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A Unified Management and Control Model of Demand-Side Resources

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Abstract

A unified management and control model is developed to investigate the response capacity and rapid response capability of different demand-side resources. Firstly, the state models of distributed generations (DGs), electric vehicles (EVs) and thermostatically-controlled loads (TCLs) are established. Then a unified state model of different demand resources is developed for power management and control is developed. A test case is used to validate the effectiveness of the unified management and control model.

Keywords: Distributed generation (DG); Electric vehicle (EV); Thermostatically-controlled load (TCL); Demand-side resource

1. Introduction

In recent years, there have been growing interests in the flexibility of the demand-side resources (e.g., distributed generations (DGs), electric vehicles (EVs), thermostatically-controlled loads (TCLs) [1]. The demand-side resources are able to serve as the energy storage system to provide ancillary services, such as the load shaping [2], the frequency regulation [3] and the voltage stability [4], for the power grid. The aggregator of the demand-side resources is able to manage and control the available resource units in its function region. However, due to their different response characteristics, there have not been a unified management and control model for describing different demand resources. In order to obtain the response capacity and realize the power control uniformly of different types of demand-side resources, a unified state model for power management and control is rather important.

In this paper, a unified management and control model for demand-side resources is developed to investigate the response capability of different kinds of resources. The state models of the DGs, the EVs and the TCLs at the demand side are established to describe the response characteristic of each resource unit. Based on the state models of different resources, the unified management and control model for the demand-side resources is developed. This model is able to obtain the response capacity and realize the power management and control of different demand resources.

2. Framework of Unified Management and Control Model

The hierarchical framework of the unified management and control model for demand-side resources in one function region is shown in Fig. 1. An aggregator is assumed to be responsible for managing the exchanged power of different kinds of demand resources. Although the response capacity of one resource unit is small, the aggregated capacity of a number of demand resources managed by the aggregator is considerable. The demand resources, such as the DGs, the EVs and the household TCLs, are able to supply part of loads under the demand resource aggregator. The aggregator acquires the information flow

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including the resource type, the exchanged power and the operation status of demand resources, which is mention in the following sections. According to the information, the power demand of the power grid is then calculated and allocated to all the available resources. These resources follows the control signal from the aggregator, and the control for the exchanged power of these resources is realized.

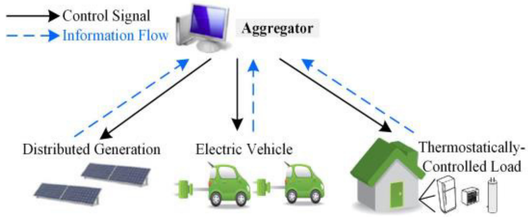

Fig. 1. Framework of the unified management and control model for demand-side resources.

3. Demand-Side Resource Modelling

3.1. State model of DG

DG, such as the rooftop photovoltaic panels and the small-size wind turbines, inject power to the distribution network. The state model of the distributed generation is given by (1).

$$E^{G}_{j,t+\Delta t} = E^{G}_{j,t} + P^{G}_{j,t}\cdot \Delta t / Q^{G}_{j} = E^{G}_{j,t} + P^{G}_{j,t}\cdot \left(\Delta t / Q^{G}_{j}\right) \tag{1}$$

where $E^{G}_{j,t}$ is the state of the accumulated energy provided by the DG j at time t; $P^{G}_{j,t}$ is the exchanged power (i.e., the power generation), and $\overline{P}^{G}_{j}$ is the generation limitations of $P^{G}_{j,t}$ ($0 \le P^{G}_{j,t} \le \overline{P}^{G}_{j}$); Δt is the time interval for simulation; Q^{G}_{j} is the accumulated energy with rated power generation calculated by (2).

$$Q^{G}_{j} = P^{G}_{j,rated}\cdot T \tag{2}$$

where is $P^{G}_{j,rated}$ the rated power generation; T is the simulation cycle (i.e., one day).

3.2. State model of EV

For a grid-connected EV, the operation area (shaded area shown in Fig. 2) is limited by the power generation limitations and the state of charge (SOC) limitations. Points *A*, *B*, *C*, *D*, *E* and *F* are used to obtain the upper and lower limitations of the operation area. The upper limitation follows the path of *A*-*B*-*C*, on which the EV j is charged at the rated charging power as soon as it plugs in at $t^{EV}_{j,s}$ until the SOC upper limitation ($\overline{SOC}^{EV}_{j}$) is reached (from points *A* to *B*). The lower limitation follows the path of *A*-*D*-*E*-*F*, on which the EV j is discharged at the rated discharging power as soon as it plugs in at $t^{EV}_{j,s}$ until the SOC lower limitation ($\underline{SOC}^{EV}_{j}$) is reached (from points *A* to *D*) and the EV j is charged at the rated charging power (from points *E* to *F*) to reach the minimum desired SOC ($SOC^{EV}_{j,d}$) at $t^{EV}_{j,d}$.

To standard the SOC value, $S^{EV}_{j,t}$ ($0 \le S^{EV}_{j,t} \le 1$) refers to the normalized SOC of EV j, which is determined by (3). When connected to the distribution network, the state model of one EV is given by (4).

$$S^{EV}_{j,t} = \left(SOC^{EV}_{j,t} - \underline{SOC}^{EV}_{j}\right) \Big/ \left(\overline{SOC}^{EV}_{j} - \underline{SOC}^{EV}_{j}\right) \tag{3}$$

where $SOC^{EV}_{j,t}$ is the SOC value of EV j at time t.

$$S^{EV}_{j,t+\Delta t} = S^{EV}_{j,t} - P^{EV}_{j,t}\cdot \Delta t / Q^{EV}_{j,r} = S^{EV}_{j,t} + P^{EV}_{j,t}\cdot\left(-\Delta t / Q^{EV}_{j,r}\right) \tag{4}$$

where $Q^{EV}_{j,r}$ is the battery capacity after correction calculated by (5); $P^{EV}_{j,t}$ is the exchanged power with distribution network ($\underline{P}^{EV}_{j} \le P^{EV}_{j,t} \le \overline{P}^{EV}_{j}$); $\underline{P}^{EV}_{j}$ is the charging power limitation with a negative value; $\overline{P}^{EV}_{j}$ is the discharging power limitation with a positive value, and $\overline{P}^{EV}_{j}$ is assumed to be equal to -$\underline{P}^{EV}_{j}$.

$$Q^{EV}_{j,r} = \begin{cases} \left(Q^{EV}_{j}\cdot \eta^{EV}_{j,c}\right) \Big/ \left(\overline{SOC}^{EV}_{j} - \underline{SOC}^{EV}_{j}\right), & P^{EV}_{j,t} < 0 \quad \text{Charging} \\ \left(Q^{EV}_{j} / \eta^{EV}_{j,d}\right) \Big/ \left(\overline{SOC}^{EV}_{j} - \underline{SOC}^{EV}_{j}\right), & P^{EV}_{j,t} > 0 \quad \text{Discharging} \end{cases} \tag{5}$$

where Q^{EV}_{j} is the actual battery capacity; $\eta^{EV}_{j,c} / \eta^{EV}_{j,d}$ is the charging/discharging efficiency.