evolutionary programming based technique for plug-in-hybrid electric vehicle charging system," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 1.3 S1, pp. 425–430, 2019, doi: 10.30534/ijatcse/2019/7381.32019.

[12] H. Suyono, M. T. Rahman, H. Mokhlis, M. Othman, H. A. Illias, and H. Mohamad, "Optimal scheduling of plug-in electric vehicle charging including time-of-use tariff to minimize cost and system stress," *Energies (Basel)*, vol. 12, no. 8, pp. 17–21, 2019, doi: 10.3390/en12081500.

[13] Y. Wang *et al.*, "Research on coordinated charging control strategy load optimization of electric vehicles in residential area," in *IOP Conference Series: Earth and Environmental Science*, Jul. 2020, vol. 510, no. 6. doi: 10.1088/1755-1315/510/6/062030.

[14] J. Ma, W. An, W. Ming, J. Du, W. Yin, and J. Chen, "Coordinated control strategy for electric vehicle charging piles to prevent overload of distribution transformer," in *5th Asia Conference on Power and Electrical Engineering (ACPEE)*, 2020, pp. 684–688.

[15] L. Chen and S. Lu, “Research on the influence of electric vehicle charging on residential distribution network in southern China,” in *Proceedings - 2021 International Conference on Power System Technology: Carbon Neutrality and New Type of Power System, POWERCON 2021*, 2021, pp. 829–833. doi: 10.1109/POWERCON53785.2021.9697874.
[16] J. C. Mukherjee and A. Gupta, “A Review of Charge Scheduling of Electric Vehicles in Smart Grid,” *IEEE Systems Journal*, vol. 9, no. 4, pp. 1541–1553, 2015, doi: 10.1109/JSYST.2014.2356559.
[17] C. K. Wen, J. C. Chen, J. H. Teng, and P. Ting, “Decentralized plug-in electric vehicle charging selection algorithm in power systems,” *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 1779–1789, 2012, doi: 10.1109/TSG.2012.2217761.
[18] S. Xu, Z. Yan, D. Feng, and X. Zhao, “Decentralized charging control strategy of the electric vehicle aggregator based on augmented Lagrangian method,” *International Journal of Electrical Power and Energy Systems*, vol. 104, pp. 673–679, Jan. 2019, doi: 10.1016/j.ijepes.2018.07.024.
[19] A. Paudel, S. A. Hussain, R. Sadiq, H. Zareipour, and K. Hewage, “Decentralized cooperative approach for electric vehicle charging,” *Journal of Cleaner Production*, p. 132590, Jun. 2022, doi: 10.1016/j.jclepro.2022.132590.
[20] S.M.Suhail Hussain, “Load flow of radial distribution system.” [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/40376-load-flow-of-radial-distribution-system (accessed Jun. 23, 2022).
[21] A. Aljanad and A. Mohamed, “Harmonic impact of plug-in hybrid electric vehicle on electric distribution system,” *Modelling and Simulation in Engineering*, vol. 2016, pp. 1–7, 2016, doi: 10.1155/2016/5968943.
[22] M. S. Ahmed, A. Mohamed, R. Z. Homod, H. Shareef, and K. Khalid, “Awareness on energy management in residential buildings: A case study in Kajang and Putrajaya,” *Journal of Engineering Science and Technology*, vol. 12, no. 5, pp. 1280–1294, 2017.
[23] J. Kennedy and R. Eberhart, “Particle swarm optimization,” in *Proceedings of ICNN’95 - International Conference on Neural Networks*, 1995, vol. 4, pp. 1942–1948 vol.4. doi: 10.1109/ICNN.1995.488968.
[24] S. S. Aote, M. M. Raghuwanshi, and L. Malik, “A brief review on particle swarm optimization: limitations & future directions,” *International Journal of Computer Science Engineering (IJCSE)*, vol. 14, no. 1, pp. 196–200, 2013.

Norhasniza Md Razali received the Bachelor in Electrical Engineering (Hons) from University of Science, Malaysia, in 2006 and the Master in Engineering Science from University of Malaya, Malaysia in 2012. She is currently pursuing the PhD in Electrical Engineering at University of Teknologi MARA, Malaysia. Her research interests include power system, smart grid and artificial intelligence.

Hasmaini Mohamad received the B.Eng., M.Eng., and Ph.D. degrees from the University of Malaya, in 1999, 2004, and 2013, respectively. She started her career as a lecturer in Universiti Teknologi MARA in 2003 where currently she is an Associate Professor at the Centre for Electrical Power Engineering Studies, Faculty of Electrical Engineering. Apart from that, she has published more than 50 journal papers including high impact ISI journals and 20 conference papers. Her major research interest includes islanding operation of distributed generation, hydro generation, load sharing technique, and load shedding scheme.

Zaipatimah Ali received Bachelor of Science in Electrical Engineering (BSEE) in 1998 from Purdue University, Indianapolis, US, Master of Science in Electrical and Computer Engineering (MSECE) in 2003 from the same university and Ph.D. in Electrical Engineering from University of Manchester, United Kingdom, in 2015. She is currently a Senior Lecturer at Department of Electrical Power Engineering, Universiti Tenaga Nasional (UNITEN). Her research interests include power system modelling and simulation, smart grid, as well as power system protection.