A New V2G Control Strategy for Load Factor Improvement Using Smoothing Technique

Peerapon CHANHOM[1], Surasak NUILERS[2], Natchpong HATTI[2]
[1]*Rajamangala University of Technology Suvarnabhumi (Nonthaburi Campus), 7/1, Nonthaburi Road, Suan Yai, Meuang, Nonthaburi, 11000, Thailand*
[2]*National Electronics and Computer Technology Center, 112, Thailand Science Park, Phahonyothin Road, Klong Nueng, Klong Luang, Pathum Thani, 12120, Thailand*
natchpong.hatti@nectec.or.th

***Abstract*—This paper proposes a new vehicle-to-grid (V2G) control strategy for improving the load factor in the power network. To operate the proposed strategy, the available storage capacity of the PEVs' batteries is considered as a battery energy storage system (BESS) for charging and discharging an amount of power corresponding to the V2G power command. Due to the remarkable advantages of the technique so-called simple moving average, it is selected for applying in the proposed V2G control strategy. In this research, for investigating the load factor improvement, the essential data including the daily-load profiles with 7-day and 14-day periods are used for the 3 studied cases. These 3 studied cases present the power network with variation of the PEVs locations for describing the PEVs usage and charging or discharging behavior. The performance of the proposed strategy is simulated and verified by the MATPOWER software. The simulation results show that the load factors of the 3 studied cases are improved. Moreover, the encouragement of energy arbitrage for the PEVs owners is also discussed in this paper**.

***Index Terms*—electric vehicles, energy storage, finite impulse response filters, power smoothing, smart grids.**

I. Introduction

Vehicle-to-Grid (V2G) is a smart system that the grid utility can communicate with the plug-in electric vehicles (PEVs) i.e., battery electric vehicles (BEVs) and plug-in hybrids electric vehicles (PHEV), through a smart communication system. In order to operate the V2G system as illustrated in Fig. 1, an aggregator is the essential service because it works as a commercial middleman between the utility and the multiple PEV's owners [1].

According to the V2G available storage capacity of the PEVs' batteries, the grid utility can buy the stored energy from the PEVs' batteries when the demand is high and sell it back when demand is low [2]. The aggregator are responsible for taking real time decisions of charging or discharging an amount of power between PEVs and the power network, depending on the grid conditions [3].

The V2G system is environment friendly by reducing the gas emission [4]. It also could provide various ancillary services i.e., voltage and frequency regulations [5-7], spinning reserves, reactive power support, peak shaving, valley filling, load following, and energy balancing [8-16].

From the literature study, there is a little information on the aspect of the load factor improvement strategy. Notice that, in the power network, the load factor can be improved by distributing the load demands over different time periods (24-hours a day). The grid utility's tools, such as demand response and energy storage systems (ESSs), have been proposed for improving the load factor and also for applying to many other grid applications [17-18]. Apart from these tools, by using the on-board batteries in the form of V2G power flow, PEVs can operate as the BESS, and provide the ability to improve the load factor. However, practical operation of the V2G system has acquired many key problems and challenges for consideration amongst power system engineers. Particularly, the grid utility should propose a new V2G control strategy which offers a simple guideline for decision-making to participate in the new V2G business by the PEVs owners [19]. To achieve this goal, the most important considerations are the following:

- Variation locations of PEVs in the power network: PEVs should be charged and discharged corresponding to the V2G power command in any location where the summation of power which is stored or delivered in the power network by the storage capacity of the PEVs' batteries (with regard to the line power losses) can be served for the desired ancillary services.
- Available time for charging and discharging power: the parking time of the PEVs should fit the charging and discharging time durations following to the V2G power command. These time durations are the key factor for contributing the encouragement of the energy arbitrage to the PEVs' owners.
- Available storage capacity for storing or delivering power: available storage capacity of the PEVs should be just-in-time and sufficient to store or deliver the amount of power corresponding to the V2G power command. The aggregator would predict and evaluate the required amount of power and fit this power with the available storage capacity of the PEVs. This procedure is necessary to regulate the State-Of-Charge (SOC) of the PEVs' batteries in a safety margin when operating the V2G system.

According to the above reasons, the new V2G control strategy is proposed in this research. Due to the remarkable advantages of the simple moving average (SMA) technique, it is applied for the proposed V2G control strategy. This paper is organized as follows; Section II describes the load factor definition and its key role as well as provides the details of the control scheme. The advantages of the SMA technique are also explained in Section II. In Section III, the

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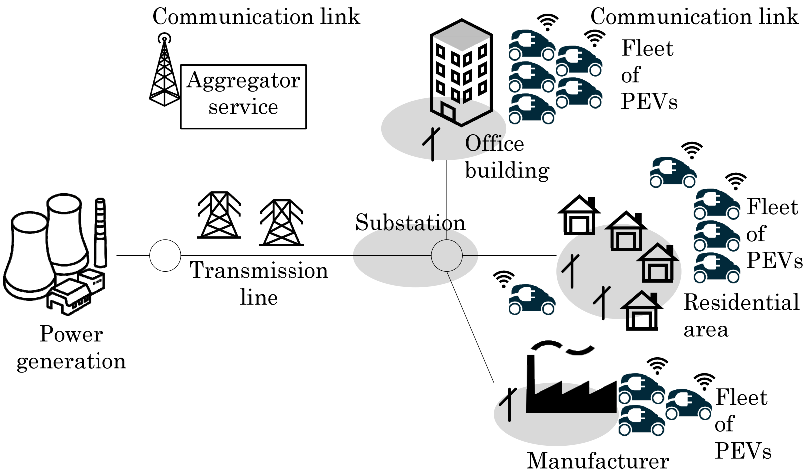


Figure 1. Smart power network with the V2G system using available storage capacity of the PEVs' batteries

studied cases are presented and modeled for the simulation using MATPOWER [20]. Section IV gives the discussion of the simulation results. Finally, Section V presents the conclusions and future works of this research.

II. The Proposed V2G Control Strategy

In this section, the overview of electric vehicle technologies is firstly provided, and the definition of the load factor as well as its key role in the power network is presented. The details of the proposed V2G control strategy and its control scheme are afterwards explained.

A. Electric Vehicle Technologies

Several types of electric vehicles have been available in the market i.e., fuel cell electric vehicles (FCEVs), hybrid electric vehicles (HEVs), plug-in hybrids electric vehicles (PHEVs), and battery electric vehicles (BEVs) [21]. Among these, PHEVs and BEVs are capable to operate with the V2G system by communicating with a smart communication system [22]. The main characteristics of PHEVs and BEVs are summarized in Table I.

Recently, the uses of charging stations have been rapidly increasing around the world. There are the well-known standards for charging stations such as SAE J1772 and IEC 62196. These standards mainly specify the safety devices and charging systems, as briefly summarized in Table II. The regular charging is for charging the vehicles with low current approximately at 16-32 A (3.3-7.4 kW) whereas the quick charging charges the vehicles with relatively high current approximately at 63 A (43 kW 3-phase) for only 30 minutes. Up to date, the charging connectors including control signal not only support the controlling for local charging, but also for allowing the electric vehicles to participate in a wider electric vehicle network.

B. The Load Factor

The load factor is defined as the average demand divided by the peak demand in a specified time period (typically for the duration of an entire 24-hour a day) as follows:

$$Load\ Factor = \frac{Average\,Demand}{Peak\,Demand} \tag{1}$$

From (1), the load factor is always less than unity because the peak demand is always higher than the average demand.

A high load factor means the power usage in the power network is relatively constant. In the case of a low load factor, the power usage is fluctuated. For supporting the peak demand, the supply side needs to increase the capacity much higher than the average demand. This results in a higher system operating cost [23].

TABLE I. BEVs AND PHEVs COMPARISON

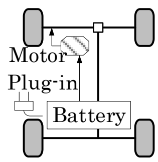
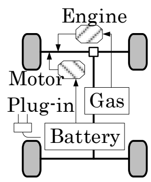
	BEVs	**PHEVs**
Propulsion, energy source and system.		
Characteristic	-Zero emission -Short range	-Very low emission -Long range
Major issues	-Charging facilities	-Multiple energy source control

TABLE II. CHARGING TECHNOLOGIES

	Quick	**Regular**
Charging Time	30-min.	8-14-hr.
Input Voltage	200V 3-phase	200V 1-phase
Hardware	Charging station	On board charger
Comm. System	CAN	No

C. The Proposed V2G Control Strategy

By considering the single line diagram of an example system illustrated in Fig. 2, since the total demand power, the total V2G power, and the total power losses compose the demand power on the studied system, then the generated power (PG) that is supplied to the studied system through the substation (slack bus: SLB) can be expressed as

$$P_G = \sum P_D + \sum P_{V2G} + \sum P_L \tag{2}$$

where, PD is the demand power, PV2G is the V2G power, and PL is the line power losses.

Fig. 3(a) shows an example of PG for 24-hour period (the daily-load profile) observed in SLB in the studied system. PG is varied corresponding to PD produced by Load Bus(2) and Load Bus(3), and PL. Without the load factor improvement, the power fluctuation is very high and the peak demand of PG is higher than its average demand power. This situation leads the power network to a low load factor.

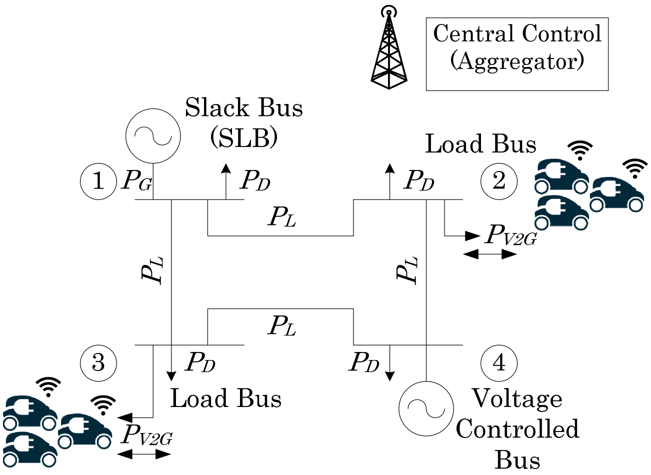


Figure 2. Single line diagram of the studied system

However, as illustrated in Fig. 3(b), the load factor can be improved. For example, to decrease the peak demand close to its average demand power, the energy storage systems (ESS) can be used to store or deliver the power for distributing the load demand over the valley time periods (along the entire 24-hour).Since the average demand is assumed as the reference power (P_{REF}) and the available storage capacity of the PEVs' batteries are considered as the BESS, the proposed V2G control strategy can distribute the load demand over the valley time periods by producing the V2G power as

$$\sum P_{V2G} = P_{REF} - \left(\sum P_D + \sum P_L\right) \quad (3)$$

As illustrated in Fig. 4, P_{V2G} can be produced by the available storage capacity of the PEVs' batteries for charging and discharging an amount of power corresponding to the V2G power command (P^*_{V2G}).

As mentioned above, the technique for generating P_{REF} is the key to achieve the load factor improvement. Therefore, calculating P^*_{V2G} and producing P_{V2G} are necessary for the V2G system. As aforementioned, the SMA technique is selected for using in the proposed V2G control strategy. The details of this technique are as provided below.

D. The Simple Moving Average (SMA) Technique

In statistics, the SMA (rolling average or running average) filter is one type of the finite impulse response (FIR) filters for analyzing data points by creating series of averages of different subsets of the full data set. It is also called moving mean (MM) or rolling mean [24]. The SMA technique is commonly used with time series data to smooth out short-term fluctuations and highlight longer-term trends or cycles. The threshold between the short-term and long-term trends depends on the applications and the parameters of the moving average are set accordingly. If those data are D, D_{-1}, …, and $D_{-(n-1)}$, the formula of the SMA can be expressed as

$$SMA = \frac{D + D_{-1} + \ldots + D_{-(n-1)}}{n} = \frac{1}{2}\sum_{i=0}^{n-1} D_{-i} \quad (4)$$

where, n is the average weight (number of subset of the full data set).

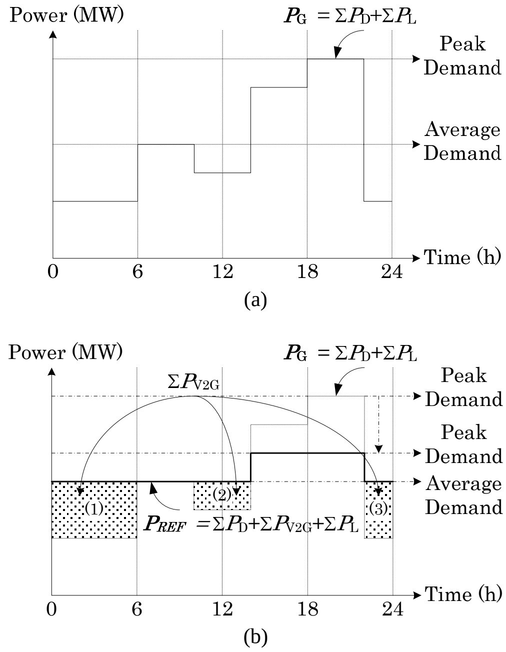


Figure 3. (a) Example of P_G of the studied system (b) load factor improvement by the V2G system

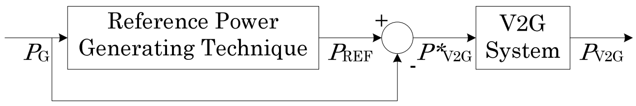


Figure 4. Control scheme of the proposed V2G control strategy

From the literature study, the finite impulse response filters such as the SMA, exponential moving average (EMA), and low-pass filters techniques have been adopted for variety of energy storage applications. These techniques are used to create the smoothing power references for solving power fluctuation problems in renewable energy systems such as wind energy system [25-26] and PV system [27-28]. Among the mentioned techniques, The SMA technique is simple and effective, but it comes with the main drawback of the phase delay between input and output data that would lead to an increasing of the required energy storage capacity [27]. However, the proposed V2G control strategy takes this drawback as an advantage by using the phase delay for shifting the peak demand from the peak hour to the off-peak periods.

In addition, the balancing amount of charging and discharging power by the V2G power during performing the load factor improvement is another concern. Without the balancing, the charging and discharging amount of power may be over the limit of the available storage capacity. From the previous research, the charging and discharging amount of the V2G power can be automatically balanced by using the advantage of the SMA technique [29]. To clarify this, this research investigates the balancing ability and analyzes the batteries' SOC of the electric vehicles in the power network corresponding to P_{V2G} when improving the load factor.

The balancing ability can be investigated by observing the trend of the energy utilization corresponding to P_{V2G}. Since P_{V2G} is the charging and discharging amount of power corresponding to P^*_{V2G}, the energy utilization by P_{V2G} can be considered as

$$E_{V2G} = \int_{t1}^{t2} P_{V2G} dt \tag{5}$$

where, $t1$ to $t2$ is the time duration of charging and discharging period.

Normally, SOC represents the electric energy available in the batteries. Since E_{V2G} is the utilized energy by P_{V2G}, SOC of the V2G system can be represent by

$$SOC = \frac{E_{MaximumAvailable} - E_{V2G}}{E_{MaximumAvailable}} \times 100\% \tag{6}$$

where, $E_{MaximumAvailable}$ is the maximum available storage capacity.

III. The Studied Scenarios

This section describes the details of the studied scenarios including the single line diagram, the busses data, and the line data of the studied system. The 3 studied cases present the studied system with the variation of the PEVs locations for describing the PEVs usage, charging, and discharging behaviors. These scenarios are necessary for performing the simulation and validating the effectiveness of the proposed V2G control strategy.

A. The Studied System

Fig. 5 shows the single line diagram of the studied system which consists of the slack bus (SLB), the 2 load busses (Load Bus(2) and Load Bus(3)), and the voltage controlled bus (VCB). These busses are configured in the so-called “ring topology”, where the SLB and VCB can dispatch the generated power (P_G and P_{VCB}) to both Load Bus(2) and Load Bus(3). During the power dispatch, the line power losses caused by the line impedance of the studied system may occur, as shown in Table III [30]. The power dispatch and the line power losses can be evaluated by using the power flow analysis. For investigating the load factor improvement, the power flow regarding to P_{V2G} must be analyzed.

The 7-day-period daily-load profile (from Wednesday to Tuesday) which has a high power fluctuation is selected for the study and simulation. Fig. 6(a) shows the simulation result without improving the load factor. The solid line is P_G (observed in the SLB) and the dash line is the generated power which is kept in 218 MW and observed in the VCB (P_{VCB}). From the busses data summarized in Table IV, generally the active power in the VCB is kept constant while the reactive power is varying for regulating the VCB’s voltage [30]. P_{D2} and P_{D3} as illustrated in Fig. 6(b) are the demand power of the load busses, respectively. The summation of P_{D2} and P_{D3} is equal to P_G observed at the SLB.

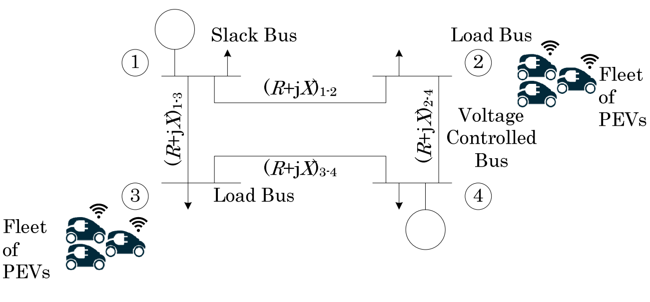


Figure 5. Busses and line data of the studied system

In the studied system illustrated in Fig. 5, the V2G system is applied to the system. The electric vehicles can travel in the studied system in any Load bus. Therefore, the proposed V2G control strategy can produce P_{V2G} in order to improve the load factor.

B. The Studied Cases

The 3 studied cases shown in Fig. 7 present the studied system with the variation of the PEVs locations. The PEVs can normally travel to and can be charged or discharged in any location or any bus in the studied system. This operating fashion is similar to the industry 4.0 concept [31]-[32], where the V2G system can cooperate with the state of the art of inter-networking of physical devices, buildings, and other items embedded with electronics, software, sensors, and network connectivity (the so-call Smart Grids). The characteristics of the 3 studied cases including the penetration levels and the traveling location are summarized in Table V. For Case(1) and Case(3) as shown in Fig. 7 (a) and (c), the penetrations are only in the Load Bus(2) and the Load Bus(3), respectively. Therefore, it is clear that the

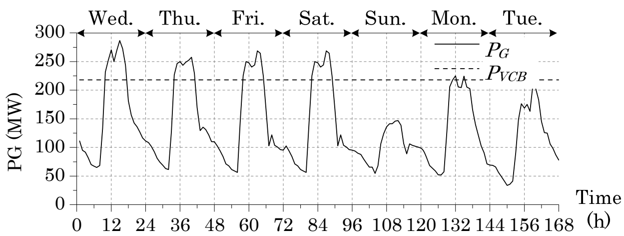
TABLE III. LINE DATA OF THE STUDIED SYSTEM (BASE 100MVA, 230KV)

Line, bus to bus	Series Z		Series $Y=Z^{-1}$		Shunt Y	
	R per unit	X per unit	G per unit	R per unit	Total Charging Mvar	Y/2 per unit
1-2	0.01008	0.05040	3.815629	-19.078144	10.25	0.05125
1-3	0.00744	0.03720	5.169561	-25.847809	7.75	0.03875
2-4	0.00744	0.03720	5.169561	-25.847809	7.75	0.03875
3-4	0.01272	0.06360	3.023705	-15.118528	12.75	0.06375

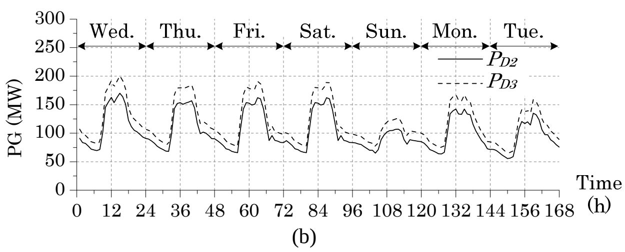
TABLE IV. BUS DATA OF THE STUDIED SYSTEM (THE Q VALUES OF LOAD ARE CALCULATED FROM THE CORRESPONDING P VALUES WITH THE POWER FACTOR OF 0.85)

Bus	Generation		Load		V, per unit	Remarks
	P, MW	Q, Mvar	P, MW	Q, Mvar		
1	*	*	50	30.99	1.00 ∠0°	Slack bus
2	0	0	*	*	1.00 ∠0°	Load bus (Inductive)
3	0	0	*	*	1.00 ∠0°	Load bus (Inductive)
4	218	*	80	49.58	1.00 ∠0°	Voltage controlled

* The corresponding P and Q values of the daily-load profile.

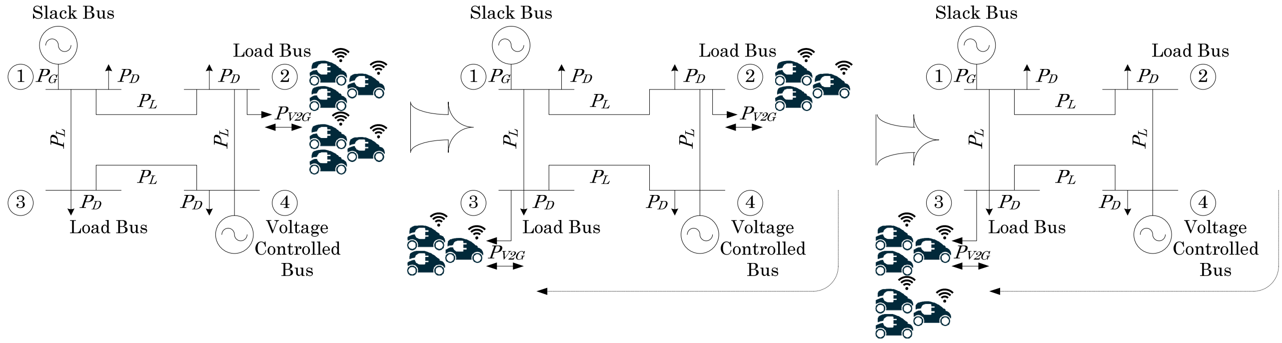


(a)



(b)

Figure 6. (a) The 7-day-period daily-load profile without improving the load factor (b) demand power of the Load Bus(2) and Load Bus(3)



(a) Case(1) (b) Case(2) (c) Case(3)

Figure 7. The 3 studied cases (a) Case(1), (b) Case(2), and (c) Case(3)

TABLE V. THE AVAILABLE STORAGE CAPACITY OF THE V2G SYSTEM FOR THE 3 STUDIED CASES

Bus No.	Available storage of the V2G system (%)		
	Case(1)	Case(1)	Case(1)
1	-	-	-
2	100	50	0
3	0	50	100
4	-	-	-

storage of the V2G system is only available in only the Load Bus(2) and the Load Bus(3), respectively. For Case(2) as shown in Fig. 7 (b), due to the penetrations are in both the Load Bus(2) and the Load Bus(3), the storage of the V2G system is then available in both the Load Bus(2) and the Load Bus(3) with the ratio of 50:50.

In this research, for investigating the effectiveness of the proposed V2G control strategy, the load factor improvement is firstly evaluated (without regard to the line power losses) by the spreadsheet software. The evaluation results are then compared to the simulation results.

The evaluation results in Fig. 8(a) show that P_G is smoothed according to the trace of $P_{SMA(12)}$. The SMA with the average weight of 12 (SMA(12)) is selected due to it can shift or distribute the peak demand from the peak hours to the off-peak hours. As shown in Fig. 8, the average demand power of P_G and $P_{SMA(12)}$ are similar. However, the peak demand of $P_{SMA(12)}$ is gradually reduced to the average demand power. The available storage capacity of the V2G system can produce P_{V2G} by charging and discharging an amount of power corresponding to the V2G power command (P^*_{V2G}). This command is corresponding to the difference power between $P_{SMA(12)}$ and P_G. Therefore, P_G can be smoothed by P_{V2G}.

IV. SIMULATION RESULTS

The following assumptions are made for the simulation:

• V2G implementation is designed at the system level. Due to large dynamics involved in the distribution system, power converters connected to the power network for charging and discharging the EVs are not modeled.

• Efficiencies of the batteries, charging system, and power converters are not considered because the aim of this work is to elaborate on the implementation of the grid support.

Case(1): Fig. 9(a) shows the generated power (P_G) observed in the SLB. It can be found that the power fluctuation is very high and the peak demand of P_G is much

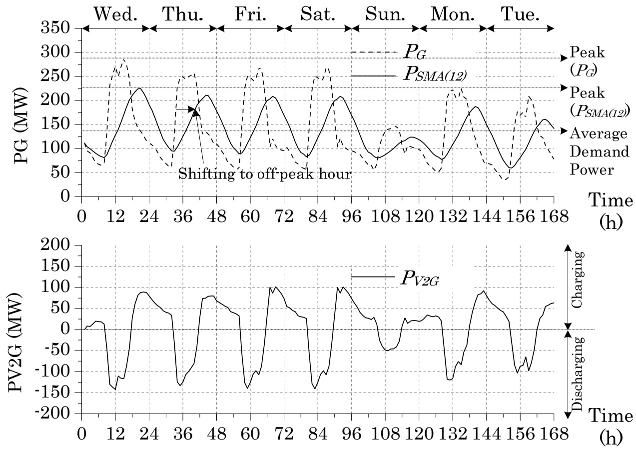


Figure 8. Desired load profile smoothed by SMA(12) at SLB and the V2G power demand for the load factor improvement

higher than its average demand power. This situation therefore leads to a low load factor.

However, in the case of operating the system with the proposed V2G control strategy, P_G is smoothed and traces $P_{SMA(12)}$. This situation therefore can improve the power network to a higher load factor. Moreover, the peak demand can be shifted from the peak hours to the off-peak hours. Fig. 9(b) shows the new demand power produced by the Load Bus(2) (P_{D2}), when applying the proposed V2G control strategy. Since the V2G power (P_{V2G}) is the charging and discharging amount of the power corresponding to V2G power command (P^*_{V2G}) (see Fig. 4), and the new P_{D2} is the combination of P_{D2} (see Fig. 6(b)) and P_{V2G} (see Fig. 7(b)), the total power observed in the SLB (with regard to the line power loss (P_L)) is the summation of P_D, P_{V2G}, and P_L. At this point, from (2) and (3), it is clear that the proposed V2G control strategy can smooth P_{G1} to trace the desirable reference power (P_{REF}) which produced by SMA(12).

By considering the demand power produced by the Load Bus(3) (P_{D3}), it can be found that P_{D3} from Fig. 6(b) and Fig. 9(b) are similar because the V2G system is only penetrated in the Load Bus(2) as described in Table V.

Case(2): even though the available storage capacity of the V2G system is divided (with the 50:50 ratio) for cooperating in both the Load Bus(2) and Load Bus(3) (as illustrated in Fig. 10(a)), P_G is smoothed to trace $P_{SMA(12)}$, similarly to Case(1). However, the differences of these two cases are as shown and compared in Fig. 10(b). The new P_{D2} and P_{D3} of Case(2) are smoother than of the Case(1). The advantage of the smoother power is that the line power losses are reduced.

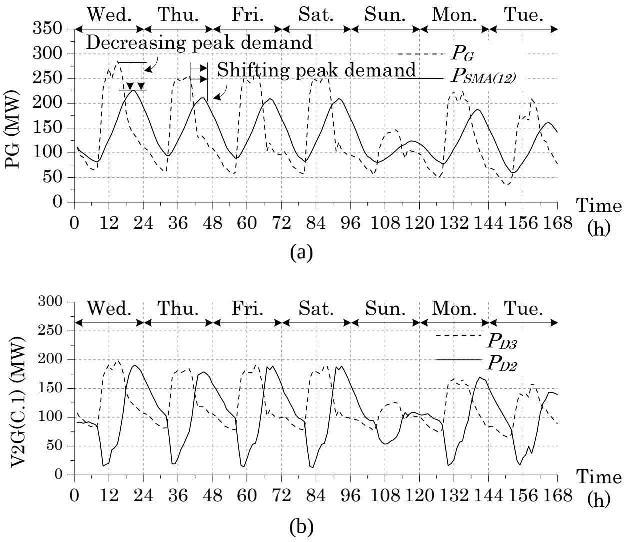


Figure 9. (a) Smoothed load profile using SMA(12) and (b) load demands of bus 2 (PD2) and bus 3 (PD3) of Case(1)

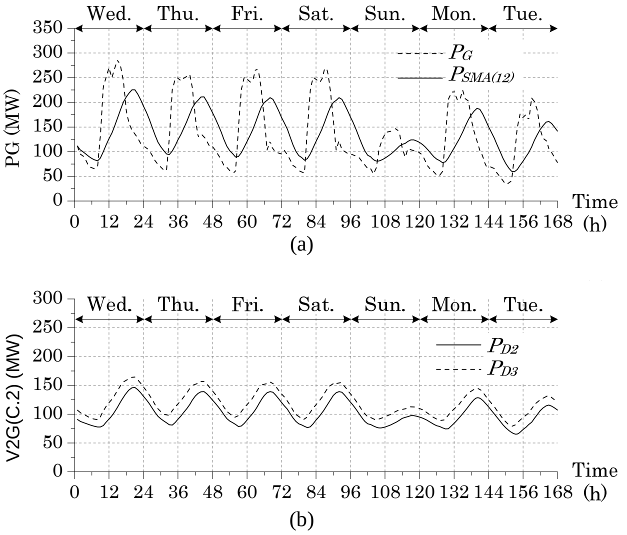


Figure 10. (a) Smoothed load profile using SMA(12) and (b) load demands of bus 2 (PD2) and bus 3 (PD3) of Case(2)

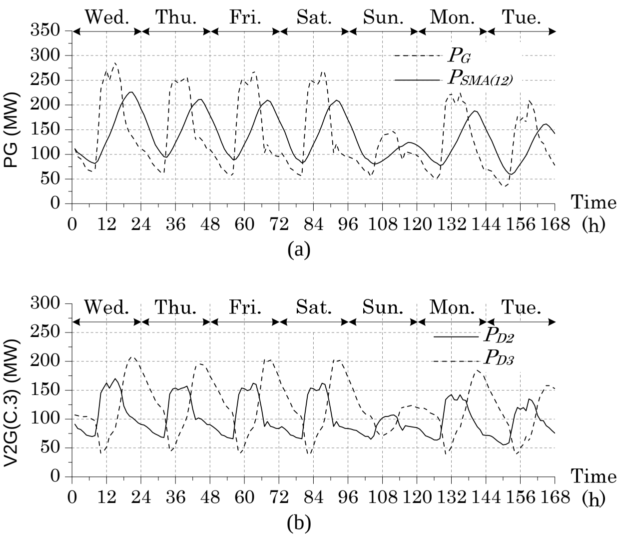


Figure 11. (a) Smoothed load profile using SMA(12) and (b) load demands of bus 2 (PD2) and bus 3 (PD3) of Case(3)

TABLE VI. LOAD FACTOR IMPROVEMENT BY THE EVALUATION AND THE 3 STUDIED CASES.

Cases Studied	Load Factor	Percentage of improvement [%]
Normal	0.471	0.00
Evaluation	0.599	27.08
Case(1)	0.596	26.45
Case(2)	0.596	26.35
Case(3)	0.595	26.27

TABLE VII. POWER LOSSES IN THE POWER NETWORK'S LINES OF THE STUDIED SYSTEM

Line, bus to bus	Power Losses (MW)			
	Normal	Case(1)	Case(2)	Case(3)
1-2	27.26	30.20	18.41	19.08
1-3	74.35	64.79	62.59	70.21
2-4	108.83	111.36	107.58	111.16
3-4	117.20	123.62	115.85	120.42
Total	**327.64**	**329.97**	**304.43**	**320.87**
Change		**0.71%**	**-7.08%**	**-2.07%**

Case(3): as expected, Fig. 11(a) shows that P_G is smoothed to and traces $P_{SMA(12)}$ similarly to the others 2 cases. However, the difference is that the new P_{D3} is the combination of P_{D3} (see Fig. 6(b)) and P_{V2G} (see Fig. 7(b)), as illustrated in Fig. 11(b). This can produce the difference line power losses depending on the impedance of the studied system, as summarized in Table VII.

Table VI summarizes the load factor values with and without the operation of the proposed V2G control strategy. It can be found that the load factor values calculated by the evaluation and simulated by the 3 studied cases are increased to almost the same value. These load factor values are improved approximately 26 – 27 %.

Table VII shows the line power losses over the power network's lines. These can be obtained by the power flow analysis. For Case(1) and Case(3), the total power losses are increased by 0.71% and decreased by 2.07%, respectively. However, for Case(2), the total power losses are significantly decreased by 7.08%. This is caused by the low power fluctuations of P_{D2} and P_{D3} and the operation of the V2G system which are operated as a distributed generation (DG) mode that can provide the electric power at the sites closer to the customers.

From the above results, the performances of the smoothing and the load factor improvement have been validated. The validation of the energy balancing ability and the SOC corresponding to P_{V2G} during the load factor improvement is analyzed as follows.

The balancing ability can be investigated by observing the trend of energy utilization corresponding to P_{V2G}. Fig. 12 shows the trend graphs of the energy utilization corresponding to P_{V2G} of the 3 studied cases. With the 14-day load profiles, the SOC corresponding to the V2G power can be obtained from (6) (as described in Section II). During the operation of PEVs in discharging mode, the corresponding SOC is continuously decreased. The corner of the trend graphs of the energy utilization appears when the working duty of the fleet of PEVs is switched from discharging mode to charging mode and vice versa. It can be found that the trend graphs of the energy utilization are kept in a boundary.

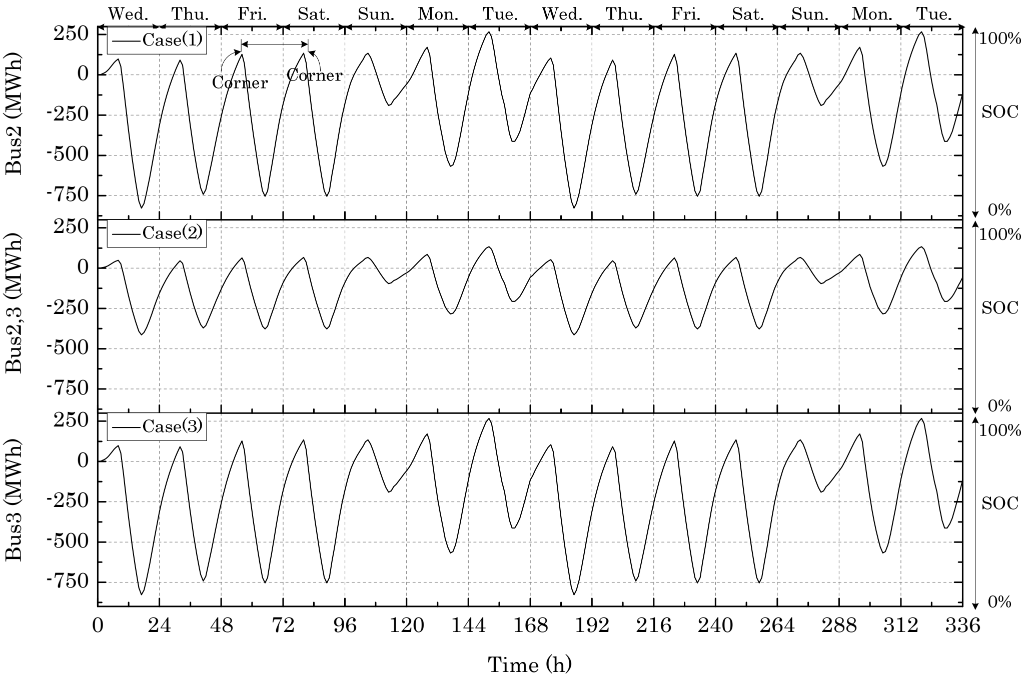


Figure 12. The energy utilization of V2G for the load factor improvement of Case(1), Case(2), and Case(3)

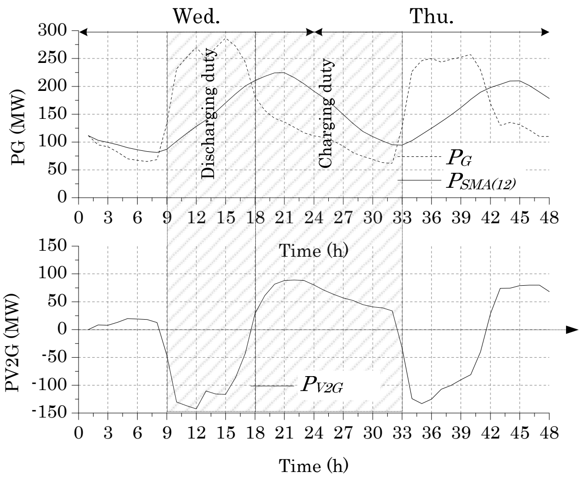


Figure 13. The periods of discharging and charging modes of the V2G system by the proposed V2G control strategy

This means that the amount of power in the charging and discharging modes corresponding to PV2G are balanced. From the trend graphs, the aggregator can simply predict and evaluate the required amount of active power and fit this power with available storage capacity of the PEVs.

The trend graphs of the energy utilization illustrated in Fig. 12 are the essential data to validate the practical operation of the proposed V2G control strategy. For clearer explanation, let's consider the energy utilization trend as the discharging mode is started from about 6:00 a.m. to 6:00 p.m. and the charging mode is started from about 6:00 p.m. to 6:00 a.m. It is clear that the working modes are repeated at almost the same time for the period of 14 days and the charging and discharging modes are available in the parking time. These could be comfortable for the PEV's owners to make decision to accept the aggregator's offer and operating conditions.

Finally, as illustrated in Fig.13, the PEV's owners could gain benefit from the energy arbitrage by storing up the cheap energy at the night time period and using or delivering this stored energy back to the grid at the peak hours. This energy arbitrage also could be possible for either both home and business applications.

V. CONCLUSION

This paper proposes the new V2G control strategy for improving the load factor in the power network. The available storage capacity of the PEVs' batteries is considered as a battery energy storage system for charging or discharging an amount of power corresponding to the V2G power command.

The simple moving average is selected to apply in the proposed V2G control strategy for generating the V2G power command. The performance of the proposed strategy is verified by simulation using the MATPOWER software. The simulation results show that the load factors of the 3 studied cases are significantly improved. Moreover, the trends of the energy utilization corresponding to the V2G power of the proposed strategy would make the PEV's owners satisfied the benefits from the energy arbitrage. At this point, it can confirm that the proposed V2G control strategy can achieve the key problems and challenges for considerations as mentioned in the literature review.

The further works of this research are such as the analysis and the simulation of the proposed V2G control strategy with the parameters including battery efficiency, PEVs trip times, and the effects on power network.

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