Evaluation of voltage stabilization on a SmartGrid simulation system for introduction of EV

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Abstract. Recently, attention has been focused on whether the SmartGrid could work efficiently in an energy network. The subject of our study is the electric vehicle (EV), which has been proposed as a potential chargeable/dischargeable part of the power grid infrastructure. As energy is transferred between an EV and the power grid, it is possible to regulate energy on the entire grid via charging and discharging the EV battery. In the future, it may also be possible to stabilize energy within the system, using information technology control embedded in the network of the SmartGrid. Compared with a case in which energy storage is fixed, more complex control is needed when EV technology is used. This study evaluates these circumstances using a simulated system.

Key words: SmartGrid, EV, V2G, energy network, simulation system

1 Introduction

Recently, the scarcity of natural resources and rapid increases in energy demands have been raised as worldwide problems; thus, it has become necessary to promote renewable energy generation as a means of energy conservation. However, controlling output power for renewable energy generation is difficult because energy output is subject to violent fluctuations. To address this issue, attention has been focused on the potential for SmartGrid to work efficiently in energy networks.

The electric vehicle (EV) is closely related to the SmartGrid. An EV has a high-capacity battery, and it is not only used as a vehicle but is also treated as a power resource that can charge and discharge energy as needed. This energy exchange is referred to as 'Vehicle-to-Grid' (V2G).

However, V2G power grids are different from traditional power grids that deliver electricity from power plants to users in a single direction. Power resources in V2G power grids are widely distributed within a given area, and electric transmission is bidirectional. In this case, meticulous control regulation to stabilize power flow is necessary, i.e., it is necessary to monitor the electric potential of each point on the grid, to exchange information through the network and to control the distribution of power sources.

In this study, simulation is used as a method to evaluate power control when EVs are connected to the SmartGrid as a power source. First, a power grid simulation environment was constructed, and the impact of EVs connected to the power grid in this simulated environment was evaluated. Specifically, we connected many EVs to the power grid environment, discharged the batteries and monitored the voltage fluctuations at each point.

The remainder of this paper is organized as follows. Section 2 introduces an outline of the SmartGrid and EV. Section 3 summarizes this study. Section 4 describes a model of the distribution network and introduces the implementation of EVs and a solar power plant in an experimental simulation system. Section 5 introduces the results of the simulation connecting EVs as a power source to a power grid. Section 6 presents a conclusion and future directions for this research.

2 Background

2.1 The SmartGrid

There is no clear definition of the 'SmartGrid'. In a broad sense, this term refers to the electric power system that can coordinate and direct the network of electric power energy. Features of this system include the ability to integrate a large amount of renewable energy, to transmit electricity in both directions at the power grids and to manage information as well as energy.

Figure 1 shows the schematic view of a SmartGrid. Figure 1 is a diagram constructed in reference to official documents from the Ministry of Economy, Trade and Industry [1]. Electric power flow (green line) and information control (blue line) are both represented in Figure 1. The SmartGrid includes a large wind power plant, a large solar power plant and solar panels on each home and building, so that electric power can be transmitted bidirectionally. This feature allows the power grids to accept abundant electric power. However, there is a concern that power in the grids will become erratic. Thus, control using IT, an important feature of the SmartGrid, is needed. The control center connects the power grids and monitors the electric power status of every point on the grids through the network. The control center enables electric power stabilization so that power generation is promoted under conditions of energy scarcity, and electric power is stored in the storage facilities under conditions of energy overabundance. As explained above, the SmartGrid is technology that stabilizes the complicated flow of electric power using IT control.

2.2 Relationship between EVs and the SmartGrid

Next, we focus on the utilization of EV power in the SmartGrid. The EV is a vehicle that uses an electric motor instead of an internal combustion engine. In this research, we examine the EV as a source of energy supply and demand.

Recently, the EV has been proposed for use as not only a vehicle but also as a power resource that could charge and discharge energy as needed. This idea has been disseminated in SmartGrid research studies and referenced by the term 'V2G'. As EV technology has spread, a huge number of batteries have been

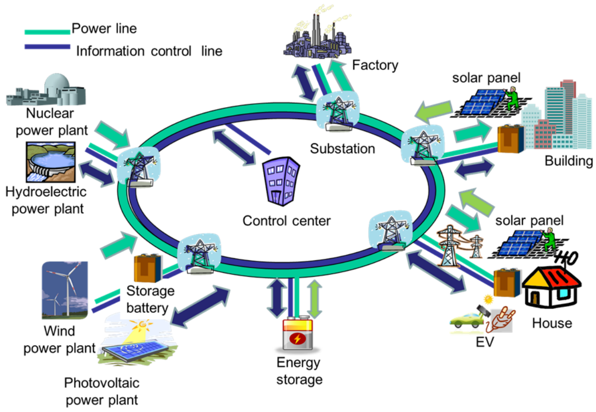

Fig. 1. SmartGrid

distributed in a variety of locations. It is possible to adjust the energy within the entire grid so that the EV batteries discharge in case of energy deficiency on the power grids and electric power is stored in EV batteries in case of an excess of energy on the power grids.

As described above, the use of IT energy stabilization control is indispensable to this system. However, it should be noted that electric power on the grids is subject to violent fluctuations because EVs move freely within the grid. In contrast to a case in which a fixed storage battery is connected to the grid, there are complicated power control issues when using EVs as a power source because EV batteries are worn out by repeated charging and discharging cycles excessively. In this paper, the effect of a solar power plant and EVs on power grids is examined via simulations in which the power output of the solar power plant and the number of EVs discharging at a given time are varied.

3 Research outline

The purpose of this research is to evaluate the efficient interaction of electric energy between EV batteries and the power grid using simulation.

Based on our research plan, a simulation is constructed that includes a large power grid connected to a power plant and EVs, and the operation of a system for assessment is then verified. Another system is added to manage data communications that adjust the electric power on a grid. Finally, a complex simulation system of the SmartGrid is constructed for final evaluation.

In this paper, we evaluate whether it is possible to perform voltage control through the SmartGrid as well as how much voltage control is appropriate by instructing the EVs to discharge based on the information from a monitor point, assuming that the control function for electric power adjustment operated correctly based on data communications. We set up a power flow simulation that considered output fluctuations from the solar power plant and the number of EVs connected to the home system as a function of time.

4 Experimental description

4.1 Experimental environment

The constructed experimental environment was based on a simulation platform by Open Distribution System Simulator (OpenDSS) [2] and a power grid model '8500-Node Test Feeder' provided by IEEE PES (Power & Energy Society) [3]. This power grid model has 8500 nodes and is approximately 10-15 km square. The grid computes power flow based on the specified load. In this model, a voltage source (115 kV, 3000 MVA) with a three-phase electrical power system and the substations to transform from 115 kV to 120/240 V via 7.2 kV are connected to the power grid. The power transmission method of each end node (120/240 V) is a split-phase electrical distribution system, and the load of each end point is 0.005-93.73 kW. The entire grid has a 10773 kW load, i.e., a load of approximately 2000 households.

4.2 Experimental outline

A solar power plant (2400 kW) at one point in a 7.2 kV area was connected to the power grid model introduced in Section 4.1.

Every end point (2354) in a 120/240 V area has one household, and 20% of the total number of households have a single EV attached. When the electric power on a grid fluctuates abnormally, charging and discharging the EV battery connected to each household stabilizes electric power within the entire grid. Figure 3 shows the model described above.

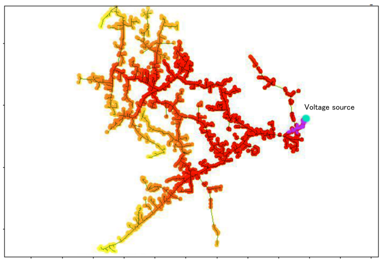

Fig. 2. 8500-Node Test Feeder

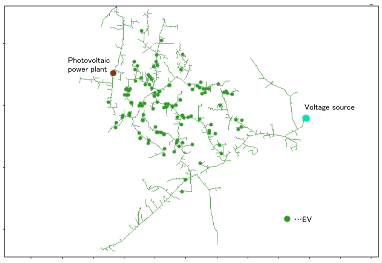

Fig. 3. Experimental system

In this experiment, we further evaluated a situation in which the output of the solar power plant decreased rapidly due to worsening weather. Figure 3 shows the power output of the solar power plant. This output curve was created by reference to data collected by the National Institute of Advanced Industrial Science and Technology (AIST) [4]. We assumed that the output power of the solar power plant drops to 0% during worsening weather. It is assumed that voltage fluctuations occur on the grid when the output from the solar power plant is reduced. Consequently, each EV battery is discharged to compensate for variations in solar power plant output, and electric power within the entire grid is stabilized.

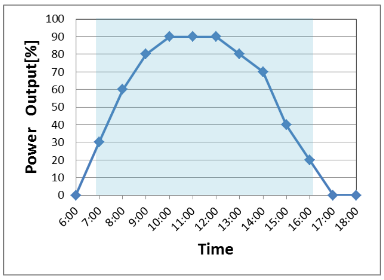

Fig. 4. Output of the solar power plant

5 Experimental result

The monitor points were observed to verify the voltage fluctuations present in the entire power grid resulting from the power output fluctuations at the solar power plant and discharge of EV batteries. The extent of voltage differences at each monitor point on the power grid was surveyed in cases of rainy and fine weather. We assumed that the voltage was within an adequate range if the voltage difference at each monitor point was -5 V or more with reference to each voltage in the case of fine weather. This range was determined based on the Regulations for Enforcement of the Telecommunications Business Law.

5.1 Voltage differences caused by weather changes

In this section, the monitor points at 1177 substations transforming electric power from 7.2 kV to 120/240 V were observed to verify voltage fluctuations present in the entire power grid resulting from the power output fluctuations at the solar power plant caused by changes in the weather. Figure 4 shows that each power output difference caused by changes in the weather occurs between 7:00 and 16:00. The simulation system then calculated the voltage difference at each point caused by changes in the weather over time.

Table 1 shows the proportion of the number of points where the voltage differences are identified within the adequate range. The voltage at each monitor point dropped to a lower value because the output power of the solar power plant decreased to 0% in the worsening weather. Between 8:00 and 15:00, the voltage at some points dipped below the adequate range. Therefore, EV discharge is necessary for electric power stabilization of the entire grid between 8:00 and 15:00.

Table 1. Proportion of the number of points within the adequate range

Time	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
points within normal limits[%]	100.0	82.9	63.4	57.4	57.4	57.4	57.4	68.3	96.8	100.0

5.2 Voltage stabilization via EV discharge

In this section, we performed a verification experiment for the reduction of dropped voltage on the entire grid caused by changes in the weather. Prior to this experiment, the change in the number of available EVs as a function of time was surveyed. In this experiment, only EVs connected to households that would not be used as transportation were used as voltage stabilization sources. For simplification, we assumed that EVs are mainly used for commuting.

We determined the change in the approximate number of EVs as a function of time based on 'Home arrival time distribute' collected by the National Household Travel Survey (NHTS 2001 [5]) and 'Departure Time to Work: 1990 - 2000' collected by the Federal Highway Administration (FHWA[6]).

Figure 5 shows the percentage of EVs connected to households as a function of time during the course of one day. We built the number of EVs connected to households into the simulation system and conducted a verification experiment to determine how many monitor point voltage drops could be reduced.

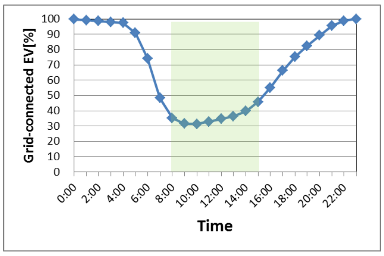

Fig. 5. Number of EVs connected to households over time

In this experiment, the battery capacity of each EV is 25 kWh, and each battery is fully charged. The output power of each EV is 5 kW, and all available EVs are discharged. Figure 6 through Figure 13 show experimental results. Each graph shows 1177 monitor points, for which voltage is observed is plotted on the abscissa and the voltage difference [V] is plotted on the ordinate axis. The range, colored in orange, shows the adequate range within which the voltage difference at each monitor point is -5 V or more with reference to each voltage in the case of fine weather. Each blue point represents the value of decreased voltage in the worsening weather, as described in Section 5.1, and each yellow point represents the voltage value with EV discharge during the same worsening weather. We can see that the voltage increases at every point. However, in these graphs, the voltage at some specific points has risen significantly; these points are nearest the point where the discharging EV is connected, and they are strongly influenced by EV discharge.

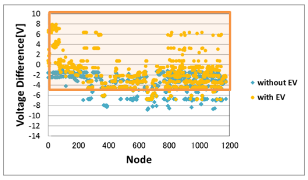

Fig. 6. Voltage difference (8 : 00)

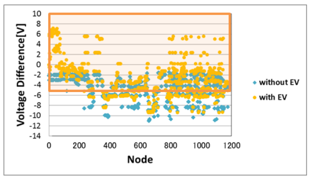

Fig. 7. Voltage difference (9 : 00)

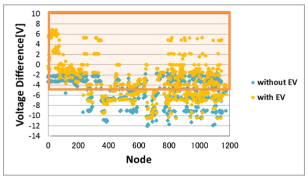

Fig. 8. Voltage difference (10 : 00)

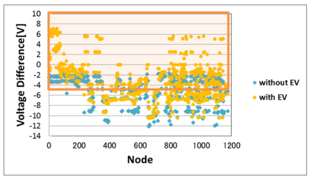

Fig. 9. Voltage difference (11 : 00)

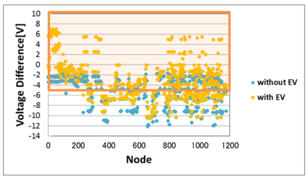

Fig. 10. Voltage difference (12 : 00)

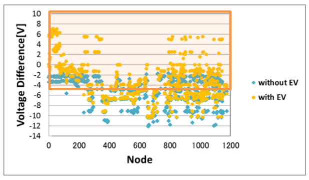

Fig. 11. Voltage difference (13 : 00)

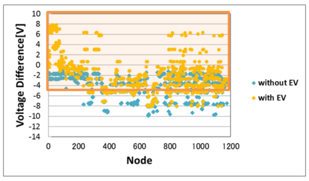

Fig. 12. Voltage difference (14 : 00)

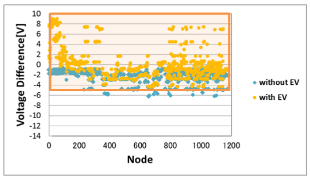

Fig. 13. Voltage difference (15 : 00)

5.3 Considerations

Table 2 shows the proportion of the number of monitor points at which the voltage difference in the worsening weather is within the adequate range for cases without EV and with EV output power at 5 kW.

Discharging EVs increase the proportion of the number of points where the voltage difference is within the adequate range. In this experiment, although the voltage at every monitor point in all situations could not be maintained within the adequate range, we expect that this problem could be solved by fine control of EV discharge. The voltages at those points nearest the discharging EVs were observed to increase significantly. Therefore, if this system can detect the point where the voltage has significantly dropped, it would be possible to

Table 2. Proportion of points within the adequate range with and without EV

Time	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00
without EV	82.9	63.4	57.4	57.4	57.4	57.4	68.3	96.8
with EV	93.7	70.2	61.9	62.0	63.6	64.5	79.4	100.0

effectively stabilize the voltage over the whole area by directing EVs to discharge near that point.However, not all conditions were considered in this simulated system. For example, the experimental environment can be affected by various factors, such as changes in the household load as a function of time and variable frequency of EV charging and discharging. It is also necessary to consider changes in the EV diffusion rate. The voltage on the grid will change as a result of these factors influencing the system. In the future, we aim to construct and verify a system that more closely resembles a real environment by including a management algorithm that can react quickly to changing conditions.

6 Conclusion and future studies

In this paper, we constructed a SmartGrid simulation system with a solar power plant and EVs. The effect of the solar power plant and EVs on the power grids was evaluated by changing the power output of the solar power plant and the number of EVs that discharged as a function of time. The efficient interaction of electric energy between the EV batteries and power grid was also examined using the simulation. Our results indicated that discharging EVs reduced the voltage drops observed on the entire grid that were caused by weather-related changes in solar plant power output.

In the future, factors to account for electric power fluctuations will be included in this simulation system to construct and verify a system that more closely models a real environment. Furthermore, we aim to construct a management center in the network to appropriately process and stabilize electric power on the entire grid and to verify and evaluate the SmartGrid system.

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References

1. Ministry of Economy, Trade and Industry http://www.meti.go.jp/
2. OpenDSS http://sourceforge.net/projects/electricdss/
3. IEEE PES http://www.ieee-pes.org/
4. Agency of Industrial Science and Technology Research Center for Photovoltaic Technologies
   http://unit.aist.go.jp/rcpvt/ci/index.html
5. National Household Travel Survey http://nhts.ornl.gov/
6. Federal Highway Administration http://www.fhwa.dot.gov/