International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 463

HOME ENERGY MANAGEMENT SYSTEM BASED ON IMPROVED GENETIC ALGORITHM AND MULTI-OBJECTIVE FUNCTION

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ABSTRACT

In order to realize the economic operation of the home energy management, the electricity cost of user needs to be reduced and user-side satisfaction should be improved. A home energy scheduling optimization model including the home electricity load model and the photovoltaic power generation model was constructed, the objective function was established, which takes minimizing the electricity cost and the user satisfaction into consideration. With the constraints of power balance, load working time and temperature control load. Finally, combining genetic algorithm with local optimization method, a hybrid Pareto genetic algorithm for multi-objective optimization is proposed to obtain the approximate solution of multi-objective function. Based on the simulation results of MATLAB platform, the optimal solution which both minimizes electricity cost and maximizes user's satisfaction has been obtained.

Keywords: House energy management, Genetic algorithm, Multi-objective function, Optimization

1. INTRODUCTION

In recent years, society has put forward an increasingly high demand for power supply stability and power quality reliability, which has brought many new problems to the development of the power grid [1]. As the development of smart grids and the widespread application of renewable energy such as photovoltaics, the Home Energy Management System (HEMS) is constructed and its energy scheduling is optimized which make the electricity consumption of user-side more reasonable for the house and valid improve their electricity efficiency. The literature[2] classifies the electricity load in detail according to the residential electricity consumption cost and load peak-valley difference but does not consider the satisfaction of electricity users. In literature[3], the household load model established by using renewable energy and storage battery is relatively simple, and the relationship between user satisfaction and user power cost is not fully considered.

To sum up, this paper proposes a home energy management scheduling model that gives consideration to household load classification and photovoltaic power generation while fully considering the factors of minimizing electricity cost and maximizing customer satisfaction.

Since the genetic algorithm was first applied to multi-objective optimization in 1985, the research in this field has been developing continuously and various improved genetic multi-objective optimization algorithms have been proposed[4]. The sub-population co-evolution method is used to improve the efficiency of finding the most solution set, but this method has the disadvantage that the common search of multiple groups makes the search efficiency slow[5]. Genetic algorithm (GA) performs the evolutionary operation on the whole population which focuses on the collection of individuals and could obtain a large number of Pareto optimal solutions corresponding to different weight distribution situations at one time. Although it has stronger applicability and flexibility, it has disadvantages such as poor local search ability and precocious convergence. In order to enhance the local search ability of GA, a hybrid Pareto genetic algorithm (HPGA) for multi-objective optimization was proposed by combining GA with direct search method[6].

2. BASIC PORTFOLIO MODEL OF HOME ENERGY MANAGEMENT

2.1 *Photovoltaic cell model*

The power generation of photovoltaic cells is affected by many factors. The output power equation of the photovoltaic panel is shown as follow[7]:

$$P_{\mathrm{PV}}^{t}=n_{\mathrm{PV}}\eta_{\mathrm{PV}}S_{\mathrm{PV}}I_{\mathrm{PV}}\left[1-0.005\left(T_{\mathrm{out}}^{t}-T_{\mathrm{stc}}\right)\right] \tag{1}$$

where P_{PV}^{t} is the photovoltaic panel output power; n_{PV} is the number of photovoltaic panels; η_{PV} is the photoelectric conversion efficiency of photovoltaic cells (%); S_{PV} is the area of the photovoltaic panel (m^2); I_{PV} is the solar radiation intensity ($\mathrm{kW/m}^2$); T_{out}^{t} is outdoor temperature (°C), ambient temperature T_{stc}=25℃.

2.2 *Load model*

Due to a large number of household users, the types of the electricity load of each household are quite different. In order to make the home energy management system have wide applicability, it is necessary to classify the household electricity load according to the characteristics of the electricity load, the demand of the use of the load, the operation characteristics of the load, and other factors.

2.2.1 Necessary load

The necessary class load usually refers to the load that is very important to the user. In the home energy management system, the electricity demand has the highest priority which should be considered at first. The working model can be expressed as [3]:

$$\begin{cases} P_i^c = x_i^c P^{c,\text{ rated}} \\ E^c = P^{c,\text{ rated}} d^c \end{cases} \tag{2}$$

where $c \in C$ is the necessary load, P_i^c is the working power of the necessary class load *c* at time i^{th}. x_i^c is the working state of the necessary class load *c* at time i^{th}. $P^{c,\text{ rated}}$ is rated power of the necessary class load *c*. E^c is the total power consumption of the necessary class load *c*, d^c is working time of necessary class load *c*

2.2.2 Transferable load

The transferable class load has the characteristics of flexible use of electricity. The transfer of this kind of load type is realized on the basis of sacrificing certain user satisfaction. The working model can be expressed as[3]:

$$\begin{cases} P_i^s = x_i^s P^{s,\text{ rated}} \\ E^s = P^{s,\text{ rated}} d^s \\ x_i^s = \begin{cases} 1, i \in H_s \\ 0, i \notin H_s \ \& i \in R_s \end{cases} \\ s \in S \end{cases} \tag{3}$$

where $s \in S$ is the transferable load, P_i^s is the working power of the transferable class load s at time *i*, x_i^s is the working state of transferable class load s at time *i*, $P^{s,\text{ rated}}$ rated power of transferable class load *s*, E^s is the total power consumption of transferable class load s, d^s is the working hours of transferable class load *s*, H_s working time interval of transferable load *s*, R_s applicable time interval for transferable load *s*

2.2.3 Air conditioning load

The air conditioning system model is mainly composed of two parts which include the air conditioning room heat transfer model and the air conditioning model[3].

(1) Model of heat transfer in the air-conditioned room

$$\frac{dT_i^{\mathrm{r}}(t)}{dt}+\frac{T_i^{\mathrm{r}}(t)}{M_{\mathrm{air}}\cdot c\cdot R_{\mathrm{eq}}}=\frac{Q_i^{\mathrm{h}}}{M_{\mathrm{ar}}\cdot \mathrm{c}}+\frac{T_i^{\mathrm{out}}(t)}{M_{\mathrm{air}}\cdot c\cdot R_{\mathrm{eq}}} \tag{4}$$

where $T^{\mathrm{r}}(t)$ is the temperature at room time t, M_{air} is the quality of air in the room, c is the specific heat capacity of indoor air, R_{eq} equivalent thermal resistance of the room, Q^{h} air conditioning cooling capacity at time t, $T^{\text{ out}}(t)$ is the outdoor temperature in t time.

(2) Air conditioning model

When the set temperature is maintained, the relationship between the operating state of the compressor of the air conditioner and the set temperature can be expressed as:

$$G\left(t_i\right)=\begin{cases} 1 & T\left(t_i\right)\geq T_{\mathrm{set}}+\varepsilon/2 \\ 0 & T\left(t_i\right)\leq T_{\mathrm{set}}-\varepsilon/2 \\ G\left(t_{i-1}\right) & T_{\mathrm{set}}+\varepsilon/2\geq T\left(t_i\right)\geq T_{\mathrm{set}}-\varepsilon/2 \end{cases} \tag{5}$$

3. MULTI-OBJECTIVE OPTIMIZATION MODEL FOR HOME ENERGY MANAGEMENT

3.1 The goal of HEMS

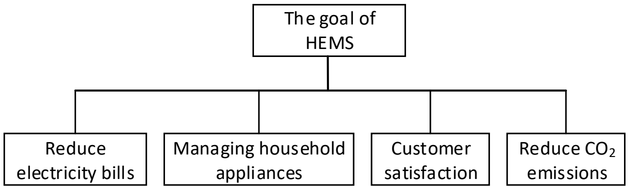

Fig.1. The goal of HEMS

3.1.1 Minimize user electricity costs

The electricity cost in the family is mainly composed of three aspects: the electricity fee to be paid from the power company, the income from selling electricity to the power company, and the state subsidy for photovoltaic power generation. The objective function is as follow[5]:

$$\min Cost=\sum_{i=1}^{24}\left[C_1(t)-C_2(t)\right] \tag{6}$$

$$C(t)=\begin{cases}P_b(t)\times P(t)\times T; & P(t)>0\\ P_s(t)\times P(t)\times T; & P(t)\le 0\end{cases} \tag{7}$$

$$C_2(t)=G(t)\times P_G \tag{8}$$

where $C_1(t)$ is the electricity purchase cost of the user in t^{th} period, $C_2(t)$ is the subsidy cost of the country for photovoltaic power generation during the t^{th} period, $G(t)$ photovoltaic power generation for the t^{th} period, $P_b(t)$ is the price of buying electricity for the t^{th} period, $P_s(t)$ is the price of electricity sold for the t^{th} period, P_G subsidized price for photovoltaic power generation in the country.

3.1.2 User satisfaction

When the HEMS is in operation, it is necessary to set the allowable operating time period $[\alpha,\beta]$ and the impact level δ of the power load for each power load in advance. The user satisfaction model can be expressed[5]:

$$f_a\left(t_a\right)=\begin{cases}\delta_a\times\dfrac{\beta_a-t_a}{\beta_a-\left(\alpha_a+l_a\right)}, & \alpha_a+l_a\leqslant t_a\leqslant\beta_a\\ 0, & t_a<\alpha_a+l_a \text{ or } t_a>\beta_a\end{cases} \tag{9}$$

where $f_a\left(t_a\right)$ is the satisfaction function of the electrical load a at the running completion time t_a , δ_a is the influence level of the electrical load a, when the electrical load a is finished at the end of time α_a+l_a, the user satisfaction is the highest; when the running time is gradually moved backward β_a ,the satisfaction will gradually decrease to zero. Therefore, the expression of user satisfaction:

$$S=\sum_{a=1}^{m+n+i} f_a\left(t_a\right) \tag{10}$$

3.1.3 Consider the objective function of user satisfaction and minimization of user electricity bills

User satisfaction is required in the model where the user's electricity bill is minimized, and the coefficient $\sigma(\sigma\in[0,1])$ is used to adjust the proportion of user satisfaction in the objective function. The objective function expression for minimizing the user's electricity bill and taking into account user satisfaction is[5]:

$$\min \mathrm{C}_{\mathrm{cost}}-\sigma\cdot S \tag{11}$$

3.2 Restrictions

According to the power flow characteristics of the power system, users' requirements for load work and load's own working characteristics, the power balance constraints, load working time constraints and temperature control load constraints are established.

3.2.1 Power balance constraint

The electrical energy produced in the system must be balanced with the electrical energy consumed at any time. The established power balance constraints are as follows[4]:

$$\sum_i\left(\sum_j W_{ij}\times A_{ij}(t)\right)+M_i(t)=G(t)+P(t) \tag{12}$$

where W_{ij} is the j^{th} load power on the i^{th} line , $A_{ij}(t)$ is the working state of the j^{th} load on the ith line in the t^{th} period, $M_i(t)$ is the unschedulable load power on the i^{th} line of the t^{th} period, $G(t)$ is photovoltaic power generation for the t^{th} period, $P(t)$ is the amount of electricity traded for the family and the grid during the t^{th} period

3.2.2 Necessary load

The load working time includes two aspects. On the one hand, the user has requirements for the total duration of the load work, and on the other hand, the load's own working characteristics determine the shortest continuous working time.

(1) The constraints on the total duration of load work are as follows:

$$\sum_{t=1}^{24} A_{ij}(t)=N_{ij} \tag{13}$$

where N_{ij} is the total length of time required in the day of load j^{th} on line i^{th} set for user

(2) The shortest continuous working time constraint is expressed as follows:

$$A_{ij}(t+x)=1, \forall x \in \left[0, L_{ij}\right], \quad B_{ij}(t)=1 \qquad (14)$$

L_{ij} is the shortest continuous working time of the j^{th} load on the i^{th} line. $B_{ij}(t)$ is the working state of the j^{th} load in the time period t on the i^{th} line

3.2.3 Temperature controlled load constraints

There is no working time constraint for temperature-controlled loads, only temperature constraints, which consider users satisfaction. The temperature constraints are as follows:

$$T_{\text{k}}(t)=T_{\text{s}}(t)\pm\Delta T \qquad (15)$$

Where $T_{\text{k}}(t)$ is the actual temperature value in the t^{th} period. $T_{\text{s}}(t)$ is the optimal temperature for the t^{th} period set for the user, ΔT is the temperature deviation allowed by the user.

4. SCHEDULING STRATEGY OF HOME ENERGY MANAGEMENT SYSTEM

4.1 HPGA flow chart

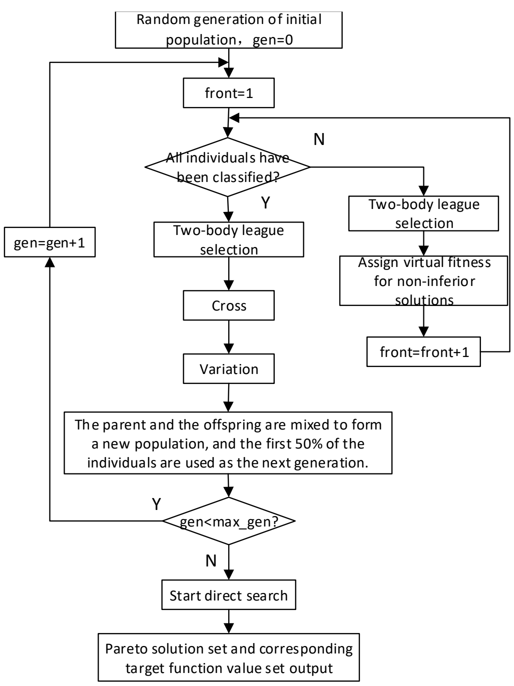

Fig.2. HPGA flow chart

4.2 Case studies

This case studies takes the family in a certain area of Tianjin as an example to construct the family energy management model, considering the user's satisfaction and the minimum cost of the user, and using the improved genetic algorithm to solve. Scenario 1 only considers user satisfaction and simulates the electricity habits of most users; Scenario 2 only considers the minimum cost of electricity; Scenario 3 considers the multi-objective function that considers the minimum cost of electricity and considers user satisfaction. The results obtained are as follows:

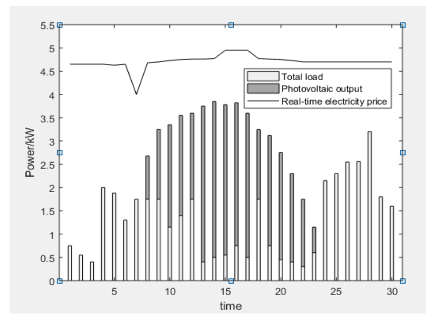

Fig.3. Only the user satisfaction of the total user load and photovoltaic output force

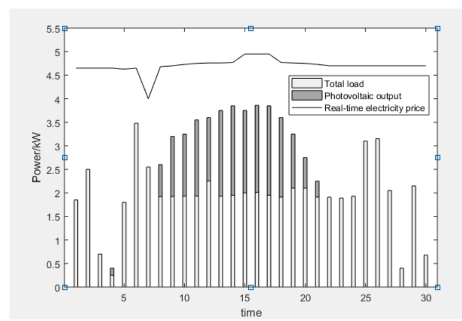

Fig.4 Only consider the total load and photovoltaic output with the lowest electricity cost

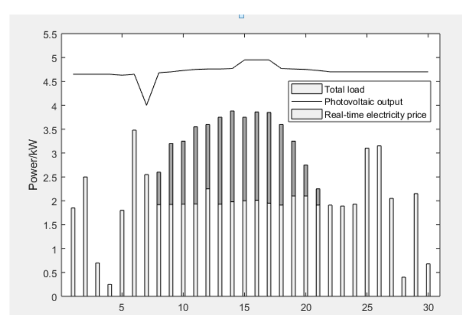

Fig.5. Total user load and Photovoltaic output based on user satisfaction and cost minimization

Table 1. Partition scheme and objective function value

Situation	customer satisfaction	Costs
Situation 1	100	39.6
Situation 2	20.14	34.3
Situation 3	95.29	35.2

5. CONCLUSIONS

In this paper, a multi-objective optimization model of cost minimization and user satisfaction is established which can effectively optimize the household load and ensure the satisfaction while reducing the cost. The improved genetic algorithm HPGA, combining Pareto genetic algorithm with local optimization method, realizes the complementarity of optimization mechanism and optimization behavior, and has not only good global optimization performance, but also strong local search ability.

ACKNOWLEDGEMENT

This paper thanks for the data support provided by Tianjin Electric Power company and the help provided by teachers. This Paper is funded by research on “Key Technologies for Real-time Remote Diagnosis and Abnormal Rapid Disposal of Operation Errors of Smart Electricity Meter in Low Voltage Station KJ18-1-39”, Headquarters Science and Technology Project of State Grid Corporation

REFERENCES

[1] ZHOU Lei, Li Yang. Modeling and Optimization of Home Load Based on Home Energy Management Systemin Time of Use Price System [J]. Technology Power System, 2015, 29(09):367-374.

[2] HOWLADER, HARUN OR RASHID, MATAYOSHI et al. Distributed Generation Incorporated Thermal Generation for Optimum Operation of a Smart Grid Considering Forecast Error [J]. Energy Conversion and Management, 2015，96(01) :303-314.

[3] Veras, Jaclason M, Silva, Igor Rafael S, et al. A multi-objective demand response optimization model for scheduling loads in a home energy management system[J]. Sensors, 2018, 18(10): 1884-2020.

[4] Gutierrez-Martinez, Victor J, et al. A heuristic home electric energy management system considering renewable energy availability[J]. Energies, 2019, 12(4):2419-2429.

[5] WANG Long, WANG Jin, et al. The Home Energy Management System Coordinated and Optimized Scheduling Based on User’s Satisfaction[J]. Journal or electric Power, 2019, 34(2):101-108.

[6] LI Heng, ChANG ZhiYong, et al. Multi-objective optimization problem based on genetic algorithm [J] Information Technology Journal,2013,12(22):6968-6973.

[7] Deb K, Pratap A, Agarwal S, Meyarivan T. A Fast and Elitist Multi objective Genetic Algorithm: NSGA- II [J]. IEEE Transactions on Evolutionary Computation, 2002,6(2):182-197.

[8] Zitzler E. Evolutionary Algorithms for Multi objective Optimization: Methods and Applications [D]. Switzerland: Swiss Federal Institute of Technology, 1999.

[9] MA Qingliang, HU Changhua, YANG Qing. Hybrid Genetic Algorithm for Multi-objective Optimization [J]. JOURNAL OF SYSTEM SIMULATION, 2004,16(5):1038-1040.

