Power System Frequency Regulation Based on Vehicle-to-Grid

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Abstract. A static frequency characteristic model of electric vehicle charging and discharging was established, and a corresponding strategy is proposed to realize the role transition of electric vehicle between distributed generation and controllable load. Load frequency control models for single-area and two-area interconnected power systems are established. Simulation studies show that electric vehicles can not only effectively improve the frequency stability of the power system, but also significantly reduce the reserve capacity of traditional frequency modulation units.

Keywords: Vehicle-to-Grid, Load Frequency Control, Frequency Regulation of Power System

1. Introduction
Renewable energy output has strong volatility, which is a big challenge for the stable operation of future power system. With development of electric vehicles, advancement of V2G (vehicle-to-grid) technology and government's policy support, the above problem is expected to be solved. Therefore, the research on electric vehicles for frequency regulation in power system becomes especially important. This article studies the rational use of V2G technology in electric vehicles for charging and discharging to provide frequency regulation assistance services for power systems.

2. Development Status
Due to the fast frequency response of electric vehicles, their participation in grid frequency regulation can achieve good results [1]. Furthermore, electric vehicles were proposed as a new type of hot standby equipment, which can quickly suppress load disturbances. It will become an important means of frequency regulation for low-carbon electric power systems in the future [2]. In 2007, the Delaware University in the United States enabled electric vehicles to successfully participate in the frequency regulation of actual power systems under the PJM electricity market environment [3]. Taking electric vehicles and various controllable household appliances as research objects, the method of tracking frequency signals is used to conclude that they participate in the secondary frequency regulation of power system in a centralized control group manner [4]. In Danish, electric vehicles participating in frequency regulation will significantly reduce the frequency response reserve capacity of traditional frequency modulation units.
3. Methodology

3.1. Fundamental
The primary frequency regulation is performed by the speed regulator of the generator set. The secondary frequency regulation is performed by the frequency regulator, which is shown in Fig. 1. And the third frequency regulation is performed by the load curve.

![Figure 1. Secondary frequency regulation](image)

3.2. Automatic Generation Control (AGC)
The computer and the automatic control device perform secondary frequency modulation on the power system to realize automatic power generation control. The control center obtains information about the frequency in the power system, the output of the generator set, and so on. If there is a deviation in the frequency, the control center can obtain the area control error (ACE) signal after measurement and calculation by the corresponding computer software, in order to determine the change value of the frequency response power. Then the change value of the power is transmitted through the downlink of the communication system channels are assigned to each frequency modulation generator set. AGC has three control modes: Flat Frequency Control (FFC), Flat Tie-line Control (FTC), and Tie-line Bias Control (TBC). And there are six combinations of automatic power generation control modes for the two interconnected systems.

In the interconnected power system, the TBC-TBC control mode is usually adopted. If the control parameters of each subsystem are selected properly, no matter which subsystem the load disturbance occurs, when the system frequency fluctuates in a small range, except for the one-time regulation of the frequency by each subsystem, only the subsystem where the load disturbance occurs will have a secondary regulation to the frequency, and other subsystems that do not experience load disturbance will not have a secondary regulation to the frequency.

3.3. Load Frequency Control Model Considering Electric Vehicle Charging and Discharging
The load frequency control model is mainly composed of generator-load model, prime mover model, governor model, auxiliary control model and tie line model. The power system is a complex non-linear dynamic system. Because the power system only exposes small load changes during normal operation, a linearized model is used to represent the system dynamics near the operating point. In the following, it is simplified to a low-order linear model, and the models are all represented by transfer functions [5], which are shown in Table 1.
### Table 1. Traditional load frequency control model.

| Model          | Equation                                                                 | Block Diagram of Transfer Function |
|----------------|--------------------------------------------------------------------------|------------------------------------|
| Generator-Load | $\Delta P_m(s) - \Delta P_L(s) = (M_s + D) \Delta \omega_r$           | ![Block Diagram](block-diagram.png) |
| Reheat Turbine | $\Delta Y = \frac{1 + s T_{ch}}{(1 + s T_{ch})} \Delta P_{rd}$          | ![Block Diagram](block-diagram.png) |
| Non-reheat Turbine | $\Delta Y = \frac{1}{1 + s T_{ch}} \Delta P_{rd}$                   | ![Block Diagram](block-diagram.png) |
| Governor       | $K \Delta P_r + \int ACE \, dt = 0$                                   | ![Block Diagram](block-diagram.png) |
| Auxiliary Control | $\Delta f/ACE = \frac{K_e}{s}$                                     | ![Block Diagram](block-diagram.png) |
| Tie-line       | $\Delta P_{12}(s) = \frac{T}{s} [(\Delta \omega_1(s) - \Delta \omega_2(s)]$ | ![Block Diagram](block-diagram.png) |

*H: generator inertia constant (standard threshold value), $M=2H$, $D$: load damping constant, $K$: frequency modulation power scaling factor, $ACE$: Area Control Error, $T$: synchronization factor.

The static frequency characteristic model of electric vehicle discharge is composed of first-order inertia link and discharge frequency response coefficient. This is shown in equation (1):

$$\Delta P_d = \frac{K_d}{1 + s T_d} \Delta \omega$$ (1)

In the equation (1): $\Delta P_d$: power change, $K_d$: frequency response coefficient, $T_d$: time constant.

Its charging static frequency characteristic model is similar to that during discharging, and it consists of a first-order inertia link and the load damping coefficient. This is shown in equation (2):

$$\Delta P_c = \frac{D_c}{1 + s T_c} \Delta \omega$$ (2)

In the charge equation (2): $\Delta P_c$: power change, $D_c$: load damping coefficient, $T_c$: time constant.

In order to achieve the goal of coordinated charging and discharging control of electric vehicles, electric vehicles need to realize synchronous charging and discharging. This can be achieved through a hierarchical dispatch center, which is shown in Fig. 2. And a large number of electric vehicles are equivalent to a virtual battery energy storage system, thereby achieving synchronous control of controllable electric vehicle charging and discharging.
4. Analysis and Results

4.1. Disturbances Occur in a Single Area
It is assumed that the number of electric vehicles connected to the power grid is sufficient, and the total energy storage of the batteries can meet the constraints of power and capacity. It is assumed that the charge and discharge conditions of the battery are similar, and the effects of battery aging and ambient temperature on charge and discharge are not considered.

When a load disturbance occurs, the comparison of system frequency deviations with and without V2G in a single-region system is shown in Fig. 3. In the two-region interconnected power system, the comparison of system frequency deviations with and without V2G in region A is similar to the above.

4.2. Disturbances Occur in Two Areas
The frequency fluctuation in the area A is similar to the frequency fluctuation in the area B. The following areas are indicated by A. The frequency deviation in area A is similar to Fig. 3, and the power of the tie line is shown in Fig. 4.
Figure 4. Tie-line power

5. Conclusion
When the power system load disturbance occurs, through the hierarchical dispatch control method, the electric vehicle can effectively switch between the two roles of distributed power and controllable load, so as to reasonably charge and discharge to participate in frequency modulation. The electric vehicle participating in the system frequency modulation can not only make the system frequency regulation faster, effectively reduce the system frequency deviation, but also reduce the reserve capacity of the traditional frequency modulation unit.

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