Distributed Demand Scheduling Method to Reduce Energy Cost in Smart Grid

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Abstract—Smart grid has attracted attentions and expresses a view for the future power systems in the world. Demand Side Management (DSM) is a significant method in smart grid that helps the energy providers to shift behind the peak load. Some methods to reduce peak load have been studied in dynamic pricing. One of the purposes is to delay the demand to periods of low electricity price. The conventional scheduling method makes load curve that is inversely proportional to electricity prices as an objective load curve, and this strategy delay the expected demand curve as close as to the objective load curve. There is a problem, however, the scope of controlled object is limited and the whole load situation is not considered. This paper presents a method to smooth the demand situation of each house to reduce electricity prices by a Genetic Algorithm, in consideration of the amount of the whole demand and coordination between each group. The proposed method is able to give a higher value of objective to the group which has more shiftable demand, by adjusting the objective curve considering the delayable time. This feature makes the load as close as the object and reduces electricity price. Simulation results show that the proposed algorithm achieve the reduction of the peak load and the utility bill in smart grid.

Keywords—Smart Grid, Demand Side Management, Dynamic Pricing, Genetic Algorithm

I. INTRODUCTION

Smart grid, a power grid which integrating advanced technologies at distribution level, has attracted attentions because of environmental problems [1]. The large peak load is a burden to generation system, thus it is significant to use the renewable power resources effectively to cover the unexpected demand. Operation of power plants to cover exceeded demand is heavy load for generation system and operational cost becomes higher. Therefore stable and effective operation is desired for future power environment.

In smart grid environment, it is assumed that the installation of power generation equipment such as solar panels, battery and electric vehicle to each household [2][3]. In addition to these batteries and generation systems, smart house has been proposed a household that can operate the power effectively via device, like smart meter or home gateway. It has been considered to schedule electric power supply and demand in smart house that aims to reduce the electricity bill. Several studies are assumed that it is possible to know the information and control the status of each demand by smart meter, and the management model for smart house is significant to control the controlled object which recently increase.

An energy Virtual network operator (EVNO), proposed business model, controls energy supply and demand among smart houses to virtually share their equipments [4]. EVNO makes a contract with smart houses to control their facilities and appliances, and manages them totally in smart grid. Figure 1 shows an overview of EVNO. EVNO exchanges necessary information with houses and then accommodates energy between houses. When energy trading between houses happens, logical energy transmission from an energy seller to and energy buyer arises. This means that each house just sends energy to power grid or consumes energy at the time designated by EVNO. As a result, the electric power is effectively used as if electric power is exchanged between seller’s and buyer’s.

EVNO pays pay the amount of the transmission energy cost to the power grid company. EVNO can reduce energy cost by minimizing energy transmission loss and, self discharge of the battery, by rising usage efficiency of facilities. As a result, EVNO takes a part of the profit as a fee. In this way, EVNO, the power grid management companies, and also subscriber can get benefit: the management companies do not need to control of distributed energy sources and get rental rate of the power grid with no efforts. EVNO does not need to own a huge infrastructure. Therefore, EVNO can start up with little initial investment and get a part of profit from contractors i.e. the power grid company. Users can reduce energy cost by operation of EVNO.

Demand side management was proposed as the efficient system allows user to make decisions their consumption in smart grid [5]. There are several demand side management scheme, algorithm and technique for smart grid [6] [7]. Previous studies proposed a method to control the duration of appliances which can be shifted its occurrence time. The strategy is based on load shifting technique which can control several types appliances by using a evolutionary algorithm, e.g., genetic algorithm. The purpose of this operation is to cut off the utility bill of electricity power by applying the method that controls the shifting time of appliances. A Heuristic evolutionary algorithm has been developed and evaluated for solving the optimization problem [8]. This management system is set up a load curve as object of demand situation, the load curve is created inversely to the electricity price. By using a genetic algorithm that shifts the appliance to close to this objective curve, the method aims to reduce utility bill.

There are some problems, however, in the conventional method, the scope of controlled object is limited and the whole load situation is not considered. If the control range is expanded, the computation time becomes large and it is forced to operate the groups that are dispersed whole scope which are not coordinated with each other to compute in limited
EVNO is demand and supply control service by on/off controlling smart meter. Total demand optimized in each divided group was not the same as optimization problem of whole range of controlled object. If the whole optimization is desired, it is necessary to consider the amount of whole demand and coordination between divided groups are required.

To solve these problems, we propose a scheduling method which coordinate between divided groups and operate optimization of each group at the same time. The proposed method uses a genetic algorithm and leads more reduction of whole energy price by efficient load shifting of appliances without changing the entire objective load. The reduction of utility bill is achieved by providing the objective curve which corresponds to each group’s demand situation. The demand curve is created with the intention to lower the price by allocation of each objective load to each group. This allows users to reduce the utility bill in consideration of whole demand situation and whole peak load to shift more to the time which forecasted load is small.

This paper is organized as follow: the demand side management (DSM) is defined in section II. In section III, the proposed optimization method is explained and in section IV, simulation results are provided to evaluate the performance of the proposed method. Finally, in section V, summarized the paper and directions for further research are given in Section VI.

II. DEMAND SIDE MANAGEMENT (DSM)

Demand side management (DSM), system that realizes peak shaving and peak shifting based on availability, is the efficient system allows subscriber to make decisions related to their consumption situation in smart grid [5]. Figure 2 shows the scheme of DSM. As a technique of DSM, the method is mentioned that adjust the operational status of appliances through the home gateway and the smart meter, when the power consumption is tight. It is monitored by Supply side. There are other system that operate the heat pumps (e.g., CHP) and electric vehicles, etc., if the surplus power is generated, or encourage voluntary efforts to conserve power by providing information about electricity demand for demand side.

How to encourage voluntary power savings are also referred as Demand Response (DR), demand response is a kind of demand side management [9]. Demand Response has been considered that pay incentives to consumers who declined to use the power during peak demand [10]. Dynamic pricing is a method of dynamically changing the electricity price by supply side operation that considering the demand situation. If the forecasted load of the certain time is higher than that of other time, the electricity price of that time is set higher and it urge demand side not to use the wasted power. These mechanisms are concept for adjusting the power consumption by exemplifying various conditions, and users can reduce energy cost by operation of DSM.

III. PROPOSED METHOD

A new scheduling method, which controls the occurrence time of the appliances by a genetic algorithm, will be proposed. This technique is to set the optimization of each group to the optimization of the whole range by providing the objective load that suited to each group’s demands, and an evolutionary algorithm, genetic algorithm, is used to solve the optimum problem as the heuristic solution.

Following steps describes the calculation of the objective load curve of the proposed optimization that is performed at the same time. At first, the delayable time of the appliances is set to the amount of delay that can be corresponding to the actual life.

Figure 3 shows how to create the objective load curve. The curve is derived inversely to the expected electricity price. In other words, time step which electricity prices are low has large value of objective curve and demand around this time is more shifted to this time step. Conversely time step which electricity prices are high has small value of objective curve and demand around this time is less shifted to this time step. Each group has the each objective curve obtained in the same way.

This paper proposes the following method for adjusting the objective curve. Figure 4 shows the proposed technique.

The objective load of time step t is calculated by using SLoad(t), SLoad(t-1), SLoad(t-2) and SLoad(t-3) as follows:
Objective \( (t) \) = \( \frac{\text{totalObjective} \( t \) \times \sum_{T=t-3}^{t} SLoad(T)}{\sum_{T=t-3}^{t} \text{totalSLoad}(T)} \) 

Where:

- \( SLoad(t) \): the value of the shiftable demand at time \( t \)
- \( \text{Objective}(t) \): the value of the objective curve at time \( t \)
- \( \text{totalSLoad}(t) \): total \( SLoad(t) \) of whole range
- \( \text{totalObjective}(t) \): total \( \text{Objective}(t) \) of whole range

By providing the objective curve as Equation (1), objective curve of time step which assumed to shift large demand is greater than that of the other. The load curve is controlled as close as to the objective curve, then the demand which shifted to the time \( t \) increases. The sum of the Objective curve does not change, but this scheme can give a objective curve according to the demand of each group. That can be approximated demand of the entire to the objective curve, and possible to reduce the utility bill. And the computation time depends on the number of households that is in the range of 1 group, because this method can control each group simultaneously.

The following describes the features of the proposed method.

- Shift peak demand intentionally by adjusting the objective curve

In the conventional method, it gives the same objective curve for all group, therefore it can’t control the load curve well on schedule for peak demand overlaps, because the time step of peak load vary depending on the controlled group. Figure 5 shows a framework of effectiveness of applying each objective curve for each group. However, the proposal can closer to the optimization of entire range by provide a objective load that fit for each group.

- To control a wide range simultaneously

When the number of controlled object increases, it may be performed batch control of entire range or simply distributed control by division of the controlled object. The former method increases the computation time dramatically with the extend of the scope, and the latter may not be the whole optimization because it can’t take account of the coordination between groups.

Proposed algorithm, however, considers the coordination between groups through giving the each objective load which suited to each demand. The proposed technique can execute a control by this coordinated genetic algorithm in each group at the same time, so it is possible to control the more households.

- Reduction of utility bill

The proposed scheme can close the each load curve to the each objective curve, which is based on electricity price and each demand situation. The value of objective curve is composed the low value in time step which electricity prices are low and high value in time step which prices are high. This characteristic of objective load makes the demand shifting to time whose electricity price is lower. Therefore it is possible to associate with a reduction of utility bill.

A. Procedure of the proposed algorithm

This proposal is a way to approximate the optimum solution by using a genetic algorithm (GA). In this method, genes are the delay time of each shiftable appliance. A chromosome is the population of genes and initialized at start of algorithm. Initialize ends the generation random population of \( n \) chromosomes that suitable solutions for the problem. The length of \( n \) chromosome is the number of shiftable devices in range of controlled object. A optimum solution of this problem is solved through the genetic operations: selection, i.e., elitism, one point crossover and mutation. Elitism is used to prevent losing the best found solution. One point
crossover and mutation are the most important elements of the genetic algorithm because these are the actual operation of gene manipulation. These operation makes chromosomes solution that is closer the demand situation to objective curve. The best chromosome is selected as a optimum solution this problem. Figure 6 shows the alternation of generations. This is a characteristic of a genetic algorithm and makes a optimum solution by heuristic method.

Fitness indicates the degree of approximation of the objective curve and its chromosomes. Fitness is calculated as follow:

\[
Fitness = \frac{1}{1 + \sum_{t=1}^{24} (PLoad(t) - Objective(t)) / \sum_{t=1}^{24} Forecast(t)}
\]

(2)

Where:
- \( PLoad(t) \): the actual consumption at time \( t \)
- \( Objective(t) \): the value of the objective curve at time \( t \)
- \( Forecast(t) \): the forecasted consumption at time \( t \)

\( PLoad(t) \) is calculated as follow:

\[
PLoad(t) = Forecast(t) + Connect(t) - Disconnect(t)
\]

(3)

Where:
- \( Connect(t) \): the value of the load shifted to time \( t \)
- \( Disconnect(t) \): the value of the load shifted from time \( t \)

Figure 7 shows the outline of \( PLoad(t) \), \( Forecast(t) \), \( Connect(t) \), \( Disconnect(t) \).

Fitness value means how the solution approximates to the objective curve, respect to the amount of expected demand. High degree of fitness means that demand curve and objective curve are more approximated, in addition, the used method could shift the demand to periods of low price. It is possible to reduce the electric bill by using the method that can obtain lower fitness value. Equation of Fitness means that the actual load consumption is consistent with the objective curve.

Figure 8 shows a flow of genetic algorithm. One point crossover selects genes from parent chromosomes and creates a new gene. After one point crossover is performed, mutation take place to change randomly the new offspring. Proposed scheme of algorithm is described as follow:

1) To determine the occurrence time and the delay time in the range of the maximum delayable time of each appliance.
2) \( n \) chromosomes are initialized randomly by giving the delay time of each appliance.
3) The generation time of appliance is determined by each occurrence time and delay time, and the load of each hour is calculated.
4) Fitness of each chromosome is calculated from the amount of demand and the objective curve, and chromosome is sorted in ascending order of fitness.
5) The one point crossover of the chromosome is done.
6) Mutation is done at a rate of 10 percent.
7) step 3-7 is repeated until 500 generation, and finally the chromosome of the highest fitness is set as the optimum solution in each group.

IV. PERFORMANCE EVALUATION

Effectiveness of the proposed method rather than the conventional method is evaluated on the following:

- Comparison of fitness
- Average of shiftable demand in a day

If the fitness is large, the actual load is to approximate the objective curve, and it means that the utility bill is more inexpensive. The utility bill and the displacement of load are compared in assumed one day.

A. Simulation model

In this simulation, elements and electricity price is assigned shown in table I, II and figure 9 shows the shiftable and non-shiftable demand in a day. We simulated the load consumption for 24 hours (8:00 - 24:00 and 0:00 - 8:00).

<table>
<thead>
<tr>
<th>TABLE I. SIMULATION ELEMENT</th>
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<tbody>
<tr>
<td>Time step(hrs)</td>
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<tr>
<td>The number of household</td>
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<td>The number of division</td>
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<tr>
<td>The number of shiftable appliance</td>
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<td>The amount total demand</td>
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<td>Attempt</td>
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<tr>
<th>TABLE II. ELECTRICITY PRICE PER 1 kWh IN EACH HOUR</th>
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<tr>
<td>time(hr)</td>
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<tr>
<td>8</td>
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In this simulation, the electricity price is assumed to dynamic pricing, such as in table II. The Value of electricity price is assumed to be the same that of the conventional method [6]. The total number of households is 800 thousand, and the number of divisions was into 10, thus the controlled object of one group is 80 thousand household. The number of shiftable appliances will be 4.48 million units, and total demand of shiftable and nonshiftable appliances will be 28 million kWh.
Fig. 11. Average of shiftable demand in a day in conventional method to spread with whole load situation in mind.

Table III shows a comparison of the average utility bill of 24 hours in the conventional method and the proposed method.

<table>
<thead>
<tr>
<th></th>
<th>Conventional method</th>
<th>Proposed method</th>
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</thead>
<tbody>
<tr>
<td>Total utility bill (ct)</td>
<td>360.81</td>
<td>357.51</td>
</tr>
<tr>
<td>Utility bill of shiftable load (ct)</td>
<td>70.20</td>
<td>66.90</td>
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</tbody>
</table>

V. CONCLUSION

This paper presented a simultaneous control of the load curve by optional adjusting for shifting consumer appliances every demand in smart grid. At present the number of house that can be controlled by ICT are increasing. A method of optimizing the time shift of the appliances demand by delaying the expected demand curve as close as to the load curve based on electricity prices have been proposed. However, there are problems in the conventional strategy. It was impossible to correspond to the increase the number of house because it does not get the correlation between some groups.

In proposed method, each group obtains the objective load curve that added the adjustment that takes account of the each delayable time. I have proposed a method for controlling appliances of the distributed groups at the same time, without changing the whole value of objective load. Thus, since the each demand is closer to the objective load curve, the simulation has shown that it is possible to reduce electricity costs of 4.71 percent of the shiftable load.

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