Management and Coordination Charging of Smart Park and V2G Strategy Based on Monte Carlo Algorithm

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Abstract—**Charging of plug-in-hybrid-electric vehicles (PHEVs) may adversely affect electric grid reliability because a large amount of additional electrical energy is required to charge the PHEVs. In this paper, a comprehensive method to evaluate the system reliability concerning the stochastic modeling of PHEVs, renewable resources, availability of devices, etc. is proposed. This method, which consists of managed charging and vehicle-to-grid (V2G) scenarios, can be practically implemented in smart grids because the bidirectional-power-conversion technologies and two-way of both the power and data are applicable. The results showed that the smart grid's adequacy was jeopardized by using the PHEVs without any managed charging schedule. The sensitivity analyses results illustrated that by using the management scenarios, not only did the PHEVs not compromise the system reliability, but also in the V2G scenario acted as storage systems and improved the well-being criteria and adequacy indices.**

Keywords—***PHEV, Management Charging, V2G, Reliability, Monte Carlo Algorithm***

I. Introduction

Electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) are considered as one of the best solutions for addressing air pollution, global warming, and the energy crisis [1,2]. The discussed PHEVs' initiatives are becoming more and more achievable through the use of smart grid information infrastructures, peer-to-peer communication, wide area monitoring, and protection and control systems (WAMPAC) [3,4]. The PHEVs are connected to electric grids in order to be charged, and therefore, a large amount of electrical energy is needed to charge the PHEVs batteries. The uncontrolled PHEVs' charging demand for electrical power may adversely affect electric distribution systems [5]. To evaluate the adequacy indices in the widespread presence of PHEVs, the amount of power and energy expected to be served must be known.

Most recently, the investigation of the PHEVs' impacts on the power grid has drawn increasing attention [4,6]. The negative impacts of PHEVs unmanaged charging, such as those on the power loss, voltage profile, and peak load have been studied [7,8], but the reliability evaluation of power systems and smart grids in the widespread presence of PHEVs and aggregated peak loads including the uncontrolled charging demand load has received much less attention.

The PHEVs can act as a storage system, and their charging can be stopped during the generation shortage without any penalty as long as the charging process can be completed when the adequate generation capacity is available [9]. The vehicle-to-grid (V2G) strategy can also be implemented by using the two-way flow of both energy and data in

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smart grids [2,10] and can provide energy back from the vehicle to the grid.

This paper focuses on introducing a novel method using Monte Carlo Simulation (MCS) to evaluate the adequacy and reliability of smart grids in the widespread presence of PHEVs. First, the negative impacts of uncoordinated PHEVs' charging on system reliability are investigated. Second, a novel management charging and V2G is proposed. However, the consumer would not desire a charging station with stop and go action. Furthermore, the discussed managed charging for reliability improvement surely would reduce the lifespan of the batteries.

The rest of this paper is organized as follows. Section 2 presents the problem statement. The modeling of PHEVs, the demand side and the wind- and solar-based distributed generation (DG) units are presented in Section 3, respectively. Section 4 present the management method. In Section 5 and 6, the case study and test results are discussed to demonstrate the significance of the paper's contributionss. Finally, the conclusion drawn from the use of the proposed method is provided in Section 7.

II. PROBLEM STATEMENT

Recently, the impacts of the uncoordinated charging of PHEVs on existing and future grids, such as impacts on load variance, power loss, and voltage deviation have drawn increasing attention [3]. As an emerging new load, the aggregated load demand of PHEVs can adversely affect the system adequacy. Unlike the uncontrolled charging of PHEVs, during the coordinated charging schedules with the characteristics of smart grids, e.g., bidirectional-power-conversion technologies and peer-to-peer communication infrastructures, EVs can not only withdraw power from the electric network, but also feedback energy to the network when needed. Hence, this paper proposes a novel method for evaluating the adequacy of smart grids in the widespread presence of PHEVs which are uncoordinatedly charged. As wells, a novel charging schedule based on the adequacy and reliability results can be useful to mitigate the negative impacts of PHEVs, or even to implement the V2G scenario. Afterwards, the merits of the introduced charging schedule can be evaluated.

This paper focuses on a stochastic investigation of the adequacy of smart grids including PHEVs, renewable resources, and the availability of power elements, based on using MCS. A novel charging schedule is introduced, using a stop and go action strategy called managed charging and the V2G scenario when needed.

III. MODELING OF PHEVS AND SMART PARK

A. PHEVs

The characteristics of PHEVs are generally divided into two categories [3]: the characteristics involving EVs' manufacturing data and electric network structures, and the characteristics of the owners' behaviors, respectively. Therefore, the determination of EVs' manufacturing data, along with the stochastic behaviors of car owners, is necessary in order to precisely study the impacts of PHEVs. In most studies of the PHEVs' impacts on the power grid, simplifying assumptions have been made. Reference [3] is one of few studies that have developed a comprehensive model of PHEVs that considers different features such as state of charge (SOC), battery capacity, type of PHEVs, and the driving range in the electrical mode. Hence, in this present study, PHEV modeling is taken into account based on the concepts and assumptions of [3], which have been taken from [3].

To simulate the arrival time, departure time and driving distance of PHEVs, the random variables should be based on the inverse of the appropriate cumulative density functions (CDFs) as shown in Eq. (1), which can be used for simulating the work and weekend days' departure time, arrival time at home and the travelling distance such as $t^{n}_{HA,Home}, t^{n}_{WA,Home/Office}, t^{n}_{HD,Home/Office}, TD^{n}_{H}, TD^{n}_{WM}, TD^{n}_{WE}$.

The variation of PHEV modeling parameters caused by the seasonal differences is also included by considering the load variations in different seasons. As shown, the normal distribution can be used for statistical modeling of the arrival time at home on weekends and the driving distances of the PHEVs' on both work days and weekends.

The simulation process of the departure time of PHEVs on work days is demonstrated in Eq. (2). To precisely evaluate the car owners, their features in different seasons are also needed.

The charging schedule is another important characteristic of PHEV modeling. In [3], it is assumed that home charging is possible and that the starting time of PHEV charging is the same as the last trip's arrival time at home. One of this paper's contributions is its simulating of the impacts of PHEVs on smart grids in two charging schedules: home charging and charging at home and the office. Accordingly, two starting times for charging are investigated: when the cars arrive at the office after the last morning trip and at home after the last evening trip. Since the behaviors of PHEV owners are simulated based on the appropriate probability distribution function, the charging schedule will be actual and precise.

$$f(x)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{(x-\mu)^2}{2\sigma^2}} \Rightarrow X=\mathrm{Inv}\int_0^x f(x) \qquad (1)$$

$$t^n_{WD,Home}=-c^n_{PHEV}\,\mathrm{Ln}(1-u)^{\frac{1}{\kappa^n_{PHEV}}}=-c^n_{PHEV}\,\mathrm{Ln}(u)^{\frac{1}{\kappa^n_{PHEV}}} \qquad (2)$$

Based on the second introduced charging schedule, the charging schedule of PHEVs on work days is different than that on weekends. As shown in Fig. 1, the CC(t,n) shows that the connectivity condition of the n-th PHEV at the t-th time segment of the MCS on work days can be assigned to one value at most times of the day if the PHEV is parked either at home or at the work place house or office. By connecting the PHEVs to the grid at more times of the day, more benefits like the V2G scenario can be derived when needed.

The SOC of PHEVs is a measure of the energy level of the battery as well as the fuel gauge of conventional vehicles. The SOC can be evaluated at any time based on Eq. (3).

$$SOC(t+1,n)=\begin{cases} SOC(t,n)-R^{cons}_n\Delta t(t,n) & \text{Driving} \\ SOC(t,n)+R^{chg}_n\Delta t(t,n) & \text{Charging} \\ SOC(t,n) & \text{Otherwise} \end{cases} \qquad (3)$$

The flow chart of PHEV modeling is shown in Fig. 1. By using the Boolean variables CC(t,n) and CC′(t,n) which correspond to the connectivity of PHEVs to the grid and charging ability, the charging schedule is implemented in the MCS. As described in Eq. (4), the PHEV that is connected to the grid and that has a SOC less than max SOC can be charged, and consequently, the one value is assigned to the Boolean variable CC′(t,n). The Boolean variable CC′(t,n) will be applicable and useful in the implementation of the proposed management methods.

$$CC'(t,n)=\begin{cases} 1 & \text{if: } CC(t,n)=1\ \&\ SOC(t,n)<SOC_{max}(n) \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

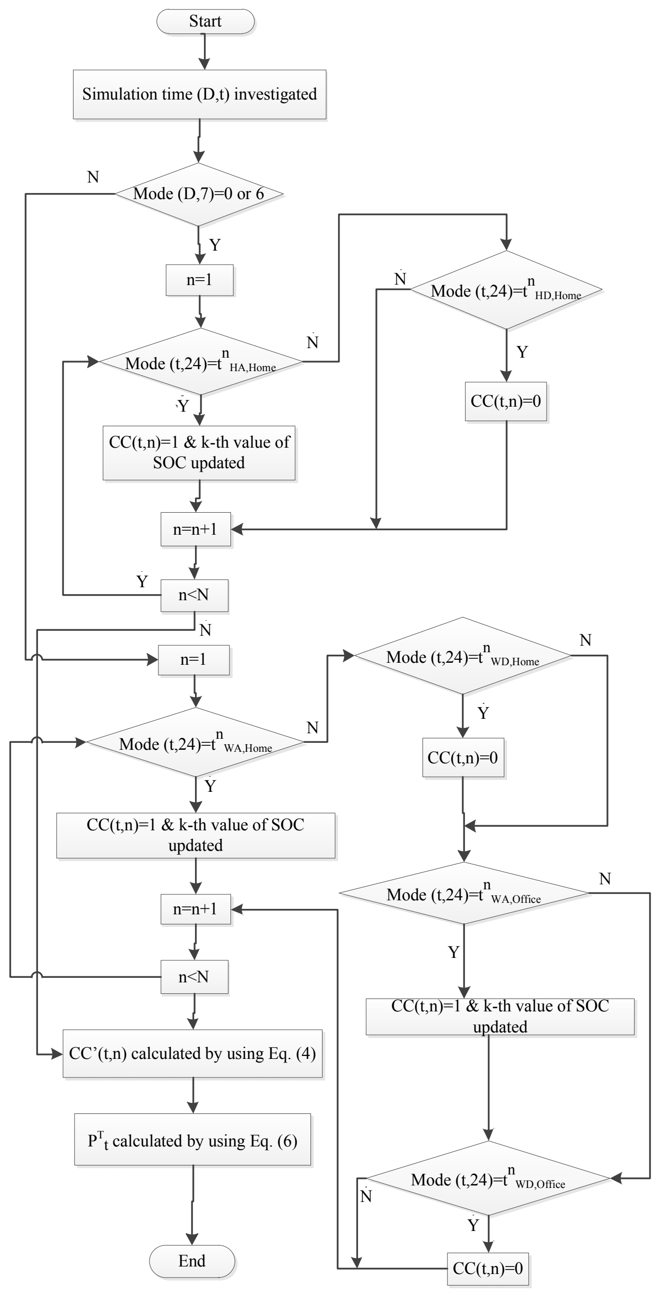

Fig. 1. Smart park modeling flowchart

B. Aggregated loads including PHEVs

In addition to modeling uncontrolled-, managed- or V2G-based charging of PHEVs, the load profiles of conventional customers were simulated to complete the demand side. Since the variations of conventional loads are less than those of the other probabilistic parameters such as solar irradiance and wind speed, the assumption of invariant conventional loads during the MCS time segment is reasonable. By updating the load value of the grid by adding the PHEV charging as an uncertain load, the appropriate modeling of the demand side is carried out. Based on this modeling, the load demand including the PHEV charging loads can be simulated as Eq. (5), and consequently the SOC of the PHEVs is updated as shown in Eq. (6).

$$\begin{aligned} P_t^T &= P_t^{R.O.C} + \sum_{n=1}^{N}(CC'(t,n).R_n^{chg}) \\ SOC(n) &= SOC(n) + R_n^{chg} \times \Delta t \end{aligned} \tag{6}$$

IV. MODELING OF WIND- AND SOLAR-BASED DGS

In order to investigate the adequacy indices, the supply-side parameters and characteristics must be simulated in addition to the demand-side data, particularly the renewable resources output power following stochastic behaviors. As explained, in the wide spread presence of PHEVs the wind- and solar-based renewable DGs have been used to supply the smart grid. To chronologically simulate the output power of wind-based DGs, the random wind speed is created based on the inverse of cumulative density function (CDF). The Weibull probability distribution has been selected for the wind speed modeling [11]. Afterwards, the output power of wind-based DGs was calculated as shown in Eqs. (7-10) and Fig. 2 [12,13].

$$P_W(v) = \begin{cases} 0 & 0 < v < v_{ci} \quad \text{or} \quad v_{ct} > v \\ P_{rated} \times (A + Bv + Cv^2) & v_{ci} < v < v_r \\ P_{rated} & v_r < v < v_{ct} \end{cases} \tag{7}$$

Where

$$A = \frac{1}{(v_{ci} - v_r)^2}\left(v_{ci}(v_{ci} + v_r) - 4v_{ci}v_r(\frac{v_{ci} - v_r}{2v_r})^3 \right) \tag{8}$$

$$B = \frac{1}{(v_{ci} - v_r)^2}\left(4(v_{ci} + v_r)\left(\frac{v_{ci} + v_r}{2v_r}\right)^3 - (3v_{ci} + v_r) \right) \tag{9}$$

$$C = \frac{1}{(v_{ci} - v_r)^2}\left(2 - 4(\frac{4v_{ci} + v_r}{2v_r})^3 \right) \tag{10}$$

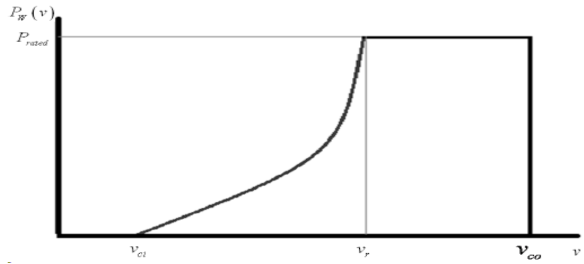

Fig. 2. Output power of wind turbines via wind speed

In this paper, the accurate formula for the output power of wind turbines has been used, but using the simplified calculations shown in Eq. (11) is also adequate.

$$P_W(v) = \begin{cases} 0 & 0 < v < v_{ci} \quad \text{or} \quad v_{ct} > v \\ P_{rated} \times \dfrac{(v - v_{ci})}{(v_r - v_{ci})} & v_{ci} < v < v_r \\ P_{rated} & v_r < v < v_{ct} \end{cases} \tag{11}$$

Furthermore, to simulate the output power of solar-based DGs, the clearness index (k_t) shown in Eq. (12) was simulated. The invertible CDF of the clearness index can result in the solar irradiance calculation. The Beta probability function is used as the clearness index in this paper [11].

$$\kappa_t = G/G_0 \tag{12}$$

Once the clearness index was generated, the output power of solar-based DGs was calculated for a specified solar irradiance, ambient temperature, etc., as Eqs. (13-16) [12].

$$T_c = T_a + \left(G \times \frac{(N_{OT} - 20)}{800} \right) \tag{13}$$

$$I = \kappa_t \times (I_{sc} + (T_c - T_a) \times \kappa_I) \tag{14}$$

$$V = V_{oc} - \kappa_V \times T_c \tag{15}$$

$$P_{PV} = N_{PV} \times I \times V \times \eta \tag{16}$$

As explained in the above formula, the output power of solar cells is a function of the solar irradiance, manufacturing characteristics and temperature coefficients. By using the introduced method, the realistic stochastic simulation of a solar-based DG is possible.

V. CASE STUDY

The IEEE 34 node test feeder is shown in Fig. 3. Five DGs are connected to this grid. The first type is a diesel DG consisting of one and two diesel generators, each of 600 kW, connected to load point 824 of the second segment and load points 836 and 838 of the third segment. The second type is a solar DG with a 375 kW DG unit connected to load point 864 of the second segment, and the third one is a wind-based DG unit of 375 kW, connected to load point 822 of the third segment. Wind-based DG units may lead to a power mismatch in some conditions particularly in the islanding operation modes. Therefore, the system under study has calculated and used the most appropriate output power generation for wind-based DG units. The cut-in, rated and cut-off wind speeds of the wind-based DG unit are considered as 4, 12 and 22 m/s, respectively. The characteristics of the PV modules utilized in the test system can be found in [13].

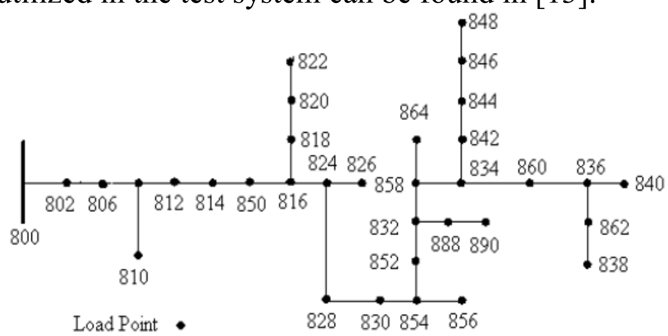

Fig. 3. IEEE 34 node test feeder

The characteristics and data of the PHEVs, i.e., the type of vehicles, energy consumption per kilometer (ECPK), size of the battery and the percentage of each EV type are presented in Table 1. The discussed data were obtained from [14]. The battery capacity of the PHEVs was determined based on the ECPK and AER.

Table 1. PHEVs data and characteristics

Vehicle class	ECPM [kWh/m]	PHEV30 [kWh]	PHEV40 [kWh]	PHEV60 [kWh]
Compact sedan	0.26	7.8	10.4	15.6
Mid-size sedan	0.30	9	12	18
Mid-size SUV	0.38	11.4	15.2	22.8
Full-size SUV	0.46	13.8	18.4	27.6

VI. TEST RESULTS

The reliability evaluation of the test system is discussed in this section. The results illustrate how unmanaged charging of PHEVs can adversely affect the test system adequacy. The following cases were studied to determine the reliability of smart grids in wide spread presence of PHEVs:

- Case 1: The system had no PHEV.
- Case 2: The PHEVs were unmanaged while being charged.
- The comparison of the results of cases 3 and 4 with those of case 2 shows that the coordinated charging schedule can not only minimize the negative effects of unmanaged charging, but also achieve reliability improvement.
- Case 3: Managed charging was applied.
- Case 4: Both managed charging and V2G scenarios were applied.

The unmanaged charging was increased by about 93.42% (from 8.48 hr without PHEVs' charging to 19.41 hr in the presence of PHEVs). The results of cases 3 and 4 show that the management scenarios were useful and effective in improving the system reliability. The PHEVs in the V2G mode were enabled to act as storage systems, and indicating a 19.06% improvement.

The results show that the reliability indices were significantly affected due to the unmanaged charging of the PHEVs. Since the penetration of PHEVs has significantly increased, the reliability of the smart grid can be seriously threatened if the appropriate management charging strategies are not implemented. In addition, the results show that the loss of energy expected (LOEE) value decreased by about 2.42% during the unmanaged charging of the PHEVs when only home charging was possible. Although, the charging schedule at the home and office seems inappropriate, by using the management charging strategies, particularly in the V2G mode, the LOEE was improved by about 2.92% when the home and office charging schedules were applied. The comparison results illustrate that by implementing the proposed risk management method, the PHEVs' risks can be converted into opportunities. If managed charging is considered, as in case 3, the problems caused by the load demand of PHEVs' charging can be controlled. In the V2G mode in case 4, the LOEE and energy expected no supplied (EENS) values were decreased compared to the values in case 1, which had no PHEV.

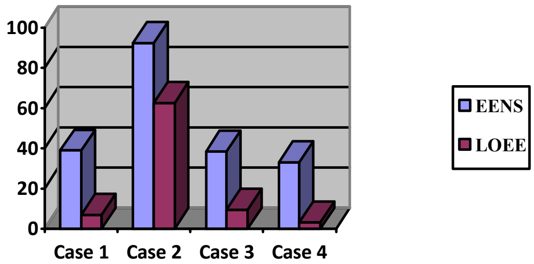

Fig. 4. LOEE and EENS of different cases

To clearly evaluate the smart grid adequacy, the sensitivity analysis of important parameters like the charging level and the PHEVs penetration into the LOEE was done as shown in Figs. 5, 6 and 7. These figures present the results of investigating the LOEE value by studying the changes in the charging level and the PHEVs penetration in cases 2, 3 and 4. In the sensitivity analysis, the LOEE was investigated for the specified charging level (CLF) and PHEVs penetration factors (PPF). The adjusted coefficients (CLF and PPF) were multiplied to the current values of the charging level and penetration of electric vehicles, respectively, and consequently, the reliability indices were determined. Hence, it was possible to evaluate the importance of the charging level and the PHEVs penetration.

The sensitivity analysis of the LOEE during the unmanaged charging for PPF and CLF between [0.1 1] and [0.1 2], respectively, is presented in Fig. 5, respectively. As shown in Fig. 6, the value of the LOEE was considerably increased by increasing the charging level and the PHEVs' penetration when the PHEVs were unmanaged charging. The system reliability was affected by increasing the number of PHEVs whose charging was uncontrolled. Also, the results show the charging level is another important parameter that can accelerate the negative effects of the unmanaged charging of PHEVs. Based on the sensitivity results, the worst state occurred when numerous PHEVs were unmanaged charged at a fast charging level. The results of case 1 show the variation of PHEVs penetration and charging level had similar effects. In systems without the capability of using the wide implementation of communication and information technologies, it can be useful to improve the system reliability by decreasing the charging level of the PHEVs.

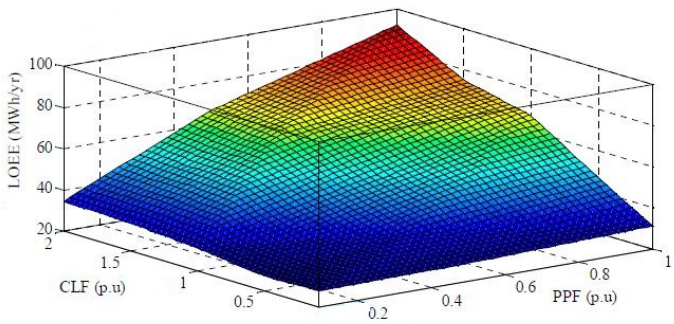

Fig. 5. The sensitivity analysis of LOEE based on *CLF* and *PPF* for case 1

Furthermore, the sensitivity analysis of the LOEE in relation to the PHEVs' penetration and charging level is shown in Fig. 6 for wide range of CLF and PPF ([0 2] and [0 2], respectively). Based on Fig. 6' results, it is clear that when the unmanaged PHEVs were charged at a high charging level, the system could not reliably operate. In the other words, due to the growing tendency towards manufacturing hybrid electric vehicles and using faster charging schedules, the importance of the coordinated charging of PHEVs is increasing.

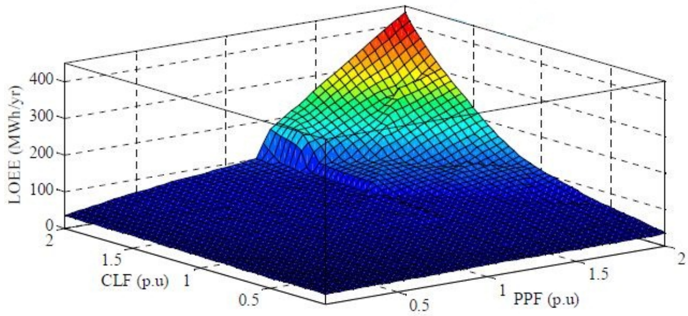

Fig. 6. The sensitivity analysis of LOEE based on *CLF* and *PPF* for case 1

The sensitivity analysis of the LOEE according to variations in the charging level and penetration of PHEVs was performed to verify the effectiveness of the V2G scenario as the proposed risk-management method. The discussed sensitivity analysis is presented in Fig. 7.

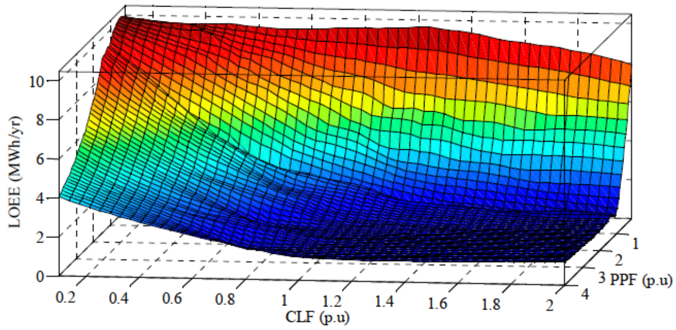

Fig. 7. The sensitivity of LOEE based V2G

By comparing the results shown in Figs. 6 and 7, for the uncontrolled charging of the PHEVs and managed charging schedule, the benefits of using the proposed management scenarios are highlighted. As in Fig. 7 reveals, if the V2G scenario is implemented, not only does the increasing of the charging level and penetration of the PHEVs affect the system reliability, but also the system reliability is improved by using the wide presence of PHEVs. By using appropriate management method like that of the V2G scenario, most of the functions of PHEVs are achievable without making fundamental changing in the power grids and generation capacities. Although the numerous PHEVs can be charged by applying the managed charging schedule scenario, it is more interesting to apply the V2G strategy. In addition to the above explanations about the test results, the generation and demand load curves of a typical day experienced the critical condition in three scenarios (unmanaged/managed charging, and V2G modes) are shown. In the discussed typical day, a bad condition has occurred because two transformers of the main substations were out-of-service. The total generation capacity consisting the generation of DG units is presented in Fig. 8. As shown, the output generation of wind- and solar-based DG units was not fixed and was a function of stochastic parameters such as wind speed, solar irradiance, and ambient temperature. The active power balance of demand and supply sides can be found in Fig. 9 when no managing strategy was implemented to charge the PHEVs. The amplitude and time of the peak load also changed through wide spread presence of PHEVs which can jeopardize the well-being criteria and consequently reduce the reliability of the system. The results show that the morning charging of PHEV at offices' parking did not cause the critical condition for adequacy aspects in compare to the evening charging at homes. In this case, the at-risk duration was considerably increased through charging the PHEVs. The unmanaged charging of PHEV in the discussed day led to increase the at-risk duration from about 8 hours (11:00 to 19:00) without the presence of PHEVs to more than 14 hours (8:00 to 22:00) during the unmanaged charging of PHEVs.

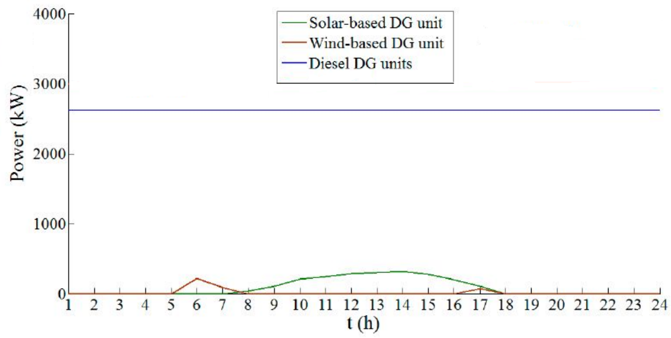

Fig. 8. A typical critical day generation curves

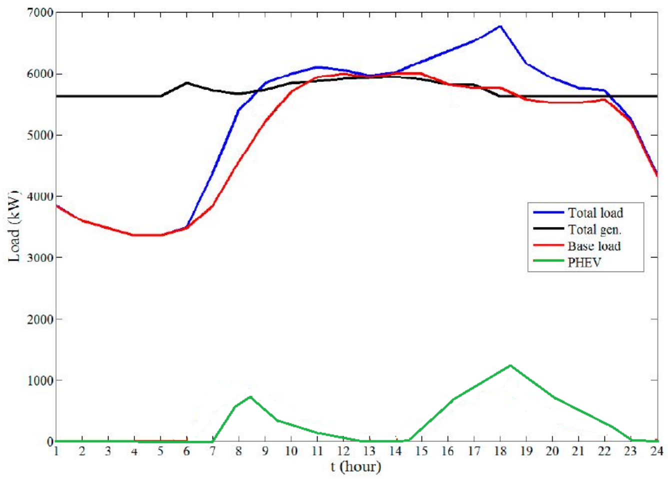

Fig. 9. The power balance curve of atypical critical day during the unmanaged charging of PHEVs.

In Fig. 10, the effectiveness of the managed scenario is demonstrated. According to the novel proposed charging schedule based on the management, the charging of PHEVs stopped when the sufficient active power did not exist. Thus, the studied time in presence of PHEVs is same as the base condition without any PHEV charging. As described in the proposed charging managing based on the adequacy aspects, during the active power imbalance between supply and demand sides, the charging of PHEVs is managed, and the charging process of PHEVs according to their priorities is stopped.

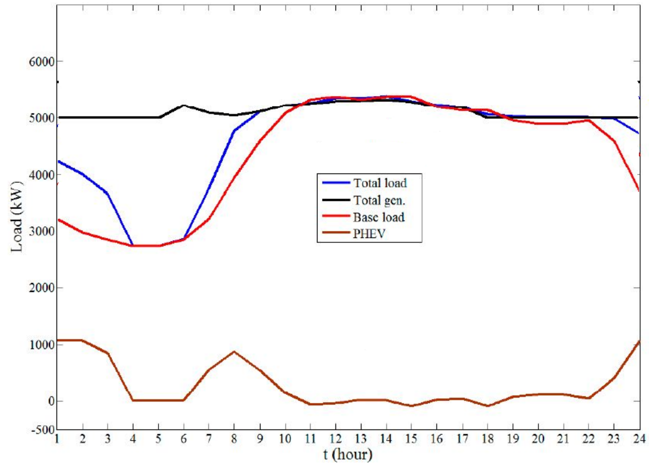

Fig. 10. The power balance curve of atypical critical day during the managed charging scenario.

The results illustrate that through implementing the managed charging scenario, the charging of PHEVs without significant negative effects. According to the managed charging scenario, the peak load demand of PHEVs' charging deferred to times that the sufficient generation capacity existed.

VII. . CONCLUSION

In this paper, a comprehensive method to evaluate the reliability of smart grids by considering the unmanaged charging effects of PHEVs was proposed. A literature review and the results of the proposed reliability evaluation method, proposing a management method by reliability improvement in the wide presence of PHEVs was presented. Hence, a novel management method consisting of the managed charging and the V2G scenarios was introduced. This paper comprehensively studied the stochastic parameters and smart grid uncertainties, i.e., the power output generation of renewable resources, behaviors of PHEV owners, practical and reasonable characteristics of electric vehicles, availability of power elements, etc by using MCS.

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