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An Integrated Fuzzy Multi-Objective Genetic Algorithm for Optimization of Residential Appliances Scheduling

Jyh-Yih Hsu [1], Chien-Hua Chu [2], Chih-Ching Chen [3]

[1, 2] Department of Management Information Systems
[3] Department of Computer Science and Engineering, National Chung-Hsing University,
No. 250, Kuo-Kuang Road,Taichung City, 402, Taiwan, ROC

Abstract. For energy conservation, considerable progress has been made to improve the efficacy of appliances. Many researches regarding peak load reducing and load transferring have been done, and there exists numerous actual examples. However, only a few researches regarding the electricity expenditure optimization are proposed. Considering total electricity expenditure (TEE), total appliances shift time (TAST), and total appliances shift frequency (TASF), this article uses multi-objective genetic algorithm with fuzzy theory to solve problems in household appliances scheduling. The use of genetic algorithm utilizes multi-point search method to identify more economical electricity use for appliances in order to achieve the purpose of having electricity expenditure at the closest point to the electricity budget; however the lowest electricity expenditure is not regarded as the only objective, but take both the electricity needs consumer comfort and convenience into account. We expect the research results could reach the goal of optimal electricity management in residential sectors without significant change of the lifestyle of consumers

Keywords: multi-objective, electricity expenditure management, fuzzy theory, genetic algorithms, load management.

1. Introduction

For residential electricity load management, the concept of intelligent residential energy management is analyzed. The above concept is mainly constructed through the best method of calculation, i.e., some of the less urgent loads are shifted to off-peak hours when the electric tariff is relatively low [1-3].

To optimize the energy consumption of residential sectors, different methods such as multilevel optimization [4], genetic algorithms [5], intelligent modeling of optimized systems (IMOS) [6], and setting up constraints of energy cost [7-8] are proposed. And so far, in contrast to researches regarding the most appropriate appliances schedule based on electricity budgets, only a few researches take comfort and convenience of consumers into account.

Scheduling problem has always been classified as a NP-hard problem. As the problem becomes more complex, the time required to find optimal solution grows exponentially. As a result, it would be impossible to find the most optimal solution. Under these circumstances, the researchers no longer seek optimal solution and turned to appropriate scheduling with good quality. Recently, genetic algorithm for NP-hard problem has demonstrated relatively good results. For example, Shadrokh and Kianfar used genetic algorithm (GA) to solve project scheduling problem [9]. Chen used multi-objective genetic algorithm to solve land-use planning issues [10].

The concept in fuzzy theory has been used to handle uncertain decision marking problems, and it could convert the environmental perception of human into values that can be processed by computers. Fuzzy theory puts more emphasis on human's experience and the controlled level of the characteristics of the problem, also settings in the parameters of membership functions more in line with the reaction of specific needs of each consumer. Fuzzy theory has already been used in many applications in the residential sectors, such as using fuzzy technology to improve energy consumption [11], using fuzzy system to control electric appliances or end-uses of the whole building [12-13].

The current international oil prices swing greatly. Thus, the electricity price would also be affected with significant fluctuations. It is a very challenging issue for residences to figure out ways to save on electricity usage without having to change and sacrifice their accustomed lifestyle too much. This paper utilizes a fuzzy multi-objective computing approach with optimized scheduling algorithm to allow the usage of non-urgent electrical appliances to shift from peak-load period to the lower priced off-peak period.

This paper is organized as follows. The fuzzy process, mathematical formulation and optimization process are presented in section II, followed by a case study demonstrating the capabilities of the proposed method in section III. Finally, conclusions are given in section IV.

2. The Proposed Model

Today, smart appliances and smart meter integration has the capability to communicate, record, and provide consumers with real-time price information for energy management of a family. Scheduling planning for home appliances could effectively achieve the purpose of optimizing the energy consumption for households, and setting a monthly target for electricity expenditure. In general, the electric appliances can be divided into non-urgent and necessary usage within a specific time period. By appropriate load transfer to avoid peak-load period, we could achieve a consumer's comfort and convenience with the lowest monthly electricity expenditure.

In the following sections, the multiple objectives of the proposed model are first formulated, followed by descriptions of optimization method, the genetic algorithm, and fuzzy decision making.

A. Minimization of total electricity expenditure (TEE)

The first objective of the optimal residential electricity management is to minimize the total electricity expenditure (TEE). TEE includes length of usage time, point of usage time, electricity time-of-use rate, and appliances wattage. TEE is one of the objectives to be optimized; this objective can be formulated as:

$$MinTEE = \sum_{i=1}^{24}\sum_{j=1}^{n_a} H_i W_j (u_{ji}/60) \ whre \ 0 \le u_{ji} \le 60 \tag{1}$$

n_a: The variable of total number of appliances

H_i: Time-of-use rate of period i

W_j: Wattage of appliance *j*

u_{ji}: Used minutes appliance *j* in period *i*

B. Minimization of total appliances shift time (TAST)

The second objective is to minimize total appliances shift time. In general, consumer can tolerate the usage of appliance shift within a range of time, either push forward or postpone. Each consumer has different tolerance for different appliances; they can set their own range of tolerance values for this model. The shorter time shift can bring lower impact on a consumer's comfort and convenience. Thus, the second objective of the proposed model can be written as:

$$\begin{aligned} &MinTAST = \sum_{j=1}^{n_a} \left| TAST_j^{After} - TAST_j^{before} \right| \ ,where \\ &(TAST_j^{Before} - TAST_j^{tolerable}) \le TAST_j^{After} \\ &TAST_j^{After} \le (TAST_j^{Before} + TAST_j^{tolerable}) \end{aligned} \tag{2}$$

$TAST_j^{After}$: Switch-on time of appliances *j* after the shift

$TAST_j^{before}$: Switch-on time of appliances *j* before the shift

$TAST_j^{tolerable}$: Shift tolerable time length of appliances *j*

C. Minimization of total appliances shift frequency (TASF)

The third objective is to minimize total appliances shift frequency. Since each appliance shift will reduce a consumer's comfort and convenience, the fewer the number of appliance shifts, the lower the impact on a consumer. Thus, the third objective function of the proposed model can be written as:

$$P = \max\left\{\sum_{i=1}^{3} \frac{X_i - X_i \min}{X_i \max - X_i \min}\right\} \quad , \; where \quad 0 < p < 3 \tag{3}$$

n_a : The variable of total number of appliances

A_j : Appliances *j* shifted

D. Optimization algorithm

Genetic algorithms (GAs) were developed by Holland as a way of studying adaptation optimization and learning [14]. GAs is adaptive methods, which may be used to solve optimization problems [15]. GAs is heuristics based on the principles of natural evolution and 'survival of the fittest'. In other word, selection of the offspring of the current generation takes place based on the individual's fitness: thus, solutions better suited to their environment reproduce, whereas poorer suited ones die.

By mimicking this process, GAs is able to generate solutions to real world problems, if they have been suitably encoded. In recent years, GAs has emerged as a useful tool for the heuristic solution of complex discrete optimization problems. In particular, there has been considerable interest in their use in the solution of scheduling and timetabling problems, for example [9], [16-18]. GAs has been widely recognized as a useful vehicle for obtaining high quality or even optimal solutions for a broad range of combinatorial optimization problems. Thus, this research adapts GAs to search for trade-offs among three objectives.

E. Fuzzy decision making

The notion of fuzzy logic was introduced by Zadeh [19]. This concept deals with unclear or vague data, such as "a handsome man" or "pretty certain". Fuzzy logic is good at exploring human knowledge. Through the grade of membership, the vague data will be assigned to the range between zero and one. So it is an appropriate tool for quantifying reasonable vagueness. In this fuzzy decision model, we utilize the S-type membership functions. Each objective value will be converted into the range between 0 and 1 to get normalized objectives of extreme value. Accordingly, the following normalized formula is adopted:

$$P_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad , \quad i = 1,2,3 \tag{4}$$

P_i : Normalized membership function value of objective *i*

X_i : The calculated value number of objective *i*

$X_{\max}$: The maximum value of objective *i*

$X_{\min}$: The minimum value of objective *i*

After defining each membership function of all objectives, the maximum P value represents an index combining the normalized objectives values. Thus, decision making can be performed after the normalized summation of the objectives value. In this model, the maximum objectives P value correspond the optimal scheduling of home appliances. Accordingly, the P value can be calculated by the following formula:

$$P = \max\left\{\sum_{i=1}^{3} \frac{X_i - X_i \min}{X_i \max - X_i \min}\right\} \quad , \; where \quad 0 < p < 3 \tag{5}$$

Characteristics of fuzzy logic allow consumers to express their needs by using the semantic variables similar to natural language [20]. The mechanism of this model searches for trade-off relation among each objective through combining standardized deviation of satisfactory levels (i.e. P_i of each objective i) with GA. By doing so, this model can assist decision markers to find out the reasonable appliances scheduling with good enough solutions.

3. Simulation of Four Scenarios

In this study, electric appliances data and real-time electric pricing data are adopted from reference [21] for scenarios simulation (These simulated appliances data and real-time pricing data are available at http://140.120.54.183/network.doc before 2012/07/31.). The proposed algorithm in previous sections was implemented in Dev-C++ environment. This research simulates four scenarios: sufficient electricity expenditure budget, minor inadequate in electricity expenditure budget, inadequate in electricity expenditure budget, and serious shortage in electricity expenditure budget as the followings:

Scenario 1: Sufficient electricity expenditure budget

This scenario simulates a day of sufficient budget in electricity expenditure, which does not completely affect the consumer's comfort and convenience. Appliances can be utilized according to the original scheduling. For example, assuming the available electricity expenditure budget is NT$50, which is more than the original scheduled electricity expenditure of NT$47.85, then there is no need to make any change of electric appliances scheduling.

Scenario 2: Minor inadequacy in electricity expenditure budget

This scenario simulates a day when electricity expenditure budget is in minor inadequacies. For example, assuming the available electricity expenditure budget is NT$47, slightly less than originally scheduled electricity expenditure NT$47.85. The differences is NT$0.85.

For meeting the objective of electricity expenditure budget, we have to adjust the appliances usage scheduling. After the modeling program computed, appliances scheduling of adjustment is shown in Table I. The adjusted appliances include air-conditioner, dryer, and electric boiler. The shifted switch-on time of these appliances is 30 minutes, 250 minutes, and 60 minutes respectively. And the total shift time is 340 minutes. Under this scenario, there is little impact on consumer convenience and comfort. After adjusting appliances scheduling, the total electricity expenditure comes to NT$45.36. And this scenario will save NT$2.49. As shown in Table II.

Table 1 Comparison between scenario 1 and scenario 2 for switch-on time

	Scenario 1	Scenario 2	
Appliance type	Switch-on time	Switch-on time	Shifting time length (Min)
Air-conditioner	19:30	20:00	30
Dryer	19:30	23:40	250
Electric boiler	22:00	23:00	60
Total shift time			340

Table 2 Comparison between scenario 1 and scenario 2 for electricity expenditure

	Scenario 1	Scenario 2	
Appliance type	Electricity expenditure(NT$)	Electricity expenditure(NT$)	Saved amount (NT$)
Air-conditioning	8.6	7.96	0.64
Dryer	1.75	0.72	1.03
Electric boiler	3.50	2.68	0.82
Total saving amount (NT$)			2.49

Scenario 3: Inadequate electricity expenditure budget

This scenario simulates a day when electricity expenditure budget is inadequate. For example, assuming the available electricity expenditure budget is NT$ 45, less than originally scheduled electricity expenditure NT$ 47.85. The differences is NT$2.85.

For meeting the objective of electricity expenditure less than the available electricity expenditure, we need to adjust more appliances usage time. After the modeling program computed, adjustment of appliances scheduling is shown in Table III. The total shifted switch-on time of these appliances is 635 minutes. Under this scenario, there is more impact on consumer convenience and comfort. After adjusting appliances scheduling, the total electricity expenditure comes to NTS44.75. And this scenario will save NTS3.1 as shown in Table IV.

Table 3 Comparison between scenario 1 and scenario 3 for switch-on time

	Scenario 1	Scenario 3	
Appliance type	Switch-on time	Switch-on time	Shifting time length (Min)
Thermos	10:05	9:45	20
Steam cooker	17:30	18:00	30
Dehumidifier	17:35	18:00	25
Washer	19:20	23:00	220
Air-conditioning	19:30	20:00	30
Dryers	19:30	23:40	250
Electric boiler	22:00	23:00	60
Total shift time			635

Table 4 Comparison between scenario 1 and scenario 3 for electricity expenditure

	Scenario 1	Scenario 3	
Appliance type	Electricity expenditure(NT$)	Electricity expenditure(NT$)	Saved amount (NT$)
Thermos	2.20	2.12	0.08
Steam Cooker	1.24	1.10	0.14
Dehumidifier	2.54	2.49	0.05
Washer	0.62	0.28	0.34
Air-conditioning	8.6	7.96	0.64
Dryers	1.75	0.72	1.03
Electric Boiler	3.50	2.68	0.82
Total saving amount (NT$)			3.1

Scenario 4: Serious shortage in electricity expenditure budget

This scenario simulates a day when expenditure budget is serious shortage. For example, assuming the available expenditure budget is NT$35, serious shortage than originally scheduled electricity expenditure NT$47.85. The differences is NT$12.85. For meeting the objective of electricity expenditure less than the available electricity expenditure, we need to adjust most appliances usage time. After the modeling program computed, adjustment of appliances scheduling is shown in Table V. The total shifted switch-on time of these appliances is 735 minutes. Under this scenario, there is serious impact on consumer convenience and comfort. After adjusting appliances scheduling, the total electricity expenditure comes NT$44.46. And this scenario will save NT$3.39 as shown in Table VI.

Table 5 Comparison between scenario 1 and scenario 4 for switch-on time

	Scenario 1	Scenario 4	
Appliance type	Switch-on time	Switch-on time	Shifting time length (Min)
Thermos	10:05	9:45	20
Steam cooker	12:20	11:50	30
Steam cooker	17:30	18:00	30
Dehumidifier	17:35	18:00	25
Washer	19:20	23:00	250
Air-conditioning	19:30	20:00	30
Dryers	19:30	23:40	250
Electric boiler	22:00	23:40	100
Total shift time			735

Table 6 Comparison between scenario 1 and scenario 4 for electricity expenditure

	Scenario 1	Scenario 4	
Appliance type	Electricity expenditure(NT$)	Electricity expenditure(NT$)	Saved amount (NT$)
Thermos	2.20	2.12	0.08
Steam cooker	1.31	1.29	0.02
Steam cooker	1.24	1.10	0.14
Dehumidifier	2.54	2.49	0.05
Washer	0.62	0.28	0.34
Air-conditioning	8.6	7.96	0.64
Dryers	1.75	0.72	1.03
Electric boiler	3.50	2.41	1.09
Total saving amount (NT$)			3.39

Analysis and comparison of the empirical results

After the above analysis, we compare our empirical results with those of [21] as a benchmark. The results shown in Table VII reveal that our model found out more suitable solutions than reference [21] for each scenario. The fuzzy multi-objective genetic algorithm we proposed has demonstrated good performance in the empirical analysis.

Table 7 Comparison between our model and reference [21]

	Fuzzy multi-objective genetic algorithms (our model)				Single-objective fuzzy algorithm [21]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total saving amount (NT$)	0	**2.49**	**3.1**	**3.39**	0	1.54	2.96	3.13
Total shift time (Min)	0	**340**	**635**	**735**	0	390	700	820
Total shift appliance frequency	0	**3**	**7**	**8**	0	5	13	13

4. Conclusions

We considered three objectives in our research: the minimization of total electricity expenditure, the minimization of total appliances shift time, and the minimization of total appliances shift frequency. We used fuzzy multi-objective genetic algorithm to search the optimal residential electricity consumption schedule. To achieve the electricity expenditure budget objective, Table VII distinguished the differences between this model and the single-objective fuzzy model by [21] in comparative analysis. For these three alternative scenarios, our model utilizing multi-objective genetic algorithms has obtained more suitable results than those of single-objective fuzzy algorithm by [21]. If the results can actually be applied to electricity management planning in residential sectors, in connection with advanced metering infrastructure (AMI) and real-time electricity pricing scheme, consumers can monitor/control their energy-consuming appliances and save their electricity expenditure. Simultaneously, the electric utility can ease peak load demand and postpone additional construction of new power plants, and the whole society can achieve the objective of carbon reduction. In other words, the residents, the electric utility and the whole society, together they form a win-win-win situation.

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6. References

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