Research on Optimal Scheduling of Home Energy Management System Based on NSGA III Multi-Objective Optimization Algorithm

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Abstract. With the rapid development of smart grid, more and more scholars pay attention to the Home Energy Management System (HEMS). In order to reduce the user's electricity cost and improve the user's electricity comfort, this paper proposes a multi-objective optimization strategy of HEMS based on NSGA III multi-objective optimization algorithm. First of all, this paper designs the basic structure of the HEMS, and builds the temperature-controlled load model, the uninterruptible load model, the photovoltaic power generation model and the battery and electric vehicle model. Then, the improved NSGA III multi-objective optimization algorithm is used to solve the model, and the working state of the schedulable load and the output power of the photovoltaic system are obtained in each period. Finally, the simulation results show that the scheme can effectively reduce the user's electricity cost and improve the user's electricity comfort. At the same time, the proposed optimal scheduling strategy can also achieve the optimization goal of the HEMS, which proves that the strategy can provide the safe and reliable optimal electricity consumption mode for the home.

1. Introduction
With the rapid development of the global economy and the increasing demand for electricity, the world energy crisis and global warming are becoming increasingly serious. At the same time, the emergence of smart grid in people's vision provides a new development space for the power industry[1,2]. As an important part of smart grid, users play an important role in improving the efficiency of grid operation, and are gradually changing their roles into active participants. The HEMS has developed rapidly because of its favorable economy and reliability in terms of user needs[3,4]. Residents can use various information in HEMS to reasonably arrange electricity consumption. HEMS undertakes the important tasks of rationally optimizing electricity, reducing peak demand, and responding to user demand side response[5].

In recent years, the problem of modeling and optimization of HEMS has received extensive attention, and scholars at home and abroad have achieved rich research results. The reference[6] introduced a new HEMS by self-consumption of photovoltaic energy to reduce daily home energy costs and maximize user benefits. The results show that although the model can greatly increase the user's income, the utilization rate of new energy is not high, and the peak-shaving effect is not obvious. The reference[7] combined with distributed energy resources and energy storage systems and proposed a simple and efficient real-time smart home energy system, reducing the energy cost of...
household appliances. However, this model has high requirements on family intelligence and strict technical requirements.

2. NSGA III Multi-objective Optimization Algorithm

The NSGA III multi-objective optimization algorithm is a non-dominated sorting multi-objective optimization algorithm based on reference points. It follows the framework of NSGA II optimization algorithm. The general multi-objective optimization problem consists of $N$ objective functions, $M$ decision variables, and several constraints. The objective function, constraints, and decision variables are functional relationships. Because of the superiority of NSGA III multi-objective optimization algorithm for solving multi-objective function equations, it is widely used in solving multi-objective problems.

![Figure 1. The main frame flow chart of NSGA III algorithm](image)

3. Model

3.1. Model of HEMS

The HEMS is an intelligent control system, which is mainly composed of temperature-controlled load, uninterruptible load, battery energy storage system and photovoltaic system. With the development of HEMS and the improvement of automation and intelligence, the compatibility of various loads in the home will become better. In this paper, photovoltaic power generation system is used as a new energy power generation system, which, together with energy storage equipment, constitutes a hybrid power generation system to guarantee the electricity demand of residential users, and also increases the flexibility of dispatching. Its structure is shown in figure 2.
3.1.1. Temperature-controlled Load Model.
This paper takes the air conditioning load as an example to study the effect of temperature-controlled load on HEMS. The thermodynamic model of the air conditioner is:

\[
T_{\text{room}}(t) = T_{\text{room}}(t-1) e^{-\frac{\Delta t}{R_C C}} + (T_{\text{out}}(t-1) - x_{\text{air}}(t-1)) \times Q \times R \left(1 - e^{-\frac{\Delta t}{R_C C}}\right)
\]

\[
x_{\text{air}}(t) = \begin{cases} 
1 & T_{\text{room}}(t) > T_{\text{room,max}} \\
T_{\text{room,min}} \leq T_{\text{room}}(t) \leq T_{\text{room,max}} & 0 \\
T_{\text{room}}(t) < T_{\text{room,min}} & 0 
\end{cases}
\]

\[
P_{\text{air}}(t) = x_{\text{air}}(t) \times P_{\text{air}}^N
\]

Where, \(T_{\text{room}}(t), T_{\text{air}}(t)\) are the indoor temperature and outdoor temperature in the period \(t\); \(T_{\text{room,min}}, T_{\text{room,max}}\) is the minimum and maximum indoor temperature set by the user; \(x_{\text{air}}(t)\) is the start-stop status of the air conditioner during the period \(t\), 1 means start, 0 means stop; \(P_{\text{air}}(t), P_{\text{air}}^N\) is the running power and rated power of air conditioner during the period \(t\); \(\Delta t\) is a scheduling period; \(R_C, C\) and \(Q\) are the equivalent thermal resistance, equivalent thermal capacitance and equivalent thermal ratio respectively.

3.1.2. Uninterruptible Load Model

\[
x_a(t) = \begin{cases} 
t_{\text{off},a} - t_{\text{on},a} + 1 & \text{if } t \in [t_{\text{on},a}, t_{\text{off},a}] \\
1 & \text{if } t \not\in [t_{\text{on},a}, t_{\text{off},a}] 
\end{cases}
\]

\[
P_a(t) = x_a(t) \times P_a^N
\]

Where, \(t_{\text{on},a}\) and \(t_{\text{off},a}\) represent the start and stop time of load \(a\) respectively; \(d_a\) is the number of continuous operation periods of load \(a\); \(x_a(t)\) is the working state of load \(a\), 1 means work, 0 means stop; \(P_a(t)\) and \(P_a^N\) are the running power and rated power of load \(a\) during the period \(t\) respectively.
3.1.3 Photovoltaic Power Generation Model.
The output power of the photovoltaic power generation system is related to solar radiation, and its output model can be expressed as follows:

\[
G(t) = P_{W_N} \times N_{PV} \times \frac{\mu(t)}{\mu_{ref}} \times \left[1 + 0.005(T(t) - T_{ST})\right]
\]  

(3)

Where, \(G(t)\) is the power of the photovoltaic power generation system at time \(t\); \(P_{W_N}\) is the rated power of photovoltaic power generation; \(N_{PV}\) is the number of photovoltaic panels; \(\mu(t)\) is the actual light intensity at time \(t\); \(\mu_{ref}\) is the light intensity under standard test conditions, generally 1000W/m²; \(T(t)\) is the surface temperature of the photovoltaic panel at time \(t\); \(T_{ST}\) is the standard test temperature, generally 25ºC.

3.1.4 Battery and Electric Vehicle Model

\[
SOC_{bt}(t) = \begin{cases} 
SOC_{bt}(t-1) + \frac{P_{bt}^{ch}(t-1) \times \Delta t \times \eta_{bt}^{ch}}{Q_{bt}} & \text{charging} \\
SOC_{bt}(t-1) + \frac{P_{bt}^{dis}(t-1) \times \Delta t}{Q_{bt} \times \eta_{bt}^{dis}} & \text{discharging}
\end{cases}
\]  

(4)

Where, \(SOC_{bt}(t)\) is the state of charge of the battery at time \(t\); \(Q_{bt}\) is the capacity of the battery; \(P_{bt}^{ch}(t)\) and \(P_{bt}^{dis}(t)\) are the charging power and discharging power of the battery at time \(t\), respectively; \(\eta_{bt}^{ch}\) and \(\eta_{bt}^{dis}\) are the charging efficiency and discharging efficiency of the battery, respectively. When the electric vehicle is connected to the home micro-grid is basically the same as that of the battery, so it will not be described here.

4. Case Study

This article selects the electricity consumption in a certain area in summer as an example, divides 24 hours (0:00-24:00) into 96 times quantum, and sets 15 minutes as a time interval to make the time unit short enough so that it is applicable to the operation interval of all household appliances.

Based on the temperature control load model, uninterruptible load model, photovoltaic power generation model, battery and electric vehicle model constructed in this paper, the NSGA III algorithm is used to iteratively optimize the multi-objective energy scheduling optimization problem, and the multi-objective optimization Pareto optimal solution is obtained. Simulation verification through MATLAB. Using the optimization strategy proposed in this paper, the distribution of household load before and after optimization and the distribution curve of electricity purchase costs are shown in figure 3 and figure 4, respectively.
5. Conclusion
Considering that HEMS has the ability to optimize and control the demand response resources of household appliances with various power consumption characteristics, this paper is based on distributed roof photovoltaic power generation, energy storage batteries and time-sharing electricity prices, and optimizes the user's economy as the optimization goal, while taking into account the user comfort, this paper proposes an optimized scheduling strategy based on NSGA III multi-objective optimization algorithm, which can maximize the comprehensive benefit of the family. The case analysis shows that the optimized scheduling strategy proposed in this paper can not only make full use of the load response potential of household appliances and battery charging and discharging capacity, but also promote the local consumption of distributed roof photovoltaic on the premise of ensuring user satisfaction and user electricity cost.
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