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ORIGINAL PAPER

Decentralize Coordinated Charging of Plug-In Electric Vehicles in Unbalanced Residential Networks to Control Distribution Transformer Loading, Voltage Profile and Current Unbalance

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Abstract Utilization of plug-in electric vehicles (PEVs) in residential feeders is gaining popularity in recent years due to the societal awareness about greenhouse gas emission and the increasing of petrol price. The potential for network stress and congestion due to uncoordinated charging of PEVs is significant as they represent sizeable unbalanced loads with unpredictable locations, plug-in times, charging rates and durations. This paper aims to mitigate the detrimental impacts of electric vehicle charging on smart grid by implementing a decentralized coordinated PEV charging algorithm that will also improve the power quality of smart grid. The idea for the individual PEV chargers is to acquire distribution transformer loading through the smart meters to dynamically coordinate their charging times, rates and durations in order to improve the overall system voltage profile, reduce transformer stress and control current imbalance. Simulation results will be generated and analysed for an unbalanced three-phase 62 node residential network populated with PEV chargers using the Simulink-Matlab software.

Keywords PEV · Decentralize charging · Smart grid · Power quality

Introduction

Smart grids are gaining worldwide acceptance as a means to improve demand-side management with smart metering and sensors [1–3], improving energy efficiency and grid reliability [4,5] while increasing the system security in response to natural disasters [6,7]. In order to develop future smart grids, the conventionally designed distribution networks need to be upgraded to cope with the growing energy requirements of the future [8–10]. This scenario is particularly related due to emerging deregulation of power industry, increasing integration of renewable energy resources and especially the growing popularity of plug-in electric vehicles (PEVs) among end users in many developing countries. Due to the growing government and public concerns to reduce greenhouse gas emissions, many automotive companies have been motivated to move toward more sustainable technology solutions such as hybrid electric vehicles and PEVs.

In [11] it is estimated that the PEV market penetration in 2016 will be about 1.5 million and over 50 million in 2030. This will lead in an annual increase of 2 % in network load growth. Although a number of coordinated PEV charging schemes are currently being explored [12–15] to conquer future network congestion issues and reduce the significant time and cost investments for upgrading and developing the required infrastructure. Meanwhile, electric vehicles can be connected to the distribution system in an uncoordinated and random manner. Therefore, electric utilities need to urgently determine how the existing distribution systems will deal with these new loading patterns, especially if coordinated PEV charging capabilities are not expected in the near future.

Power transformers are expected to be intensely influenced by the appearance of smart grids, smart appliances and nonlinear loads such as PEVs at residential houses, offices and charging stations. One of the main concerns of elec-

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tric utilities is how local distribution circuits will react to the extra loading presented by the high penetration of PEV charging at owner's properties. In particular, local distribution transformers will suffer from reduced operational life and early failure from overloads. This could harshly impact the efficiency, security, reliability and economy of developing smart grids [16]. To overcome these problems and to find applicable solutions, two general PEV coordination schemes have been considered:

- *Centralized Coordinated PEV Charging* [12–15]—The system operator as a centre controller sends commands through the smart grid communication network to each individual PEV to set the charging start time and rate. The decisions can be made based on several factors such as system capacity, system loss minimization, node voltage profiles, final state of charge (SOC), budget, etc. Therefore, a stable and more secure network can be achieved. However, centralized architectures with few central data stores require customer information and may lead to un-scalable systems and costly initial infrastructure investments.
- *Decentralized Coordinated PEV Charging* [17,18]—Each PEV is allowed to determine its own charging pattern. The decision can be made on the base of system capacity and conditions. The consequence of a decentralized approach may or may not be optimal, depending on the information and methods used to determine local charging patterns. Indeed, this approach does not require substantial knowledge of individual customers [19].

This paper proposes a decentralized coordinated PEV charging algorithm (DC-PEV-CA) that will also prevent distribution transformer overloading, regulate bus voltages and limit phase current unbalances. It is assumed that the PEV chargers have access to the distribution transformer output power and phase currents through the smart meters. The performance of DC-PEV-CA will be demonstrated for an unbalanced three-phase 62 node residential network populated with PEV chargers.

Problem Formulation

Distribution transformers are commonly designed for specific load carrying capabilities based on typical load consumption patterns. When PEVs are deployed, the normal electric power demand pattern will be changed and the power system might not be capable of handling the new operating conditions and demands. Based on recent studies [20,21], PEV owners may most often charge their vehicles as soon as they arrive home at early evening hours, which may cause an unexpected daily load peak around 5 pm–9 pm. Moreover, by deploying PEVs at residential houses, the average current unbalance will be increased which could consequently result in undesired increase of voltage unbalance and causing problems to the power system especially the distribution transformer.

The proposed DC-PEV-CA (Fig. 2) takes several inputs including transformer apparent power, network line currents, nodes voltage profile and PEV parameters. Then it considers the arrival of PEVs and also their preference charging times and delay the charging till reach the requested time zone. Next step is to check the network constraints. If it does not meet one of the constraints, will go back to the next iteration.

The First constraint is for limiting the total loading of the distribution transformer to prevent an overload condition from PEV charging. The idea is that the PEVs will be charged if the transformer loading is within the rated value. Otherwise, charging will be delayed until the transformer loading falls below the threshold value. As the power demand of PEV charger is a function of its voltage and current, the capacity of the battery determines the length of charging time.

$$\mathrm{P_{charge}} = \mathrm{V_{node}} \times \mathrm{I_{battery}} \tag{1}$$

$$\mathrm{W} = \int_{\mathrm{t_1}}^{\mathrm{t_2}} (\mathrm{V_{node}} \times \mathrm{I_{battery}})\mathrm{dt} \tag{2}$$

where t_1 and t_2 are the start and termination times of PEV charging while P_{charge} is the rated battery capacity.

The second constraint is voltage profile of the distribution system which is considered by setting the upper and lower limits to correspond with voltage regulation limits typically set by utilities. In this paper, the voltage limits are set to +/− 10 % ($\mathrm{V_{min}} = 0.9$ pu and $\mathrm{V_{max}} = 1.1$ pu) which is typical of many distribution systems [12,13].

$$V_{min} \le V_k \le V_{max} \text{ for } k = 1, \ldots, n. \tag{3}$$

where k is the node number and n is the total number of nodes.

The third constraint is the network line currents. This constraint is used to determine the connected phase of each PEV (A, B or C). Then it jumps to the next step if the amplitude of connected PEV line current is less than the other two line currents and also less than network rated line current. This is due to prevent raises of unbalances to the system by charging the PEVs and moreover, if possible by charging the PEV, reduce the network unbalances. Therefore, the paper has proposed three different charging rates (high, medium and low) to facilitate a possibility of reduce system's unbalances. This fact can be done by introducing current unbalance factor (CUF). The current unbalance factor is defined similar to Voltage unbalance factor (VUF). Unbalanced voltages can result in adverse effects on equipment and on the power system, which is intensified by the fact that a small unbalance in the phase voltages can cause an excessively larger unbalance in the phase currents [22,23]. Under unbalanced conditions, the power system will incur more losses and heating effects, and be less stable [24].

To quantify and investigate the degree of current unbalance, the CUF is defined similar to the VUF as the ratio of the negative-sequence component to the positive-sequence component [25]:

$$\mathrm{CUF} = \frac{\text{I2 (Negetive sequence of three phase current)}}{\text{I1 (Positive sequence of three phase current)}} \times 100 \quad (4)$$

where $I_1 = \frac{1}{3} \times \left(I_a + xI_a + x^2 I_a\right)$, $I_2 = \frac{1}{3} \times \left(I_a + x^2 I_b + xI_c\right)$, $\mathrm{x} = \mathrm{e}^{\mathrm{j} \times \frac{2\pi}{3}} = 1\angle + 120\ deg$.

The CUF values are chosen for this particular network and maybe vary for other network conditions. In this case the high and low charging rates are assigned to high and low CUF values, respectively. Since the charging will be done if the amplitude of line current of related PEV is less than other line currents, therefore by PEVs charging process the amplitude different between network line currents will be reduced and consequently the system unbalances will be decreased. As illustrated in Fig. 4b, it is clear that the process of PEV charging reduces the system current unbalance (compared to Fig. 4a) and in Figs. 9e and 10e, it can be seen that the PEVs have been charged with three different charging rates.

The 62 Node Unbalanced Residential Network

The 62-node unbalanced low voltage 415 V residential feeder of Fig. 1 connected to the high voltage system through a 350 kVA 22/0.415 kV distribution transformer [26] and will be simulated to test the proposed DC-PEV-CA. The PEV penetration level is assumed to be 50 %. The PEV locations and arrival times are randomly assigned; but kept unchanged for comparison of results. Furthermore, an average house peak demand of 5.0 kW with a constant power factor of 0.95 is assumed for each household.

The vehicle data are obtained from typical PEV specifications [27] and the national transportation survey [28]. The battery capacity is 16 kWh which is proposed to get fully charged between four to several hours (maximum charging of 4 kW per hour) with the unity power factors. This charger rating is within the capability of most modern residential circuits and wiring standards (e.g., in Western Australia) which can typically carry 15–20 A from a single phase 230 V supply.

As distribution systems usually consist of single-phase, two-phase, and untransposed three-phase lines feeding unbalanced loads, it is necessary to keep the identity of the self and mutual impedance terms of the conductors and take into account the ground return path for the unbalanced currents [29].

Proposed Decentralized Coordinated PEV Charging Algorithm (DC-PEV-CA)

To mitigate the detrimental impacts of PEV charging, a DC-PEV-CA (Fig. 2) is proposed and implemented which will simultaneously reduce distribution transformer loading and bus voltage fluctuations while dynamically compensating line current unbalances. In [26] authors present a new decentralized coordinated charging of PEVs by introducing variable electricity prices. However, the method and simulation results show dramatic improvement of distribution transformer loading and bus voltage fluctuations, worse cases are not addressed in the paper. The control method in [26] does not include any constraints and just relies on consumer preference charging zones. If most of PEVs decide to charge on fast charging (red zone), the network will face several problems. As can be seen from Fig. 7 (Case C), when most of customers choose red charging time zone, the transformer and network face overloading and overcurrent during PEVs charging which is not considered in [26].

The proposed PEV charging approach in this paper not only takes the consumer preference as an option, also consider the network data (transformer apparent power, network line currents and node voltage profile) in order to charge the PEVs. As shown in Fig. 2, three constraints of transformer loading, network line currents and node voltage profile have been used. Therefore, it is more reliable and also secure the safe operation of distribution network under PEVs charging. Therefore, this paper proposes a decentralized charging of PEVs based on network data and guaranties safe operation of network under high penetration of PEVs.

Based on Eq. 4 the minimum and maximum charging times for one PEV battery are 4 and 13 h, respectively. Each PEV decides the starting time and charging rate on its own charging condition depending on the online status of the distribution transformer provided by the smart meters. Therefore, it is not possible to predict the charging durations of the PEVs as the transformer operating condition is continuously changing within the 24 h. Moreover, to encourage PEV owners to improve their energy usage behaviour and shift their energy consumptions to off-peak hours, variable electricity prices are offered. By considering these variable prices, the following three charging time zones (Fig. 3) including red, blue and green charging time zones corresponding to high tariff (most expensive), medium tariff (normal electricity charge) and low tariff (less expensive) are defined and offered to PEV owners [12,13]. In this proposal three battery charge rates are considered (Eq. 3 and Fig. 2).

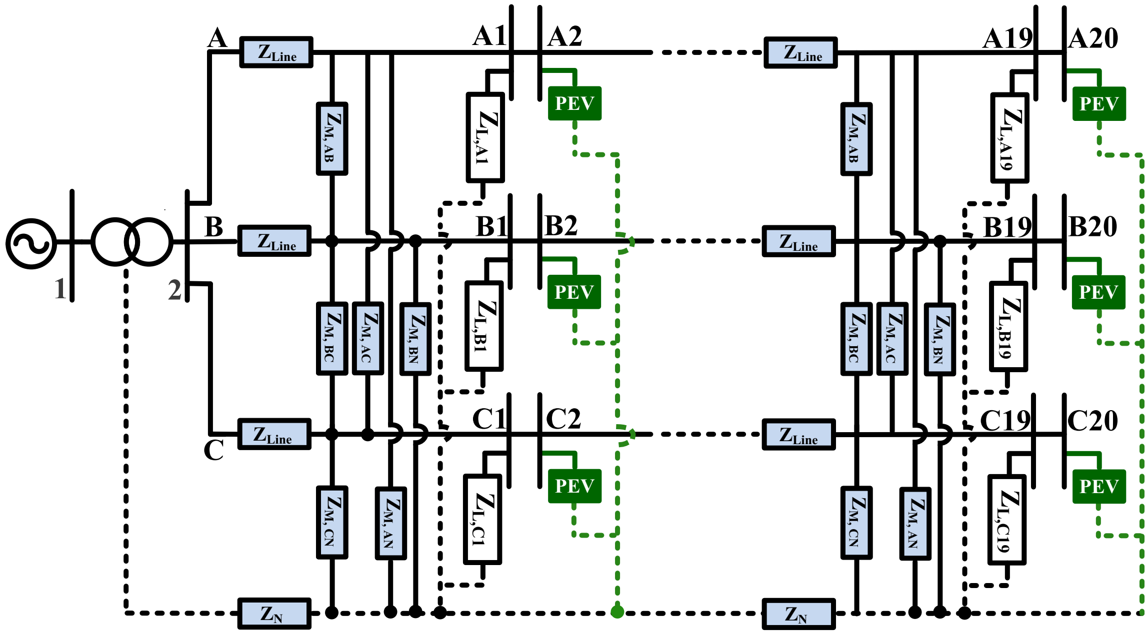


Fig. 1 62-node unbalanced residential network with 30 PEVs

$$\begin{cases} \text{If } 0\,\% < CUF < 4\,\%, & then:\ \mathrm{I}_{\text{charge}} = \mathrm{I}_{\text{low}} = 0.011\ (\text{pu})\,, \\ \text{If } 4\,\% < CUF < 8\,\%, & then:\ \mathrm{I}_{\text{charge}} = \mathrm{I}_{\text{med}} = 0.023\ (\text{pu})\,, \\ \text{If } 8\,\% < CUF < 16\,\%, & then:\ \mathrm{I}_{\text{charge}} = \mathrm{I}_{\text{high}} = 0.037\ (\text{pu})\,. \end{cases} \tag{5}$$

These charging rates are selected to reduce the CUF of the system as well as guarantee a safe operation condition for PEV's battery. The maximum charging rate (I_{high}) is chosen firstly to cope with the capability of most residential wiring standards and secondly to avoid the batteries to be charged more than their nominal current.

The batteries have a limited life due to the amount of the undesirable chemical or physical changes to the active materials of which they are made. Regardless of battery type, many factors can affect the performance of batteries such as chemical change, temperature, depth of discharge, charging level, charging rate and voltage effects. Battery life is influenced by the charging rate. For example, there is a limitation as to how quickly the Lithium ions batteries can be charged. Trying to force too much current through the battery during the charging process reduces the battery life time. Furthermore, by charging a cell above its upper voltage limit can produce chemical reactions which can damage the cell. Based on above discussion, the algorithm tries to maintain the battery life time by introducing three high, medium and low charging rates and prevent charging the batteries with very high charging rates.

Simulation Results and Discussions

To investigate the performance of the proposed DC-PEV-CA (Fig. 2), six PEV charging scenarios (Table 1, Cases A–F) are simulated for the network of Fig. 1. As shown in Fig. 4a, the network line currents over the 24 h are unbalanced without any PEV charging activities due to the unbalanced loading.

Case A: Uncoordinated PEV Charging (Unbalanced Network, Non-Uniform PEV Distribution)

A realistic case is simulated where the residential network is slightly unbalanced (Fig. 4a) and the PEVs are distributed non-uniformly over three phases. That is 53.3, 30 and 15.7 % of vehicles are located in phases A, B and C, respectively. PEVs are randomly plugged in (between 3:30 pm and 6:30 pm) and are individually charged without considering network parameters. Detailed simulation results are also presented in Fig. 5. According to Fig. 5a, b, the distribution transformer is facing around 15 % overloading while the worst node voltage profile located at node 20 (phase A) is dropping below 0.9 pu from 4 pm till 8 pm. Moreover, the VUF (Fig. 5c) increases to about 2.65 % which is more than standard value of 2 % [30]. The CUF and the SOC of batteries are shown in Figs. 5d, e, respectively. In this case the last PEV starts charging at 6:30 pm and is fully charged at 10:30 pm. Therefore, without any PEV coordination strat-

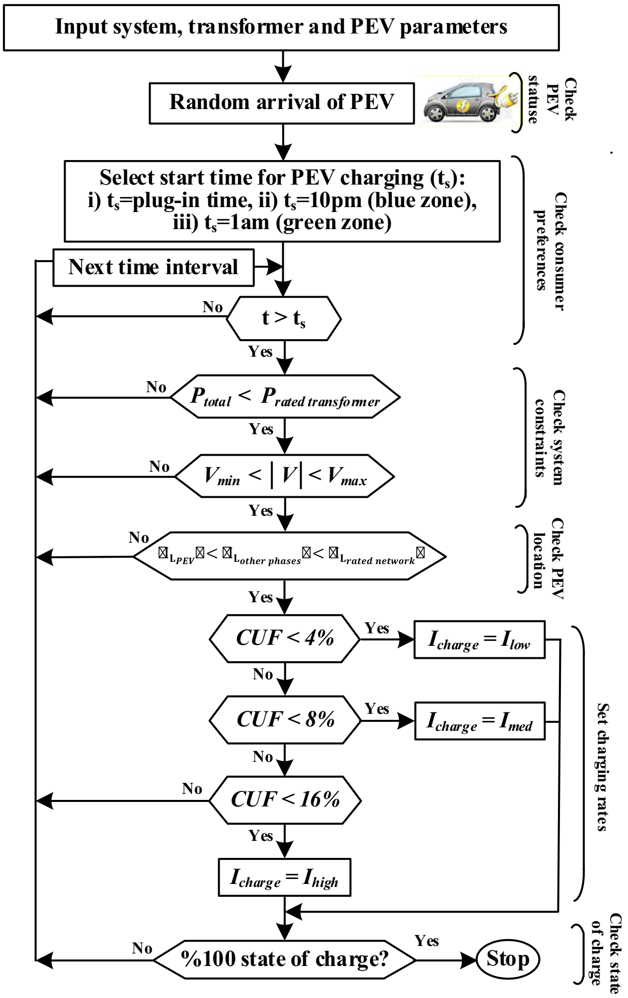


Fig. 2 Proposed DC-PEV-CA to simultaneously reduce distribution transformer loading and bus voltage fluctuations while dynamically compensating line current unbalance

egy, the distribution network will face many problems such as transformer overloading and undesirable voltage profiles.

Case B: Uncoordinated PEV charging with random plug-in of 20, 40 and 40 % of vehicles in red, blue and green time zones, respectively

The results for uncoordinated PEVs charging (Case A) have shown that if the PEV owners charge their vehicles as soon as they arrive home and without any control or coordination strategy, the distribution network becomes unstable and unsecure. In such a condition, variable electricity price and different charging time zones (Fig. 3) can be provided in a way to reduce detrimental problems to the distribution networks. Therefore, the owners charge their vehicles based on their budgets and priorities of waiting time. In this case study, it is assumed that 20 % of PEVs owners want to charge their vehicles in a red time zone to have them fully charged as

Table 1 Simulated case studies

Case study	Description	Simulation results
Uncoordinated (random) PEV charging		
A	Uncoordinated PEV charging with random plug-in of vehicles from 3:30 pm to 6:30 pm	Figure 5a–e
Uncoordinated (random) PEV charging considering variable electricity price		
B	Uncoordinated PEV charging with random plug-in of 20, 40, and 40 % of vehicles in red, blue and green time zones, respectively	Figure 6a–e
C	Uncoordinated PEV charging with random plug-in of 80 and 20 % of vehicles in red and blue time zones, respectively	Figure 7a–e
Coordinated PEV charging based on worst node voltage profile considering variable electricity price		
D	Coordinated PEV charging based on worst node voltage profile with random plug-in of 80 and 20 % of vehicles in red and blue time zones, respectively	Figure 8a–e
Coordinated PEV charging based on proposed DC-PEV-CA		
E	Coordinated DC-PEV-CA without consumer preferences	Figure 9a–e
F	Coordinated DC-PEV-CA with all consumers selecting the green charging time zone	Figure 10a–e

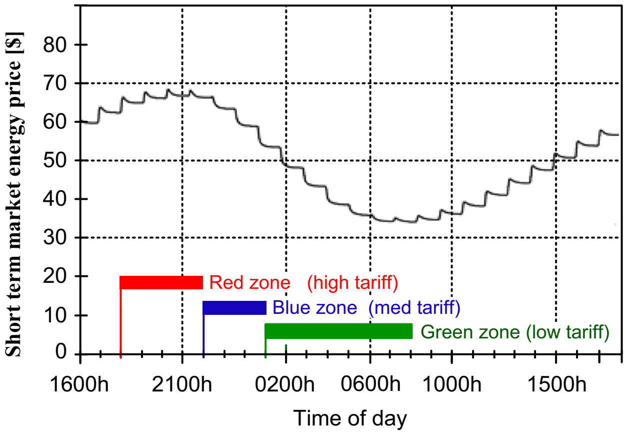
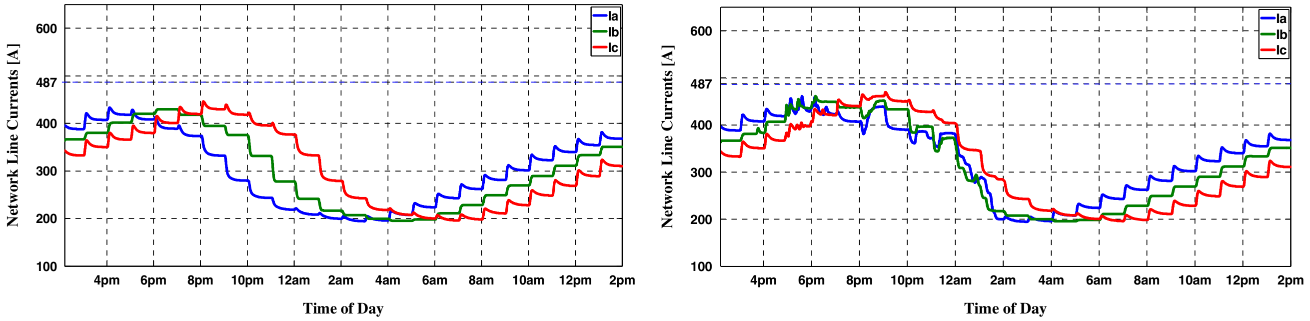


Fig. 3 Variable short term market energy pricing, including the options of charging time zones for PEV owners



(a)

(b)

Fig. 4 Unbalanced network line currents; **a** without PEV charging, **b** with coordinated PEV charging (Case E)

soon as possible, while 40 % of the owners prefer the blue time zone and the rest have selected the green time zone. Figure 6 shows the simulation results indicating significant improvements compared with Case A. Figure 6a shows that the peak demand period that was 5 pm–9 pm (Fig. 5a) is now distributed over the night time. The capacity of each battery is 16kWh requiring 4 h to be fully charged. As a result, the last group of PEVs will finish charging at around 5am (Fig. 5e). Consequently, transformer loading will be kept within its designated range. In addition, the worst node voltage profile and VUF will be also controlled as shown in Fig. 5b and c, respectively. Figure 5d indicates how by charging PEVs, the CUF drops compared with case A. Therefore by offering variable electricity price, the detrimental effects of PEV charging can be reduced. However, if the majority of consumers select the red charging time zone, the results will be not satisfactory.

Case C: Uncoordinated PEV charging with random plug-in of 80 and 20 % of vehicles in red and blue and green time zones, respectively

In this case study, most of PEV owners prefer to have their vehicles charged as quickly as possible within the high charging tariff. This will probably cause undesirable results as the arrival time of most PEV owners will coincide with the peak load hours. To simulate this operating condition, it is supposed that 80 % of PEV owners select the red charging zone and the rest choose the blue charging zone. The simulation results are demonstrated in Fig. 7. According to this figures, the distribution transformer (Fig. 7a) faces overloading conditions. Figure 7b, c illustrate that the worst node voltage profile and VUF are not within the desirable limits. The CUF and battery SOC are shown in Fig. 7d, e, respectively. Therefore, if the most of consumers choose the red charging time zones, the option of “variable electricity prices” alone can not solve the transformer overloading problem.

Case D: Coordinated PEV charging based on worst node voltage profile with random plug-in of 80 and 20 % of vehicles in red and blue and green time zones, respectively

This case aims to overcome the problem by implementing a relatively simple decentralized PEV coordinated charging approach based on online monitoring and measurement of the voltage magnitude at the worst node which is usually located at the end of the longest residential feeder. The PEV chargers receive the voltage profile of the worst node through their smart meters and will only operate if the voltage fluctuations are within the permissible highest and lowest limits. The justification is that distribution systems are designed to keep the network voltages, line current, and transformer loading within their rated values. Moreover, the conductors (overhead lines) and transformer tap-changer are designed to keep the voltage at the worst node within the standard values (e.g., 0.9 pu to 1.1 pu) under normal operating conditions. Therefore, any abnormal loading activity such as widespread and simultaneous PEV charging will cause unacceptable voltage drops especially at locations close to the worst node.

This case is identical to case C with the difference of considering voltage profile of the worst node. The PEVs keep charging their vehicles as long as the voltage variations of the worst node are within an acceptable range. Figure 8 represents the simulation results of this case. The results show that the loading of the distribution transformer is within the nominal range (8a). Figure 8b, c present the worst node voltage profile and the VUF, respectively. Also the CUF and battery SOC are shown in Fig. 8d, e, respectively. By comparing Figs. 7a and 8a or 7e and 8e, it can observed that the charging of PEVs has distributed over nights rather than peak-demand hours.

Therefore, by monitoring the voltage of worst node, the decentralize coordination of PEVs can be achieved. However, due to lack of control the three phase network currents, the unbalance factors in a network may raise upper the limit

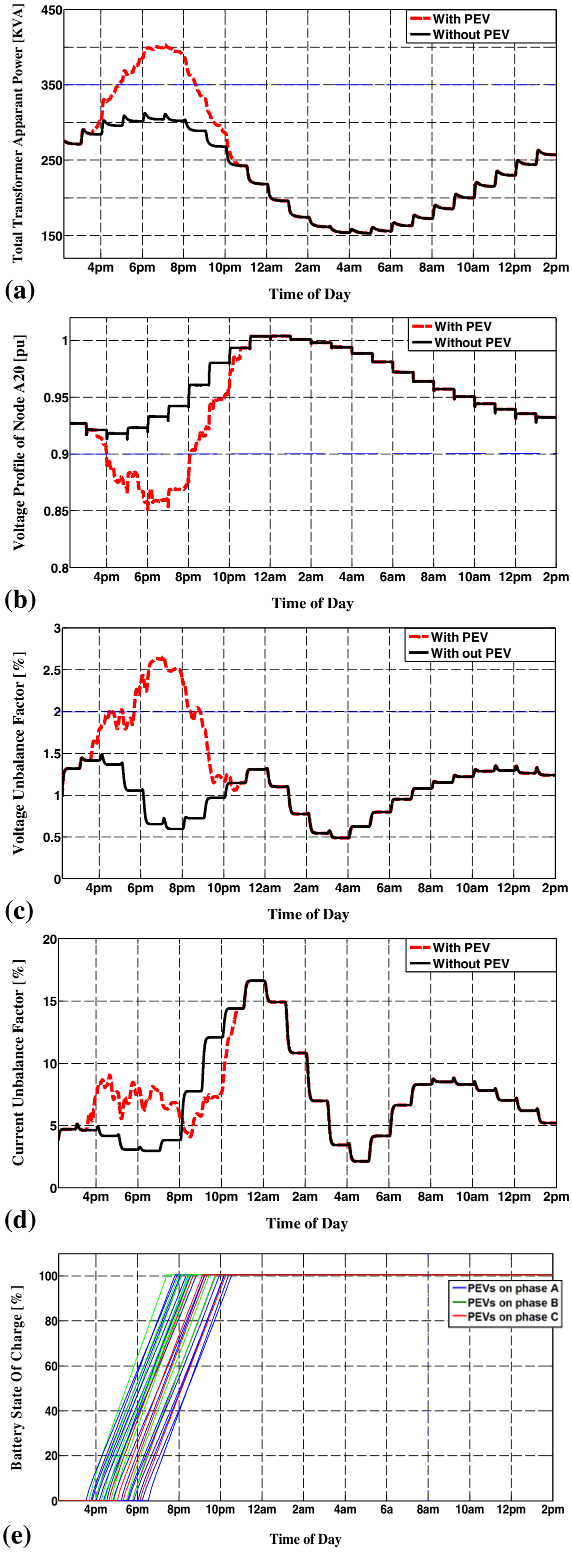


Fig. 5 Simulation results for Case A; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

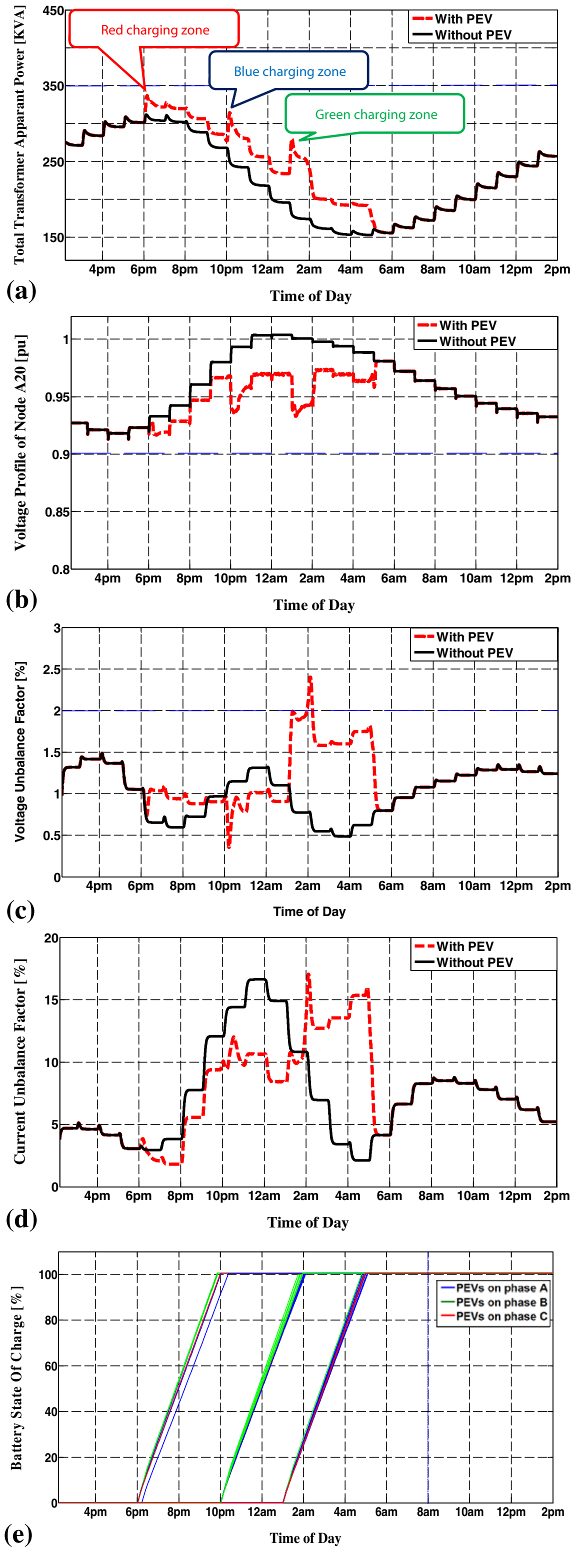


Fig. 6 Simulation results for Case B; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

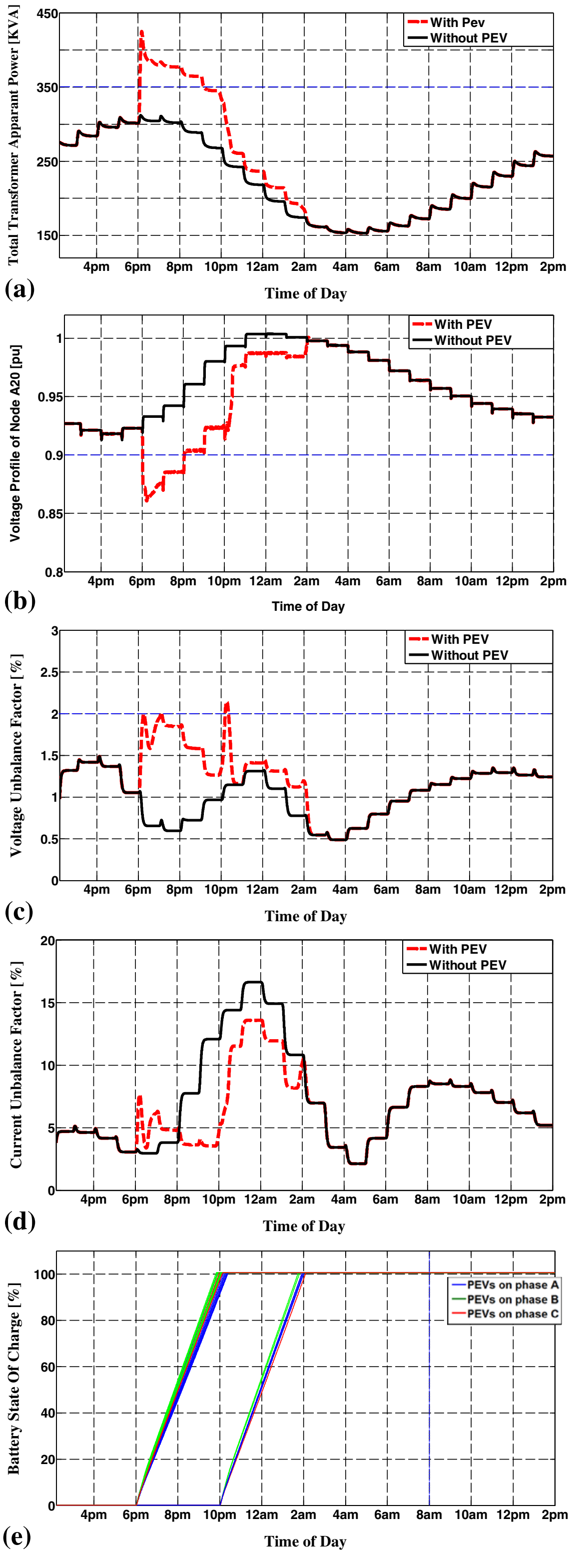


Fig. 7 Simulation results for Case C; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

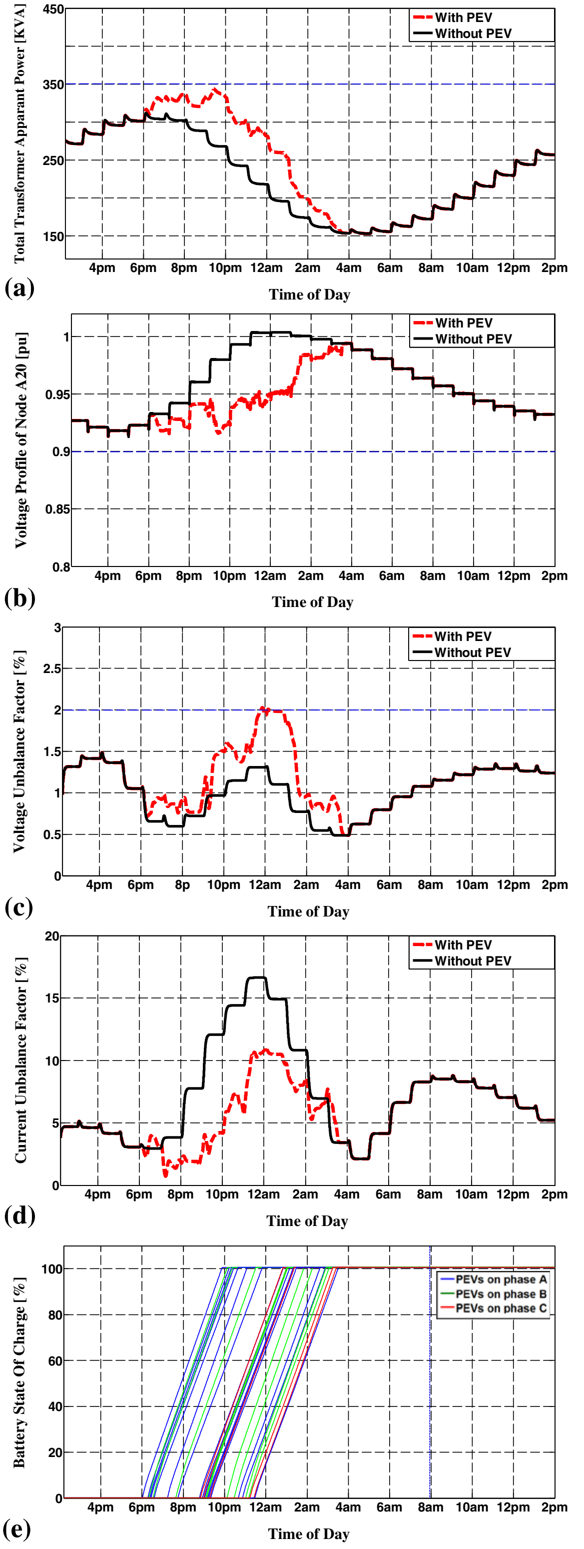


Fig. 8 Simulation results for Case D; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

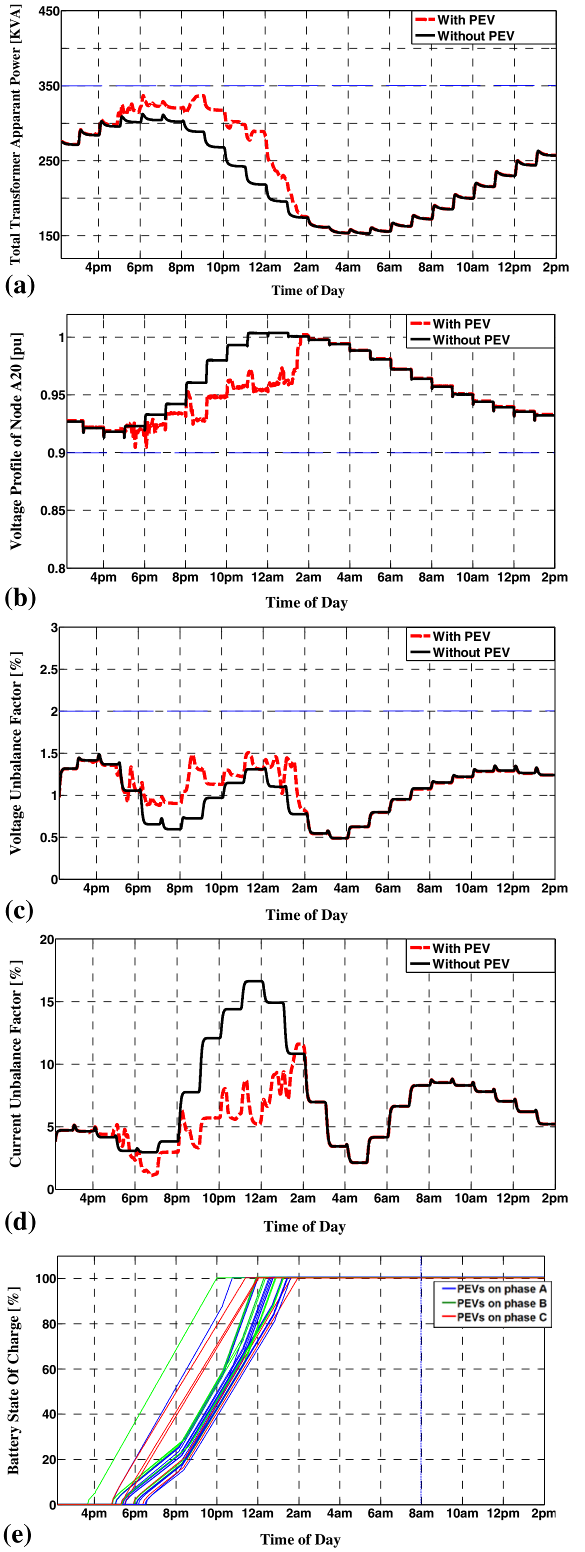


Fig. 9 Simulation results for Case E; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

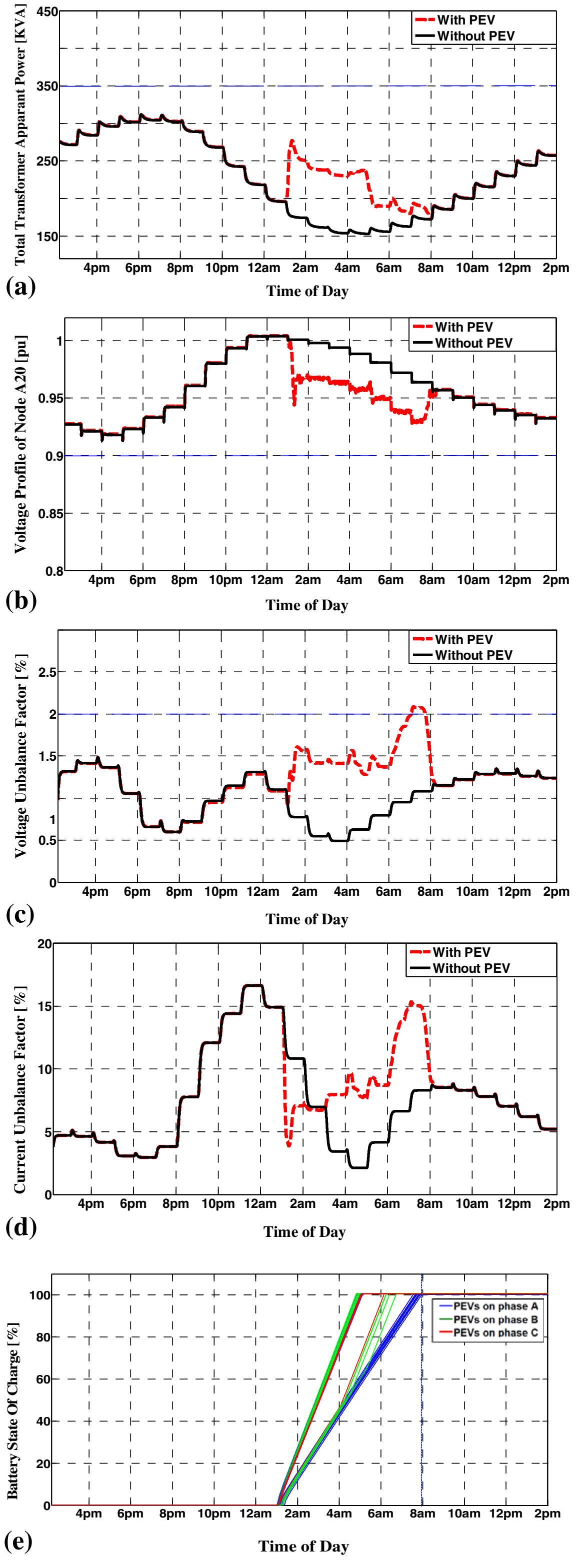


Fig. 10 Simulation results for Case F; **a** total three-phase distribution transform apparent power; **b** worst node voltage profile (A20); **c** VUF; **d** CUF; **e** battery state of charge

and cause further problems. Therefore, a new DC-PEV-CA is applied to overcome these problems.

Case E: Coordinated DC-PEV-CA without consumer preferences

The proposed DC-PEV-CA algorithm is applied in an attempt to overcome the significant performance degradations observed with uncoordinated random PEV charging. The transformer load profile is represented in Fig. 9a. In this case instead of charging the PEVs at the same time during the peak demand, vehicle charging are performed over night to keep transformer loading within the safe margin. Based on this figure, charging activities started with the first PEV plugged- in at 3:30 pm, while the last plugged-in PEV completed its charging about 2 am (Fig. 9e). Also the worst node voltage profile is within the acceptable margin (Fig. 9b). Moreover, the VUF value (Fig. 9c) is controlled below the standard range of 2 %. Figure 9d revealed how by charging the PEVs, the value of CUF drops. A closer inspection of Fig. 9e shows that batteries are charged with three different charging rates (Eq. 4 and Fig. 2). Therefore, the PEV charging time (duration) is not constant as it is based on network conditions.

Case F: Coordinated DC-PEV-CA with all consumers selecting the green charging time zone

To consider practical citations with variable energy prices, DC-PEV-CA allows consumers to provide their preferred times to start PEV charging. In this case study, all consumers have selected the green charging time zones. This case is considering the most realistic scenario as most PEV owners will try to take advantage of the cheap electricity price during the early morning hours. At the same time, it is the most challenging scenario for online coordination since all vehicles will start charging at 1:00 am and it might not be easily possible to fully charge all of them by 8:00 am. Simulation results are presented in Fig. 10. As expected, the results before 1:00 am are identical with the case without any PEVs since all vehicles are being charged in the green time zone. The transformer loading is shown in Fig. 10a. Due to coinciding charging the PEVs with off-peak hours, there are no issues with transformer loading. Figure 10b represents the voltage profile of worst node with an acceptable minimum value of 0.93 pu. The VUF and CUF values are shown in Fig. 10c, d, respectively. Note that the network is experiencing some unbalances and the VUF value is slightly (about 0.1 %) above the limit of 2 %. This can be due to coinciding charging of many vehicles in the green time zone. Figure 10e shows SOC of batteries during the charging period. Despite the fact that all PEVs started charging their batteries very late at 1:00 am, the last PEV has finished charging around 8:00 am.

Conclusion

This paper highlights the detrimental impacts of random PEVs charging on unbalanced distribution network with non-uniform distributions of PEVs on the single-phase residential feeders. The first approach consists of defining three charging time zones with high, medium and low tariffs to encourage PEV owners to shift their vehicle charging to off-peak hours. Simulation results indicate that this approach will partially solve the problem and the network will face difficulties if most PEV owners select the red zone and start charging their vehicles as soon as they arrive home. The second approach is similar to the first one with the difference of considering voltage profile of the worst node. Despite that the simulation results show moderate improvements in grid performance compared with the uncoordinated random PEV charging but the system might experience some unbalances and there is no guarantee to keep the unbalances in the network within designated range. Finally, a novel decentralized coordinated PEV charging algorithm (DC-PEV-CA) is developed for coordinating the scheduling of multiple PEVs while considering distribution and residential grid performances, including transformer loading, voltage profile and unbalance factors.

References

1. Rahimi, F., Ipakchi, A.: Demand response as a market resource under the smart grid paradigm. IEEE Trans. Smart Grid **1**, 82–88 (2010)
2. Bruno, S., Lamonaca, S., La Scala, M., Rotondo, G., Stecchi, U.: Load control through smart-metering on distribution networks. In: Proceedings of IEEE Bucharest PowerTech, Bucharest, pp. 1–8 (2009)
3. Masoum, M.A.S., Moses, P.S., Deilami, S.: Load management in smart grids considering harmonic distortion and transformer derating. In: Proceedings of international conference on innovative smart grid technologies (ISGT), Gothenburg, pp. 1–7 (2010)
4. Russell, B.D., Benner, C.L.: Intelligent systems for improved reliability and failure diagnosis in distribution systems. IEEE Trans. Smart Grid **1**, 48–56 (2010)
5. Moslehi, K., Kumar, R.: A reliability perspective of the smart grid. IEEE Trans. Smart Grid **1**, 57–64 (2010)
6. Metke, A.R., Ekl, R.L.: Security technology for smart grid networks. IEEE Trans. Smart Grid **1**, 99–107 (2010)
7. Garrity, T.F.: Getting smart. IEEE Power Energy Mag. **6**, 38–45 (2008)
8. Jiyuan, F., Borlase, S.: The evolution of distribution. IEEE Power Energy Mag. **7**, 63–68 (2009)
9. Lightner, E.M., Widergren, S.E.: An orderly transition to a transformed electricity system. IEEE Trans. Smart Grid **1**, 3–10 (2010)
10. Ipakchi, A., Albuyeh, F.: Grid of the future. IEEE Power Energy Mag. **7**, 52–62 (2009)
11. New York ISO: Alternate route: electrifying the transportation sector, Technical report, New York ISO (2009)
12. Deilami, S., Masoum, A., Moses, P.S., Masoum, M.A.S.: Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. IEEE Trans. Smart Grid, Paper number TSG-00112-2010 (2011)

13. Masoum, A.S., Deilami, S., Moses, P.S., Masoum, M.A.S., Abu-Siada, A.: Smart load management of plug-in electric vehicles in distribution and residential networks with charging stations for peak shaving and loss minimisation considering voltage regulation. Gener. Transm. Distrib. IET **5**(8), 877–888 (2011)
14. Sortomme, E., Hindi, M.M., MacPherson, S.D.J., Venkata, S.S.: Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses. IEEE Trans. Smart Grid **2**(1), 198–205 (2011)
15. Clement-Nyns, K., Haesen, E., Driesen, J.: The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. IEEE Trans. Power Syst. **25**(1), 371–380 (2010)
16. Masoum, M.A.S., Moses, P.S., Smedley, K.M.: Distribution transformer losses and performance in smart grids with residential plug-in electric vehicles. Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES, pp. 1–7 (2011)
17. Ma, Z., Callaway, D.S., Hiskens, I.A.: Decentralized charging control of large populations of plug-in electric vehicles. IEEE Trans. Control Syst. Technol. **99**, 1–12 (2011)
18. Vaidya, B., Makrakis, D., Mouftah, H.T.: Efficient authentication mechanism for PEV charging infrastructure. In: IEEE international conference on communications (ICC), 2011 , pp. 1–5 (2011)
19. Callaway, D., Hiskens, I.: Achieving controllability of electric loads. Proc. IEEE **99**(1), 184–199 (2011)
20. Hadley, S., Tsvetkova, A.: Potential impacts of plug-in hybrid electric vehicles on regional power generation. Electr. J. **22**(10), 56–68 (1999)
21. Battelle Energy Alliance, U.S. Department of energy vehicle technologies program—advanced vehicle testing activity plug-in hybrid electric vehicle charging infrastructure review, final Report (2008)
22. Muljadi, E., Schiferl, R., Lipo, T.A.: Induction machine phase balancing by unsymmetrical thyristor voltage control. IEEE Trans. Ind. Appl. **IA–21**(4), 669–678 (1985)
23. Lee, C.Y.: Effects of unbalanced voltage on the operation performance of a three-phase induction motor. IEEE Trans. Energy Convers. **14**(2), 202–208 (1999)
24. Broadwater, R.P., Khan, A.H., Shaalan, H.E., Lee, R.E.: Time varying load analysis to reduce distribution losses through reconfiguration. IEEE Trans. Power Deliv. **8**(1), 294–300 (1993)
25. Dugan, R.C., McGranaghan, M.F., Beaty, H.W.: Electrical Power Systems Quality. McGraw-Hill, New York (1996)
26. Moghbel, M., Masoum, M.A.S., Shahnia, F., Moses, P.: Distribution transformer loading in unbalanced three-phase residential networks with random charging of plug-in electric vehicles. In: 22nd Australasian Universities Power Engineering Conference (AUPEC), pp. 1–6 (2012)
27. Agency, U. E. P.: 2011 electric vehicles, fuel economy. http://www.fueleconomy.gov/feg/evsbs.shtml (2011)
28. Hu, P., and Reuscher, T.: Summary of travel trends. U.S. Department of Transportation and Federal Highway Administration. http://www.nhts.ornl.gov/2001/pub/STT.pdf (2004)
29. Kersting, W.H.: Distribution System Modeling and Analysis, pp. 17–108. CRC Press, Boca Raton (2001)
30. Australian Standard Voltage, AS60038-2012. http://infostore.saiglobal.com.au (2012)