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Research on intelligent power consumption strategy based on time-of-use pricing

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Abstract. In this paper, through the analysis of shortcomings of the current domestic and foreign household power consumption strategy: Passive way of power consumption, ignoring the different priority of electric equipment, neglecting the actual load pressure of the grid, ignoring the interaction with the user, to decrease the peak-valley difference and improve load curve in residential area by demand response (DR technology), an intelligent power consumption scheme based on time-of-use(TOU) pricing for household appliances is proposed. The main contribution of this paper is: (1) Three types of household appliance loads are abstracted from different operating laws of various household appliances, and the control models and DR strategies corresponding to these types are established. (2) The fuzzified processing for the information of TOU price, which is based on the time intervals, is performed to get the price priority, in accordance with such DR events as the maximum restricted load of DR, the time of DR and the duration of interruptible load and so on, the DR control rule and pre-scheduling mechanism are led in. (3) The dispatching sequence of household appliances in the control and scheduling queue are switched and controlled to implement the equilibrium of peak and valley loads. The equilibrium effects and economic benefits of power system by pre-scheduling and DR dispatching are compared and analyzed by simulation example, and the results show that using the proposed household appliance control (HAC) scheme the overall cost of consumers can be reduced and the power system load can be alleviated, so the proposed household appliance control (HAC) scheme is feasible and reasonable.

1 Introduction

In summer, if the room temperature gets improved 2oC, air conditioning peak load will be reduced by 10% ~ 15%, that is, it will cut about 0. 5 million to 0. 75 million kw of peak power capacity demand [1]. Intelligent use of electricity, as an important part of 'generating, transmitting, transferring, transforming, distributing, using' power, is the key to smart grid service [2]. More and more researchers start from the demand side, devote to power market consumption and demand-side management [3-6]. In terms of improving user's demand response, the traditional way is to cut power for the peak-load adjustment, which seems more passive for users [7-8]. Under the environment of the smart grid, advanced metering system, electricity information exchange platform, two-way interactive technology can provide users with intelligent, diversified, and convenient electricity consuming services [3-4, 9].

Based on the abstracted architecture model in literature [15], this paper puts forward the household appliance control (HAC) system and scheme, analyzes the effect of the improved power load at different times, among different electrical appliances, and combined with concrete examples verifies the effectiveness of the control scheme.

2 HAC System

2. 1 System Introduction

Using the time-of-use price information, and according to the needs of users, HAC system realizes automatic DR control. The designed HAC system topology as shown in Figure 1, each part adopts two-way communication technology to achieve interconnection and intercommunication.

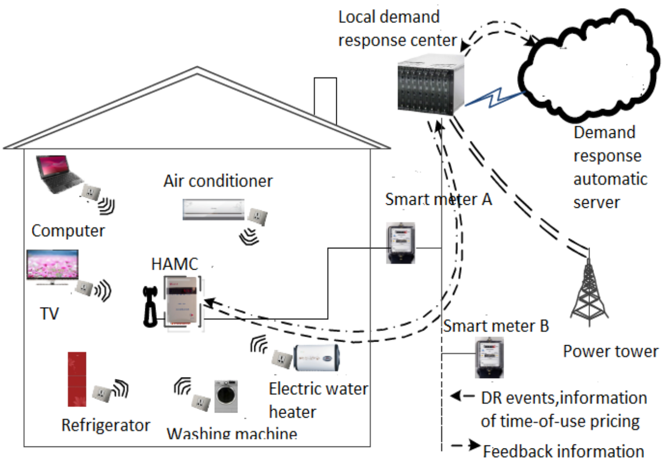

Figure 1. Topology of HAC system

There are household appliance master controller (HAMC), smart socket, smart meters, local demand response center and automatic demand response server. The local demand response center issued the latest electricity price information and the DR event (maximum load, demand response time, interruptible load time) to the HAMC. Demand response automatic server sends the DR event to the local demand response center and collects feedback information delivered from the demand response center. HAMC finishes state acquisition and state switching of household appliances via smart socket, which can control intelligent home appliances and communicate with the local demand response center.

2. 2 Types of Load and DR Strategy

The loads of household electrical equipment are divided into 3 categories in accordance with demanding time for electrical energy during its duty cycle and they usually have the following characteristics:

1) Non-interruptible load type: It requires continuous energy input (such as personal computer, alarm system as well as refrigerator, TV, etc.).

2) Controllable type: The states and working time can be controlled according to the user's using plan. Such appliances (like washing machine, HVAC equipment, etc.) generally takes up the greatest portion of household energy consumption.

3) Transferable type: Such appliances may be approached or delayed according to the user's habits. It usually can transfer or convert electric energy, such as water heaters, electric cars.

2. 3 Load Control Model

1) Non-interruptible load type

This kind of home appliances cannot be interrupted, so its control model is constant. For example, the control model for personal computer

$$S(L, t)_{L=PC}=1, \text{when needed} \quad (1)$$

Where: L is the device type, t is the time variable. When the device type L is a personal computer, $S(L, t)_{L=PC}$ represents PC status (0 for off, 1 powered) at time t.

2) Controllable type

The control model of controllable appliances generally has similarity. Take air conditioner cooling for example: In summer, when the temperature is higher than the maximum comfortable temperature set by the user, air conditioner starts to work until room temperature down to the comfortable temperature range set by the user. When the temperature is below the minimum comfortable temperature, air conditioner switches off, room temperature naturally warmes. When it is in a comfortable temperature range, air-conditioner' s state does not change. Its control model:

$$S(L,t)_{L=AC} = \begin{cases} 0, & T_{AC,t} < T_{AC} \\ 1, & T_{AC,t} > T_{AC} + \Delta T_{AC} \\ S(L,t-1)_{L=AC}, & T_{AC} < T_{AC,t} < T_{AC} + \Delta T_{AC} \end{cases} \quad (2)$$

S(L, t)$_{L=AC}$ is air conditioner' s state at time *t* (0 for off, 1 powered). $T_{AC,t}$ is room temperature at time *t*. T_{AC} is the lowest temperature set by the user. ΔT_{AC} is the temperature difference of comfortable temperature range set by the user.

3) Transferable type

Transferable appliances (such as electric cars, electric water heaters), usually required to transfer the desired amount of energy in a specified period of time, such appliances also have similarities. Like electric water heater, its working state is related to water temperature, the control model:

$$S(L,t)_{L=H} = \begin{cases} 0, & T_{H,t} > T_H \\ 1, & T_{H,t} < T_H - \Delta T_H \\ S(L,t-1)_{L=H}, & T_H - \Delta T_H < T_{H,t} < T_H \end{cases} \quad (3)$$

S(L, t)$_{L=H}$ is electric water heater' s state at time *t* (0 for off, 1 powered). $T_{H,t}$ is water temperature at time *t*. T_H is the highest water temperature set by the user. ΔT_H is the temperature difference of maintaining temperature range set by the user.

3 HAC Control Mechanism

3. 1 Get Parameters

HMAC screens controllable device type out from historical using records, and calculates sequentially running time T1. If there is transferable appliances, calculate the ratio F1 of the total power in all DR load appliances, and record adjustable DR load maximum Pmax declared by user.

3. 2 Generate Scheduling List

*3. 2. 1 Blurring Equipment Power.*The HAC system will not conduct DR control for the first kind of appliances, the other 2 types of equipments are done fuzzy process in accordance with the power values, and are given the corresponding appliance priority, the power priority rating is realized by the formula (4).

$$Z(P;a,b) = \begin{cases} 1, & P < a \\ 1-2((P-a)/(b-a))2, & a < P \leqslant (a+b)/2 \\ 2((P-a)/(b-a))2, & (a+b)/2 \leqslant p \\ 0, & b < P \end{cases} \quad (4)$$

Where: a is average power value of non-interruptible load type, b is average power value of transferable load type, a and b are known parameters of the processing function. P is the power value of household appliances. After fuzzification by formula (4), Z (p; a, b) is the priority of the appliance

3. 2. 2 Fuzzification for Time-of-Use Electricity Price. HAMC will fuzz released time-of-use electricity price in the interval [0~1], and generate priority of time-of-use price. The fuzzy factor is set to 1/24, the fuzzy result for each period equal the product of proportion and basic factor, which stands for price priority.

3. 2. 3 Regularization for DR operation. 1) If user's priority is the highest, the user can change the priority value of the DR operating matrix. 2) The highest priority value is 1, the lowest priority value is 0. 3) DR conducts the DR operations according to the priority value. The value represents the economic factor for the use of different home appliances in different periods, the larger the value is, the more suitable for the DR control. The generated DR priority order is DR scheduling queue.

The process of DR regularization is:

$$\begin{bmatrix} a_1 \\ a_2 \\ \cdots \\ a_n \end{bmatrix}_{n\times 1} \bullet \begin{bmatrix} b_1 & b_2 & \cdots & b_m \end{bmatrix}_{1\times m} = \begin{bmatrix} a_1 b_1 & \cdots & a_1 b_m \\ \cdots & \cdots & \cdots \\ a_n b_1 & \cdots & a_n b_m \end{bmatrix}_{n\times m} \quad (5)$$

Where: $[a1\ a2\ \ldots\ an]^T{}_{n\times 1}$ is priority matrix of electricity price, $[b1\ b2\ \ldots\ bm]_{1\times m}$ is appliances' priority matrix.

3. 2. 4 DR adjusts scheduling queue. Without the appliance, without the scheduling queue adjustment, the adjustment steps are as follows.

1) Pre scheduling period. Enhance its DR priority according to the ratio of the power value of transferable appliance in the whole interruptible loads.

2) DR period. Restore the priority during DR scheduling interval.

3. 3 Implement DR control

HAMC will conduct DR control for household electrical appliances with higher priority value sequentially. When there are several home appliances needing to be scheduled at the same time, i. e. total power consumption Pt is beyond Pmax, isolate from the conflicting home appliances by a simple regression, the basic steps.

1) Select the number N of conflicting appliances from the M home appliances participating in the DR control.

2) Randomly select a non-repeated random number Ri from the [0~2N], randomly assign to N home appliances.

3) When the random number of a household appliance is decreased from Ri to 0, HAMC switches its working state.

The HAC control algorithm is shown in Figure 2.

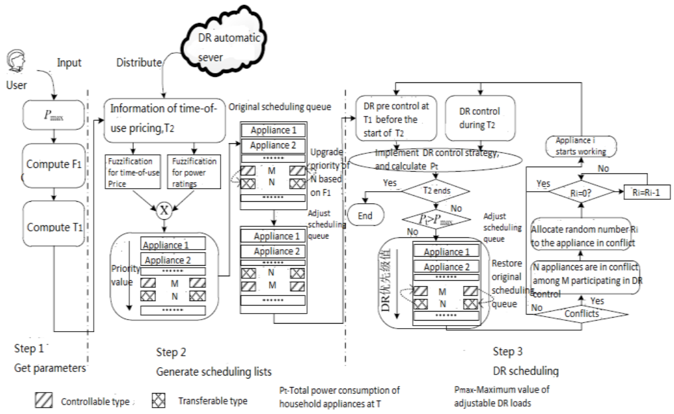

Figure 2. Conception diagram of HAC algorithm

4 Example analysis

4. 1 Example parameters

In the example, the DR control of the type is not considered, the air conditioner (Controllable type) and the electric water heater (Transferable appliance) are simulated, the corresponding parameters and DR strategy are shown in Table 1.

Table 1. DR strategies for three typical appliances according to load types

Appliance	Load type	Power	DR strategy
Air conditioner	Controllable	About 1. 4kW	T_{AC}=22℃, ΔT_{AC}=6℃ interruptible
Electric water heater	Transferable	About 1. 8kW	T_H=65℃, ΔT_H=30℃ interruptible
Light	Non-interruptible	Below 0. 5kW	Non-interruptible

User input 3kW Pmax of the DR control to the HAMC controller, the local demand response center released the DR time-the evening peak, peak hours. That is Pmax=3kW, T1=30min, T2=[18:00, 22:00], and so the example of the electric water heater F1=9/16.

In this example, the latest electricity price information obtained from a power company is in Table 2, the table shows the results after fuzzy measure.

When a=500, b=2000, after the fuzziness of its home appliances according to (4), priority as shown in Table 3.

Table 2. TOU price information and corresponding priority

Electricity price type	Time interval	Rate (yuan /kW·h)	Priority of TOU
Low load period price	0:00-7:00 22:00-24:00	0. 208	9/24=0. 375
Flat period price	7:00-11:00 14:00-18:00	0. 52	8/24=0. 33
Peak period price	11:00-14:00 18:00-19:00 21:00-22:00	0. 832	5/24=0. 208
High load period price	19:00-21:00	0. 926	2/24=0. 09

Table 3. Appliance information and priority

Equipment power range/W	Appliance	Example power value/W	Power priority
1250~1500	Air conditioner	1400	0. 32
1500~2000	Electric water heater	1800	0. 04

After regularization for DR operation, DR priority of each period of air conditioner, electric water heater is shown in Table 4.

Table 4. DR operation priority

Time interval	Air conditioner(1400W)	Electric water heater(1800W)
Low load period	0. 12	0. 015
Flat period	0. 1056	0. 0132
Peak period	0. 0665	0. 0083
High load period	0. 0288	0. 0036

4. 2 Simulation analysis

DR pre control, the priority of the water heater is up to 0. 0206 after being increased F1, which is prior to the air conditioner. Therefore, it starts pre scheduling at T1 before T2 start time, in the period T2, the priority reduces to the original priority (i. e. 0. 0132). The simulation results are shown in Figure 3.

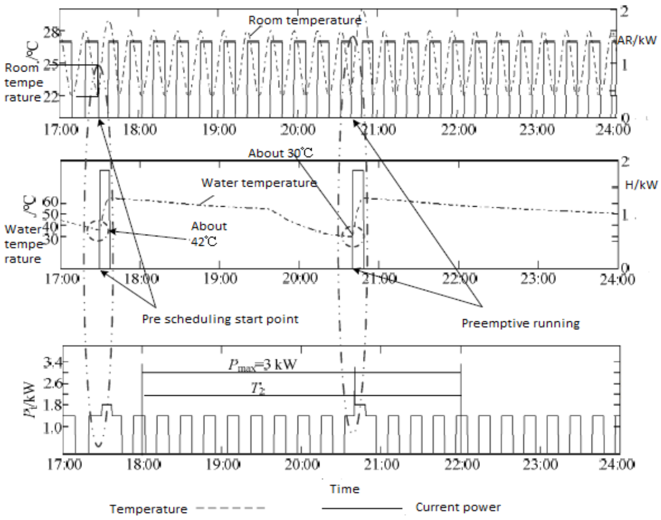

Figure 3. Simulation results in stage PreDR scheduled by HAMC

If no pre scheduling, the simulation is shown in Figure 4.

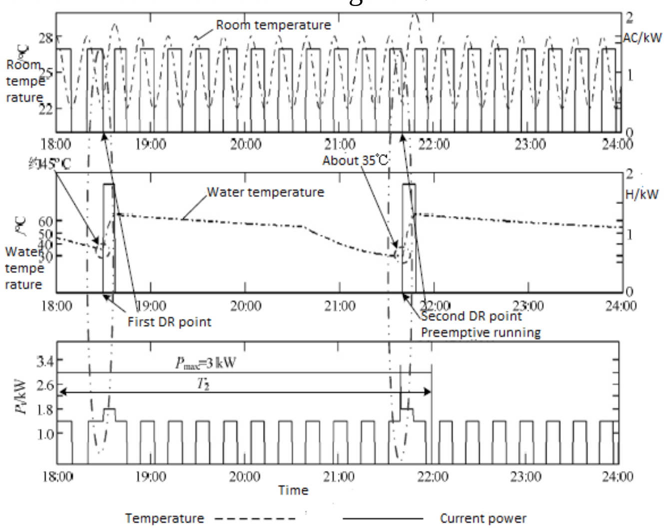

Figure 4. Simulation results in stage T2 scheduled by HAMC

Compared with Figure 3, 4, we found that DR pre control at T1 before T2 start time reduced the using times of water heater during the DR time (T2). However, the temperature of the hot water used in the peak time is lower than that of the non pre scheduling.

The amount and the cost of energy consumption of controlled appliances are shown in Table 5.

Table 5. Total power and cost appliances consumed by two appliances in two cases

Condition	Electricity consumption of air conditioner/kW·h	Electricity consumption of electric water heater/kW·h	Total electricity fees
Pre scheduling	3. 266 7	0. 6	3. 631 0
Period scheduling	3. 266 7	1. 2	3. 847 9

5. Conclusion

This paper presents smart home appliances management control scheme based on time-sharing pricing. Using different characteristics of high load period, peak period, flat period and low load period fees, after fuzzy processing for electricity and power of equipment, we get the DR operation priority, and adjust priority of appliances according to DR events, maximum value of DR load. The simulation results show that:

1) The greater DR operation priority value is, the better for the user and the grid using electrical appliances in the corresponding period of time.

2) During DR, the more equipment involved in the DR control, the more probability of priority challenges. When there are more large power equipment in DR events, after DR pre control, the more power is transferred to the flat and valley segment.

3) Advancing (or delaying) DR control can reduce power load demand during the peak period, the amount of work required will be made up in advance (or later).

4) After distributed energy storage power supply accessed to living environment, during peak periods, the distributed storage energy equipment increases the load supply of the corresponding period through the access of the HAMC, which to a certain extent, reduces the dependence on grid load, improves the load curve of power grid.

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