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Robust load scheduling in a smart home with photovoltaic system

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Abstract

A robust optimization model was proposed for smart home load scheduling to tackle the uncertain challenges brought by PV system, in which an adaption parameter, Γ, is defined to control the robust level of the final optimal solution. The proposed robust optimization is capable of producing load schedules with different electricity cost and robust levels. Final decisions can be made as a tradeoff according to users' financial situation and risk preference.

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1. Introduction

In the future, energy sources of smart homes will be more diverse. Besides electricity from the bulk power grid, more and more distributed generation using renewable energy will be encouraged to be installed in smart homes. Household photovoltaic (PV) system is an important type of renewable distributed generation, which converts solar energy to electrical power for residential users. However, the integration of PV system presents new challenges to smart home energy management because of the randomness of solar energy. [1-3] involved PV system in the optimization of smart home energy services, but did not consider the forecast uncertainty of its power output. [4] concluded that there is no value in making accurate solar insolation forecasts when the feed-in tariff equals to the time-of-use tariff exactly at every minute of the day, whereas that is a quite special scenario and the real situations are far more diverse and complicated in different places all around the world. [5] tackled the forecast error of PV system output by online adapting the operation schedule during the execution, but only heuristic rules are referred when making the adaption, which is not the optimal way. [6] took the lower limit of the 95%

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confidence interval for the solar irradiance forecast in the optimization, through which the schedule was robust but only the worst situation was considered. In this paper, an alternative robust optimization model was proposed for household load scheduling to tackle the uncertain challenges brought by PV system.

2. Problem formulation

2.1. Device model

According to the controllability, the loads are divided into controllable loads and noncontrollable loads. Noncontrollable loads cannot be scheduled and thus are modeled by fixed power curves over the scheduling horizon. Controllable loads can be divided into three categories: interruptible loads, noninterruptible loads and thermostatically controlled loads. Device model and comfort constraints for the three categories of controllable loads are presented as follows:

1) Interruptible Loads

An interruptible load is allowed to begin to work after t_b, and its task is required to be finished no later than t_e. The power consumption of interruptible loads is assumed to be constant, and the duration of the task consists of L_{IL} time steps. Thus, the on/off status of an interruptible load throughout the scheduling horizon should satisfy

$$I_{\mathrm{IL},i} = 0 \qquad \forall i \in [1,\mathrm{b}] \cup (\mathrm{e},\mathrm{N}],\ i \in \mathbf{N}^{+} \tag{1}$$

and

$$\sum_{i=\mathrm{b}}^{\mathrm{e}} I_{\mathrm{IL},i} = \mathrm{L}_{\mathrm{IL}} \quad i \in \mathbf{N}^{+} \tag{2}$$

where N represents the total number of time steps throughout the scheduling horizon (usually one day), $I_{\mathrm{IL,i}}$ is the on/off status of the interruptible load at the *i*th time step ("1" for "on", "0" for "off"), and $\mathbf{N}^{+}$ represents the set of all positive natural numbers.

2) Noninterruptible Loads

Noninterruptible loads differ from interruptible loads in the fact that the operation of a noninterruptible load is not allowed to be stopped once it starts. Therefore, not only satisfy (1) and (2), but also an additional constraint should be satisfied: [7]

$$\sum_{i=j}^{j+\mathrm{L}_{\mathrm{NL}}-1} I_{\mathrm{NL},i} \geq (I_{\mathrm{NL},j} - I_{\mathrm{NL},j-1}) \cdot \mathrm{L}_{\mathrm{NL}} \quad \forall j \in (\mathrm{b}, \mathrm{e} - \mathrm{L}_{\mathrm{NL}} + 1],\ i, j \in \mathbf{N}^{+} \tag{3}$$

where $I_{\mathrm{NL,i}}$ is the on/off status of the noninterruptible load at the *i*th time step, and L_{NL} is the number of time steps for which the noninterruptible load has to work.

3) Thermostatically Controlled Loads

Thermostatically controlled loads are interruptible but with unique characteristics. Water heaters, air conditioners and refrigerators are three typical appliances of thermostatically controlled loads. In the following, a water heater with hot water storage is chosen to demonstrate the modeling process. The thermal dynamic behavior of the water heater is described by [8]

$$\theta_{i+1} = \theta_{\mathrm{en},i} - (\theta_{\mathrm{en},i} - \theta_i)\exp(-\Delta \mathrm{t}/(RC)) + I_{\mathrm{TCL},i} \cdot QR(1 - \exp(-\Delta \mathrm{t}/(RC)) \qquad \forall i \in [0,\mathrm{N}) \cap \mathbf{N}^{+} \tag{4}$$

where θ_i is the temperature of the water in the hot water storage at the *i*th time step, $\theta_{\mathrm{en},i}$ is the environmental temperature at the *i*th time step, $I_{\mathrm{TCL},i}$ is the on/off status of the water heater at the *i*th time step, Q, R and C are heater capacity, thermal resistance and thermal capacitance of the water heater respectively. When hot water is consumed, the water temperature should be modified by [8]

$$\theta_i = (\theta_{\mathrm{cur},i}(\mathrm{M} - d_i) + \theta_{\mathrm{en},i} d_i)/\mathrm{M} \quad \forall i \in [1,\mathrm{N}] \cap \mathbf{N}^{+} \tag{5}$$

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