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EVALUATION OF STABILITY AND PHOTOVOLTIC SELF-CONSUMPTION RATE OF MICRO GRID UNDER DIFFERENT ELECTRIC VEHICLE PENETRATION RATES

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ABSTRACT

Vehicle to grid (V2G) is a technology which is receiving much attention as a method for achieving an efficient energy management system by connecting electric vehicles (EVs) to an electric power grid. In recent years, the amount of EV and renewable energy, such as photovoltaic (PV), increases rapidly. To make full use of energy, the relationship between self-consumption rate (SCR) of PV and EV penetration rate (EVPR) is a valuable issue. In addition, the stability of micro grid (MG) with different EVPR is also considered. This paper aims to find how the EVPR influence the stability of MG and SCR of PV. To achieve the main objective of this paper, a typical PV installed capacity is adopted and several scenarios with different EVPR are compared in MATLAB programming environment. The result shows that under a stable MG environment, with the growth of EVPR, remarkable increase occurs in both the stability of MG and SCR of PV. But there is an ultimate capacity for EV. Under ultimate capacity, stable load curve and fewer dump energy can be achieved simultaneously.

Keywords: electric vehicle, photovoltaic, micro grid, self-consumption rate, vehicle to grid, scenarios comparison

NONMENCLATURE

MG *Micro grid*	*SOC* *State of charge*
ESS *Energy storage system*	*SCR* *Self-consumption rate*
V2G Vehicle to grid	*EVPR* *Electric vehicle penetration rate*

1. INTRODUCTION

The target behands the emergency of renewable energy is reducing the consumption of fossil fuel and limiting the electricity dependence to fuel rising price. However, there are some drawbacks of the usage of renewable energy. In one hand, the variability of weather and climate especially wind speed variability can dramatically influence the output of renewable energy. In the other hand, the low efficiency is a bottleneck limiting the development of clean energy. Apart from that, with the rise of amount of renewable energy, local infrastructures cannot consume them all. Thus, surplus energy is sent to low-voltage grid which may cause fluctuation on the grid[1]. In this paper, photovoltaic (PV) power is chosen as representative renewable energy because its power generation is relatively regular in a typical day. Its self-consumption rate and influence to the grid are evaluated in this research.

To make full use of clean energy, more attentions are drawn to electric vehicle (EV) and the vehicle-to-grid (V2G) technology. V2G technology developed quickly because EV ownership has soared with encourage policies in recent years. In this contract, 90% of total vehicle ownership will be contributed up by EVs which will lead to extra demanding on the grid especially during peak hours[2]. However, the charging of EVs have spatial and temporal distributions based on their transportation characteristic. Thanks to the popularity of charging piles in the parking stations, EVs can charge in most kinds of locations such as residential, business, recreation areas and workplaces. Meanwhile, smart charging management can also be a supplement of V2G, to achieve load-shifting and minimize the effect of EVs charging[3].

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To evaluate the influence of renewable energy and EVs, we need to find the daily routine of energy produced by PV and the charging file of EV. Based on [4], the data about PV system is available. The National Household Travel Survey (NHTS) datasets provides us a good opportunity to find the daily usage rule of EV. From where the data about EV, like the time leaving home and backing to home, can be extracted[5]. Based on the data obtained from above websites, the simulation can be achieved in MATLAB. Detailed simulated process, 3 different scenarios, result and conclusion are introduced in Section 2.

2. METHODOLOGY

2.1 Micro grid power system

The proposed MG power system consists of renewable energy, diesel generator and energy storage system (ESS) for the purpose of meeting the consumers' load requirement. For remote areas and isolated systems which are not connected with traditional grid, MG is the most convenient and economical viable solution to solve the energy usage problem due to the technical and complexity of the terrain. Its capital cost and maintenance cost are relatively lower compared with traditional grid. With proper operation, the self-consumption proportion can be quite high which is good for reliability and minimize the cost of a power system[6].

2.2 Photovoltaic power

Solar photovoltaic power is a generic term used for electrical power that is generated from sunlight. The availability of the power supply generated from PV system depends on the availability of the prime sources such as solar irradiance. PV output tends to fluctuate depending on the time corresponding to the fluctuation of its prime sources. Data about prime sources applied in this paper are mainly solar radiation and outside air temperature from 18-5-2018 to 18-5-2019 collected from [4]. Take the average of one year as the typical load. Time slot is 1 hour which is precise enough to estimate the output of PV system.

In the PV system, we assume that a maximum power point tracker will be used. The maximum power output is presented by Eq. (1).

$$p_s = \eta SI\left(1-0.005\left(t_o-25\right)\right) \quad (1)$$

where η is the conversion efficiency of the solar cell array (%); *S* is the array area (m^2); *I* is the solar radiation (kW/m^2); and t_0 is the outside air temperature (℃).

In this paper, η and *S* are assumed to be 10% and 1000 m^2 respectively[7]. Solar radiation and outside air temperature average the data in the whole year as the data in a typical day. Based on formula (1), power generated from PV system is shown in Fig. 1.

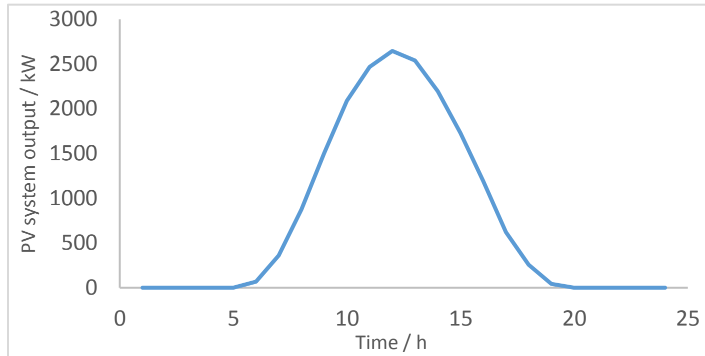

Fig. 1 Typical PV system output

2.3 Vehicle-to-grid technology

In recent years, EV penetration increases rapidly under various promotion policies. EVs gradually become an important component of MG. The widespread deployment of EVs also gives it potential to act as a part of ESS because most EVs are idle in almost 95% time in a day. And V2G is the vital technology to make full use of EVs[8].

The concept of V2G is that EV gets power from grid in valley period and feedback to the grid when power is needed. Every vehicle attended V2G has to satisfy three points as below: (1) connection between EV and grid for power flow; (2) proper electrical wiring which can sustain power flow of EV and double-directional transfer wiring for sending power back to the grid; (3) smart control or logical connection for the communication with the grid operator. Up to now, normal V2G process and its influences have been studied thoroughly. Hence, we assume that all the vehicles attend V2G only in day time, after leaving home and before backing to home, when PV system starts working. This paper mainly focuses on the comprehensive influence of EV, V2G and PV.

In this simulation, one day is separated into 96 segments, interval between contiguous time slots is 15 min which is enough to make precise control of the system. Let $t \in \mathbb{N}$ denote the discretization step of the time of day and let T is the total number of time slots, as we can see in Eq. (2).

$$t = \{1, 2, 3, \ldots, 95, T\} \tag{2}$$

Additionally, let n be the EV connecting with the grid, N be the total number of EV, m be the EVPR and V be the total number of vehicles, as shown in Eq. (3).

$$n = \{1, 2, 3, \ldots, \mathrm{N}\}, \quad N = m*V \tag{3}$$

The optimal charging situation is to determine the states of EVs connecting with the grid in every time slot. Including charging, discharging and idle three states, Each EV can only have one state in one time slot. For each time slot, the number of EV attending V2G is different and PV output is also changing. Consequently, the optimization objective, minimizing the overall load variance of the regional grid during the coming one-day cycle should be achieved in every time slot[9]. Hence, the problem can be formulated as:

$$\min \quad S = \sum_{t=1}^{T}\left[\frac{1}{T}\left(P_{\mathrm{Con}}^{t} + P_{PV}^{t} + \sum_{n=1}^{N} P_{ACP-n}^{t} - P_{\mathrm{Avg}}\right)^{2}\right] \tag{4}$$

Subject to:

$$P_{Avg} = \sum_{t=1}^{T}\left(P_{Con}^{t} + \sum_{n=1}^{N} P_{ACP-n}^{t}\right)/T \tag{5}$$

$$P_{acp-n}^{t} = \begin{cases} P_c & charging \\ 0 & idle \\ -P_{dc} & discharging \end{cases} \tag{6}$$

$$SOC_{lower} \le SOC_n^t \le SOC_{upper} \tag{7}$$

$$SOC_n^{final} \ge SOC_2 \tag{8}$$

Where S is the parameter evaluating the stability of MG. P^t_{ACP-n} is the charging power of n-th EV in t-th time slot; P^t_{pv} is the output power of PV system in t-th time slot; P^t_{con} is the estimated grid base load in t-th time slot; P_{Avg} is the estimated average power of the grid during the coming one-day cycle; P_c and P_{dc} are charging power and discharging power of EV respectively; SOC^t_n is the state of charge (SOC) of n-th EV in t-th time slot; SOC_{lower} and SOC_{upper} are the limitation of SOC; SOC_n^{final} is the final SOC of n-th EV after V2G process. SOC after leaving home and final SOC are both uniformly distributed random value, between 0.3-0.7 and 0.5-0.9 respectively.

In this paper, SOC_{lower} and SOC_{upper} are separately assumed to be 20% and 100%. Charging power is same as discharging power, both set 6.6 kW[10]. Therefore, SOC can be calculated by Eq. (9).

$$SOC_n^e = SOC_n^s + \sum_{t=1}^{e-s}\left[\Delta t \cdot P_c / BAT\right] \tag{9}$$

Where s and e are V2G starting time slot and ending time slot. SOC^e_n and SOC^s_n represent SOC at V2G starting and ending time slots separately. BAT is the capacity of EV battery.

As for self-consumption rate of PV output, higher self-consumption rate means less dump energy and lower management cost for MG. It is an indicator to judge the completeness of a MG system. It represents the proportion of PV output consumed by EV where PV output can be calculated by integrating PV output curve.

2.4 Simulation and results

In this section, different scenarios with EV penetration rate from 0% to 100% are researched. In detail, in the first scenario, EVPR is 0% which means there is no EV and the MG load is base load. Following that, EVPR rises to 20%, 40% until 100%, totally 6 scenarios. In the last scenario, all the vehicles are assumed to be EVs, sum to 1000 EVs. All the EVs obey the regular summarized from NHTS and adopt level 1 charging/discharging power. Take the average of 10-times simulation results as the final result. The load of MG under 6 various EVPR is shown in Fig. 2.

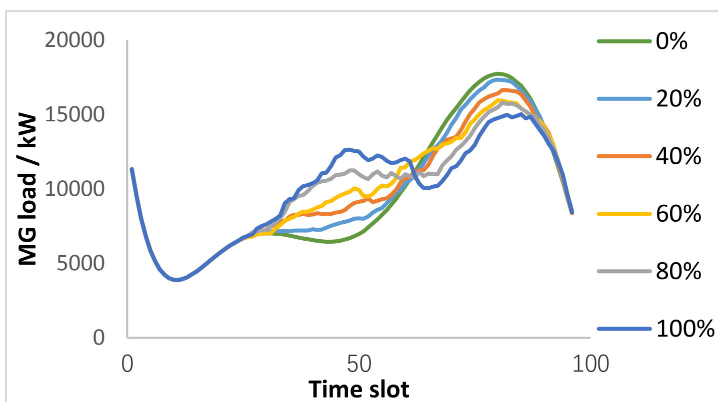

Fig. 2 MG power load under different EVPR

With the growth of EVPR, we can see that the peak-load shifting occurs distinctly. The highest load point of MG decreases from 1772kW in 80th time slot to 1501kW in 85th time slot. By contrast, load in valley period shows obvious increase, from around 650kW to almost 1000kW under 80% EVPR, closing to average power load. While with further ascending of EVPR, fluctuation of MG load emerges and parameter S also rises which means the MG has overloaded under the burden of 1000 EVs. Table. 1 gives detailed value of S. It is clear that S drops gradually with more and more EVs attending V2G until EVPR reaches 80%. Once the number of EV exceeds 800, V2G technology can not maintain balance between EV charging requirement and MG stability.

As for SCR of PV power, it keeps going up with the increase of EVPR. Whereas, SCR reaches 89% when the EVPR is just 60%. After that, SCR climbing slowly, increases less than 10% although EVPR rises 40%.

Table. 1 SCR and S under different EVPR

Data/EVPR	0%	20%	40%	60%	80%	100%
SCR(%)	0	42	71	89	93	98
S (×10^5)	6.1	5.3	4.8	4.2	4.0	4.4

2.5 Conclusion

This paper studies stability and PV SCR of MG under different EVPR. The result shows that:

1. MG has an ultimate capacity of EV, before reaching it, EV can be helpful to achieve peak-load shifting with V2G management. Once exceed that, the balance will be broken and fluctuation shows up. For the scenarios studied in this paper, the ultimate capacity is 800 EVs (80% EVPR).

2. More EVs bring higher PV SCR. However, SCR reaches 89% when EVPR is just 60% and rises slowly after that. There is nearly no dump energy after 600 EVs (60% EVPR) attending V2G which means there is no need to arrange more EV attending V2G for consume the rest PV output.

3. Considering both stability and SCR of PV, 80% penetration rate (800 EVs) is the best scenario for this MG. It guarantees stable load curve and fewer dump energy simultaneously.

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