Impact Analysis of Fast Charging to Voltage Profile in PEA Distribution System by Monte Carlo Simulation

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ABSTRACT

This paper presents a method to obtain electric power consumption of charging station based on the Monte Carlo simulation. The state of charge (SOC) of battery, charging time and arrival time to charging station will be considered. After obtaining the charging profile, the voltage profile will be analyzed by DIgSIENT Powerfactory. Subsequently, an analysis of the impact of electric vehicle charging stations to the voltage profile of the Provincial Electricity Authority distribution system is carried out. The simulation results indicate that charging station affects changes of voltage profile and voltage drop in the distribution system. However, if the power to the charging station or distribution system changes, an approach presented in this research can also be applied to analyze the impact on voltage.

INTRODUCTION

Due to the rising fossil fuels prices and the required reduction of greenhouse gas emissions in the transportation sector, plug-in electric vehicles (PEVs) are expected to increasingly be adopted rapidly in the near future [1],[2].

Distribution systems are typically designed for specific load carrying capability based on load consumption. With various standards for PEV charging level, they have been grouped into 3 levels, i.e. Level 1 refers to home charging level, 250 V single phase or 480 V 3 phase AC and charging current not exceeding 16 A, Level 2 refers to 250 V single phase or 480 V 3 phase AC and charging current not exceeding 32 A, and Level 3 refers to "quick charge" or "fast charging". To achieve a very short charging period of time, Level 3 charger supplies very high current (125-250 A) at very high voltage (300-500VDC). [3] In this paper, impacts of fast charging stations on a medium voltage distribution grid are investigated by using Monte Carlo simulation. When PEVs are charged in the system, electric power demand increases. The PEV charging characteristic depends on many factors such as charging start time, initial state of charge (SOC), charging power level and charging period. Fast charging of PEVs requires delivering large amount of energy in a short period of time, usually in a range of minutes, and results in demand of high charging power. The power input of each charger is 110.85 kW. The simulation results of the fast charging station consisting of 8 chargers are carried out in this study.

TEST SYSTEM

Distribution system in Pattaya

We use system data of Pattaya city which the smart grid pilot project of Provincial Electricity Authority (PEA) in Thailand. The electric energy in Pattaya city is supplied by Banglanumg substation. Typical distribution network in Pattaya city mainly is radial network and overhead lines. This paper focus on the radial distribution network in 22 kV distribution system. The Banglamumg substation complete with two power transformers, each power transformer consist of five feeders such as feeder 1-5 and feeder 6-10. We use system data of feeder 10 Banglamung substation which 9.9 km maximum line length as illustrated in figure 1.

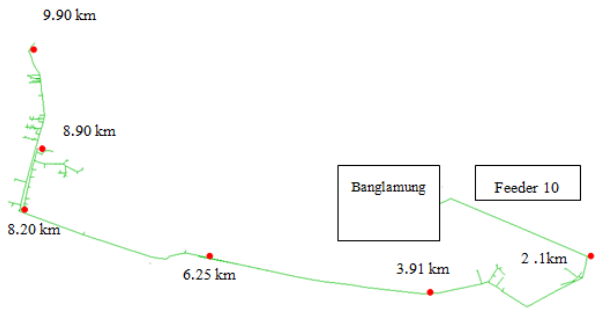

Fig. 1. Pattaya's distribution system.

Daily load profile

We use power system data of Pattaya city, Thailand to establish the test system for simulating impacts of fast charging station by using Monte Carlo simulation. When the fast charging station is installed at the 8.9 km far from the 115/22 kV substation. The voltage profile at the end of feeder (9.9 km far from the 115/22 kV substation) fluctuates. The daily load profile of feeder 10 is shown in figure 2. Peak load of feeder 10 is 8.54 MW and 4.10 MVAR at 19.30.

VEHICLE CHARGING PARAMETERS

Battery sizing

This paper uses PEV battery size of 24 kWh and PEV maximum travelling distance is 47 miles (80 km).

Charging Station and Number of EVs

A fast charging station with 8 charging poles, each with charging capacity of 110.85 kW, and there is a probability that eight EVs arrive at the fast charging station at same time, this will result in a power demand up to 0.88 MW. This sudden jump power leads to a voltage fluctuation in distribution system.

In this study we assume the total EVs is 500 PEVs and 2,500 PEVs, but each EV has a difference SOC then all day the EVs are charged less than 500 PEVs, depending on SOC probability density function.

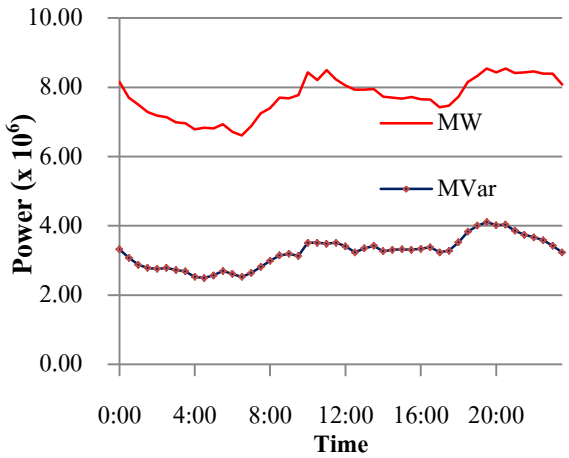

Fig. 2. Daily load profile in feeder 10.

Charging Power in Each Pole

In this paper we assume the driver wants to go to the fast charging station when SOC less than 50 percent with time duration depend on SOC, charges in 100 kW and 110.85 kW constant output and input power respectively. Each pole is connected in three phase, 400 V system. [4]

Battery State of Charge and Travelling distance

The battery state of charge (SOC) has a strong impact on PEV charging profile. The battery's SOC which depends on traveling distance and maximum distance of PEV. In this paper, the maximum distance is 47 miles.

To simulate the SOC of battery, it is important to know the distribution of the travelling distance. Figure 3 shows the travelling distance in Seattle.[5]

From figure 3, the SOC of battery will be calculated from travelling distance according to equation (1).

$$SOC = \frac{D_{\max} - D_{drive}}{D_{\max}} x100\% \qquad (1)$$

SOC is battery state of charge (%)

$D_{\max}$ is maximum distance (miles)

D_{drive} is travelling distance (miles)

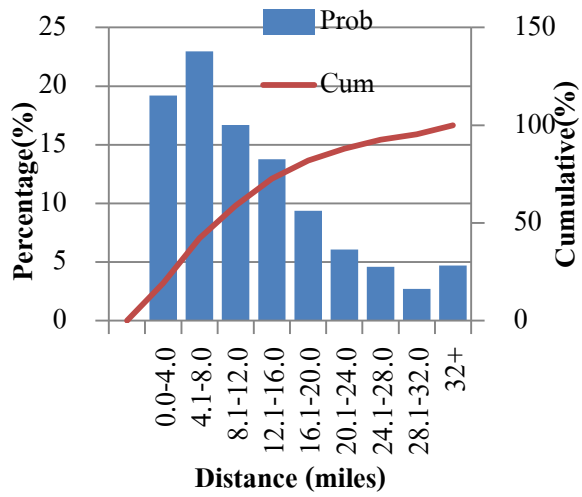

Fig. 3. Daily travelling distance.

In this study, SOC of each PEV is a stochastic variable whose value is selected by a random number generator.

It is assumed if SOC less than 50 percent then the EVs owner will go to the charging station. The amount of EVs all day depends on the arrival time of EVs.

The total numbers of EVs are 500 EVs and 2,500 EVs. Each EV has different SOC, which will be modeled in the simulation study.

Arrival time

The Arrival time distribution of EVs determines the demand profile of the charging station. The arrival time distribution of EVs at charging station during a day is shown in figure 4. [6]

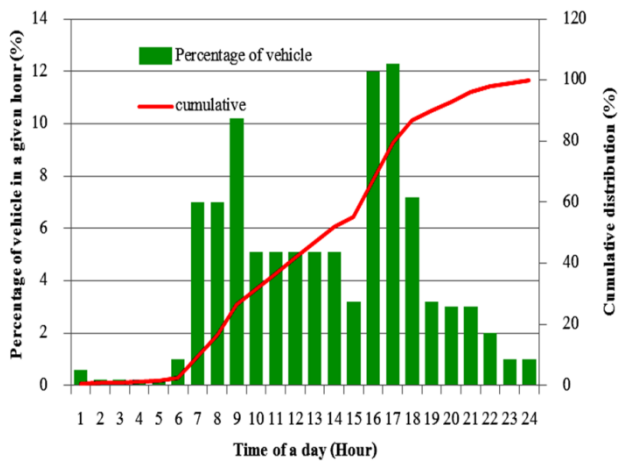

Fig. 4. Arrival time distribution of EVs.

FAST CHARGING MODEL

In this paper, the Monte Carlo simulation is employed to determine charging impacts of PEVs. The Monte Carlo simulation is applied by selecting randomly values of inputs consisting of daily distance travelled for calculating the SOC of battery, arrival time and charging

duration. The Monte Carlo simulation is performed as follows:

1. Initialize the input factors
   1.1 Total number of vehicles in the area
   1.2 Charging power
   1.3 Number of chargers in a charging station
   1.4 Arrival time distribution for vehicles at a charging station
   1.5 Daily distance travelled for calculating the SOC of battery
2. Generate charging profile
3. Repeat step 1 to 2
4. Find the total maximum charging power of a charging station in each minute from 100,000 scenarios.
5. Solve power flow by DIgSILENT PowerFactory
6. Investigate the voltage profile at the end of feeder.

SIMULATION RESULTS

The results are divided in 3 parts; first part is the charging profile at the fast charging station during a day. Second part presents the voltage profile at the end of feeder in the medium voltage system. Third part presents probability of voltage change in distribution system when there is a PEV fast charging station in the area.

Charging Profile

The EVs charging profile depends on charging characteristics such as charging start time, the initial state of charge (SOC), charging power level, charging period and number of PEVs in the area.

Charging profile is divided in 2 cases as 500 PEVs in area and 2,500 PEVs in area.

First case shows the result of charging profile in fast charging station with 8 pole of charger and 500 PEVs in area. Figure 5 shows per minute charging profile from EV charging. The peak demands occur at 15.44 hour. This figure shows the pulsating of EV loads which lead to the voltage fluctuation in distribution system. Figure 6 shows maximum charging power of a charging station in each minute from 100,000 scenarios.

Second case shows the result of charging profile in fast charging station with 8 pole of charger and 2,500 PEVs in area. Figure 7 shows per minute charging profile from EV charging. The peak demands occur around 8.00 and 16.00 hours. This figure shows the pulsating of EV loads which lead to the voltage fluctuation in distribution system. Figure 8 shows maximum charging power of a charging station in each minute from 100,000 scenarios for computing voltage profile by using DIgSILENT PowerFactory.

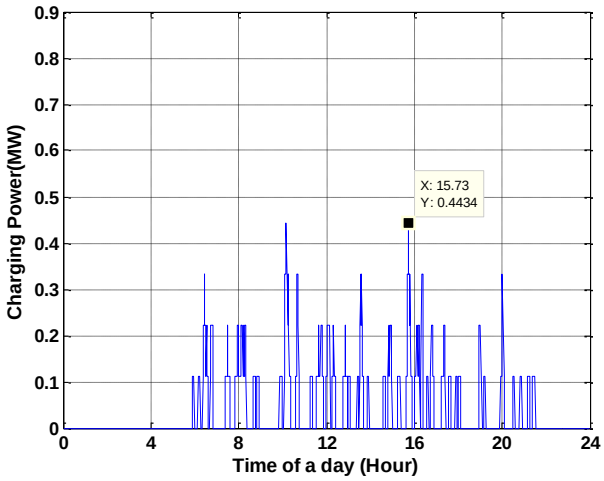

Fig. 5. Per minute charging profile (500 EVs in area)

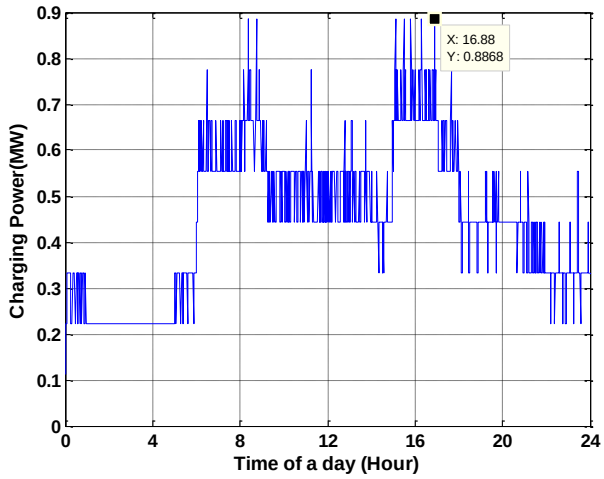

Fig. 6. Maximum charging profile from 100,000 scenarios. (500 EVs in area)

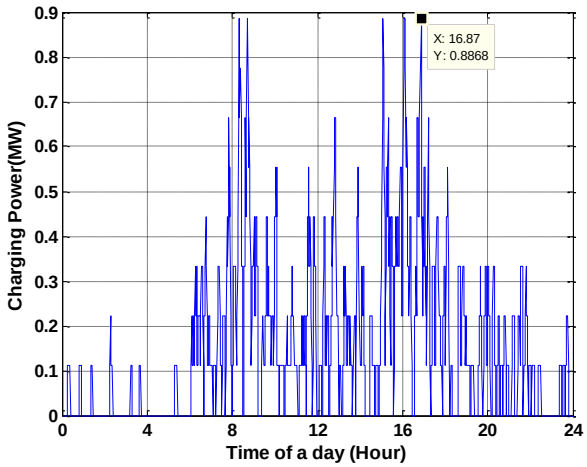

Fig. 7. Per minute charging profile. (2,500 EVs in area)

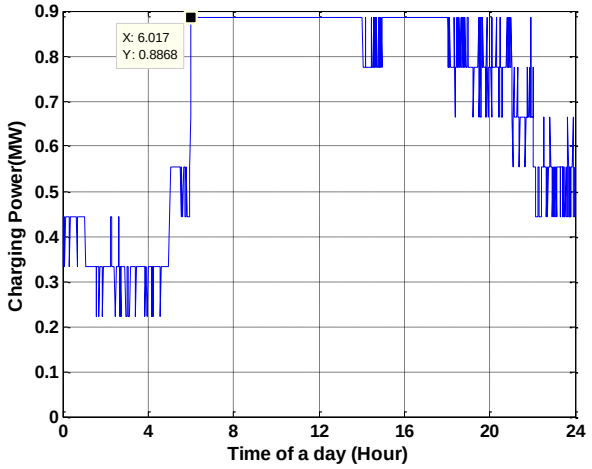

Fig. 8. Maximum charging profile from 100,000 scenarios (2,500 EVs in area.)

Voltage Profile

We use power system data of Pattaya city, Thailand to establish the test system for simulating impacts of fast charging station by using Monte Carlo simulation. Current levels on distribution line will increase because the fast charging station is operated. The location of fast charging station is shown in figure 9. (8.9 km far from the 115/22 kV substation)

Fig. 9. Fast charging station location.

This section presents the voltage profiles in two study cases; the fast charging station with 500 PEVs and the fast charging station with 5,000 PEVs.

First case presents the voltage profile at the end of feeder in case 500 PEVs. Figure 10 shows the voltage profile at the end of line when system without fast charging station (base load) and with fast charging station. Blue curve is the voltage profile when system is with base load. Voltage at the end of feeder still meets voltage criteria. Red curve is the voltage profile after running load flow with 1 scenario charging profile. Figure 11, Red curve is the voltage profile after running load flow with the maximum charging profile. The voltage at the end of line is fluctuated but still meets voltage criteria.

Second case presents the voltage profile at the end of feeder in case 5,000 PEVs. Figure 12 shows the voltage profile at the end of line when system is without fast charging station (base load) and with fast charging station. Red curve is the voltage profile after running load flow with 1 scenario charging profile. Consequently, the voltage fluctuation occurs.

Figure 13, Red curve is the voltage profile resulting from base load profile plus the maximum charging profile. As can be seen in this figure, the system is operating well within the allowable limit (1.05-0.95 pu).

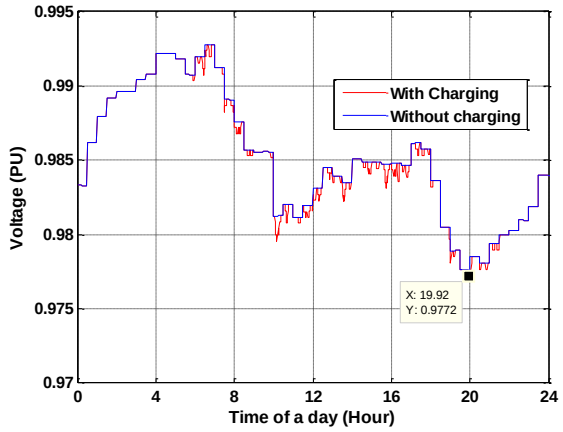

Fig. 10. Voltage profile in case of 500 EVs in area.

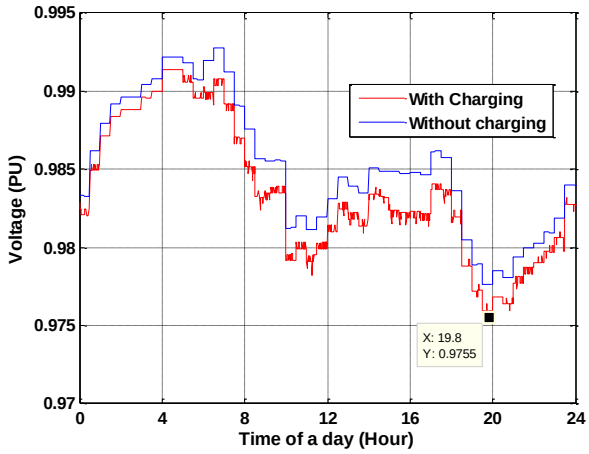

Fig. 11. Minimum voltage profile in case of 500 EVs in area.

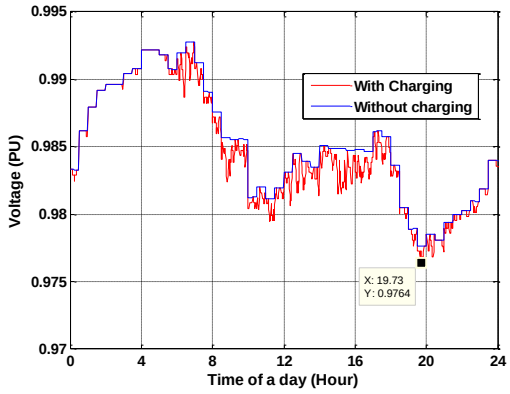

Fig. 12. Voltage profile in case of 2,500 EVs in area.

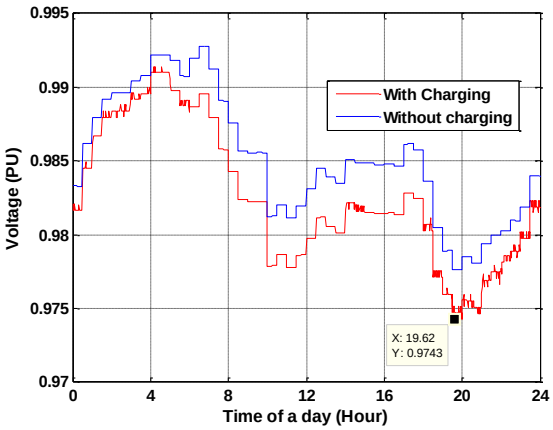

Fig. 13. Minimum voltage profile in case of 2,500 EVs in area.

Probability of voltage change

From voltage profile, we can calculate percentage voltage change when compare with base load voltage profile. Figures 14 and 15 show probability of voltage change in cases of 500 PEVs and 2,500 PEVs in area, respectively. The results show the probability of voltage change depending on the number of PEVs in the study area. The maximum percentage voltage change is 0.35 percent.

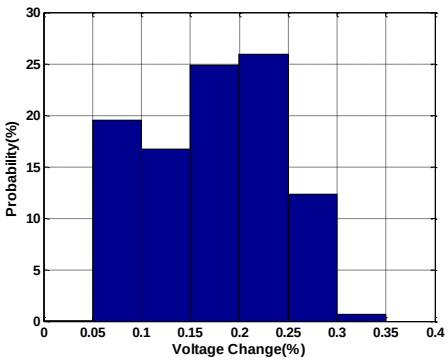

Fig. 14. Probability of voltage change in case of 500 PEVs in area.

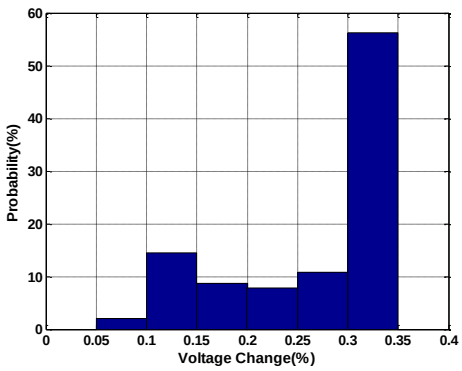

Fig. 15. Probability of voltage change in case of 2,500 PEVs in area.

CONCLUSION

From simulation results, the voltage characteristics in distribution system are affected by the fast charging station. The fast charging power leads to abrupt voltage change in distribution system. This phenomenon affects sensitive loads in the system. The bus voltage which is near the power substation has little effect from PEVs fast charging, but the bus which far from the substation affected from PEVs fast charging. In addition, this method can also be applied to find the maximum charging station.

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