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Household Appliance Scheduling

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Abstract: ***Many countries in the world have a variable power rate, which a consumer can exploit to reduce electricity cost for running the appliances accordingly. In this greedy consumption, power surge is possible during that low cost slots and may result in load shedding in many parts. A consumer can schedule his appliance in some other way to minimize the cost and prevent power overloading. Appliance scheduling for cost optimization only addresses a local problem. A holistic view of the problem where the cost of consumers is reduced and also the load on the suppliers can be managed is a better approach. In this thesis we focus on scheduling the different appliances of different consumers so that total load on power supplier does not exceed the maximum load capacity and subsequently the total cost of consumer is minimized. We consider that there is only one power supplier for a given area with varying cost per unit hour. The hourly data collected from the smart meters are fed into the scheduler and the scheduler equipped with a wireless sensor schedules the appliances so that the maximum number of appliances are scheduled keeping overloading problem as constraint. Optimization using both Integer Linear Programming is discussed in this thesis.***

Keywords: Appliance scheduling, ILP, cost optimization, overloading, smart meter

1. Introduction

Across the globe there has been a huge uproar from several environmentalists to reduce the consumption of electrical energy and consequently lessen the percentage of carbon dioxide in our atmosphere. This has forced governments of many countries to adhere to several energy saving policies. Some of these energy saving policies are creating a new paradigm on residential electricity markets as energy optimization becomes an increasingly important challenge in our society.

A recent survey by the European Commission [1] has shown that over 60% of the total world population lives in urban areas and about 80% of total energy demand is due to the cities. Moreover the growth of the urbanization and the transformation of suburbs into complex and dense social environment forecast the rise of these percentages in the short and long period. Studies have found in [2][3]that 74% of the total electricity consumption of a nation occurs in buildings. Efficient electricity consumption is not used in most of these buildings leading to waste of billions of money.

In this paper, our goal is develop an efficient Energy Consumption Management system for residential consumers so that cost at the consumer end is minimized. This system not only focuses on minimizing customer cost, but it also benefits the supplier by preventing power overloading and black out. Nowadays suppliers provide electricity with varying rates per hour. Fluctuating rates provide incentives to the customers to use limited electrical appliances during peak load hour. In summer, during the day, the usage of Air Conditioners by consumers increases the peak load. If other appliances are used during that period, the peak load may exceed the maximum load capacity of the supplier leading to cable fault and other problems. In order to prevent such unexpected or sudden change in the load, the suppliers intentionally increase the rate per unit electricity so that customers minimize their usage during the peak load hour.

Our Energy Consumption management focuses on optimization of electric consumption along with subsequent cost optimization of consumers. Both the consumers and suppliers can be benefitted by our scheduling method (a) consumers are benefitted as their *cost will be minimized* (b) Suppliers will not face any *over-loading problem*. We have considered multiple power suppliers in this paper. Implementing multiple power suppliers provide an opportunity for the supplier to minimize over-loading and consumer to optimize their cost.

Sustainable Energy Authority of Ireland (SEAI) in [4] has suggested relations between price and demand. At present the majority of electricity customers pay a flat rate for their electricity. They pay the same for a unit of electricity regardless of when they use it. Under time-varying pricing, the price per unit of electricity varies according to the time of the day or night at which the consumption occurs. The reason for implementing such time-varying tariffs is to send price signals to customers that better reflect the actual underlying costs of generating and the electrical demand at a given moment in time. By exposing customers to prices based on these costs, utility companies can reduce or shape customer demand profiles which lead to a more efficient system. If the cost of adding new generators to meet certain demand profiles can be avoided by instead modifying these demand profiles the overall cost of the electricity system is reduced.

As part of a plan by the California Public Utilities Commission in [5] to ensure greater power reliability and a better energy future, businesses are moving to a Time-Varying Pricing electric rate structure. Instead of a single flat rate for energy use, time-of-use rates are higher when electric demand is higher. This means when you use energy is just as important as how much you use. Winter has two rate periods: off-peak and partial-peak. Summer has three: off-peak, partial-peak and peak. During peak periods, defined as weekdays from noon to 6 p.m., May through October, your business' electric rates will be higher. In return, time-of-use rates at all other times will be lower than the peak rate.

Thus, it can be concluded that the cost of electricity is directly proportional to the cost of the power generation and the total electrical demand at a given moment in time.

The remaining of this paper is organized as follows. In the next section, we review the related work. In Section 3, we explain the preliminaries of our infrastructure. In section 4, we describe the architecture of our system. In section 5, we explain the cost optimization methodology along with prevention of power overload using ILP method. We discuss the experimental results in Section 6. Finally, we conclude the paper in Section 7.

2. Related Work

The development of a suitable procedure for optimization of electrical consumption using smart meters have been well documented in literature [6][7][8]. They aim at reducing the Peak to Average Ratio (PAR) and peak load of the electrical household thereby minimizing the total cost of the consumption. Authors in [6] focuses on incentive based Demand Response Program (DR) strategies to decrease the peak load growth and subsequent consumer electricity bill cost. However this paper has some drawbacks. The main purpose of this paper is to reduce peak load but customer bill cost is not always customers minimized. The example cited in this paper uses only one power supply. However in real life scenario there may be more than one power supplies. This scheduling approach is not applicable for cases with more one power supplies. The maximum load capacity constraint is not considered. The reduced peak load may sometime exceed the maximum load capacity which may lead to black out and cable fault. No precautions taken before the scheduling so that the peak load does not exceed the maximum load capacity.

The Demand Response program discussed in [7] is used to schedule the appliances according to the past records collected by Smart Meters an Automated Meter Reading. The drawbacks of this algorithm are: (1) Peak is reduced but cost is not always minimized; (2) Only one power supplier is considered. But in reality there are more than one power suppliers.

A Real Time Pricing (RTP) model is discussed in [8] which give a more real world exposure to the electrical households rather than common flat price rates. A trade-off between minimizing the electricity payment and waiting time is tried to achieve using Linear Programming. The system model considers one power generator, more than one retailer and each consumer are connected to only one Retailer. Each consumer provides the total energy needed for each appliance and the start interval and end interval for the operation of each appliance beforehand. This information is fed into the Energy Scheduler. The Energy Scheduler then schedules the appliance so that the cost is minimized. It considers the cost of waiting as a part of the total cost. The total price of the scheduling in the mathematical formulation is the combined summation of the total price and the total cost of waiting. As the customer waits for the start of the operation of the appliance, the cost of waiting increases adding it to the total cost. This cost function is minimized. However there are some drawbacks in this paper: (1) only one retailer is considered for each customer. In reality there can be more than one retailer and the customer should be scheduled to consume power from the retailer with minimal cost; (2) the cost of waiting follows a linear pattern with time. However the waiting cost may sometimes be negative i.e. the total cost may decrease if the consumer waits for a longer time; (3) also each consumer is equipped with an Electric Scheduler which schedules the appliance of the consumer. But the Maximum Load of the supplier is not taken into account. This can easily overload the Generator and ultimately cause blackout and load shedding.

3. Preliminaries

Smart Meter is the latest technology that has been implemented in many cities around the globe. It records consumption of electric energy in certain interval and communicates that information back to the central head end systems for monitoring. The huge data is collected by the central head end system using data analytics method discussed in [9]. Smart meter data analytic involves collection of serial data, processing it accordingly and drawing useful conclusions that can be useful to all the consumers involved.

In our paper, the smart meter collects electricity consumption data every minute and sends this data to the central head end system at the end of each hour. The central head end system consists of a data aggregator unit (DAU) which stores the data received from the smart meter and analyses the data using statistical parameters. The objective of the statistical parameter is to deduce the optimal electrical energy that is consumed by each consumer hourly. The DAU takes into consideration the past electricity consumption records of a particular consumer for a specific hour of a day, combines it with the statistical parameters and finds the optimal electricity that the consumer consumes. The probability of the consumer consuming more electricity than the optimal electricity calculated by the DAU should be as low as possible. This value is the maximum load capacity for each customer for every hour.

Let us consider an example which has a 5 hour continuous slot and the customer needs to operate 3 appliances. The details of the appliance are given below in table I.

Table 1: Appliance details

Appliance	*Preferred Interval*	*Duration*	*Unit/hr*	*Type*
App 1	0-5	2	15	Continuous
App 2	2-5	2	10	Discrete
App 3	1-5	1	20	Discrete

A consumer would arbitrarily schedule the above appliances without calculating the total cost and hence he will be unaware of the fact that whether there is any scope for cost optimization.

Table 2: Hourly Cost and Capacity details

Hour	Cost per unit	Maximum Load
0-1	2	20
1-2	3	20
2-3	4	20
3-4	2	20
4-5	1	20

The hourly cost per unit along with the maximum load capacity of each hour is given in table II above. The maximum load capacity generally varies with time in general and the value is fixed by the statistical analysis performed by the DAUs. In this table, we have taken the maximum load capacity as constant.

If the consumer randomly schedules the above appliances in the order App1 (0 to 2 hours), App2 (3 to 5 hours) and App3 (2 to 3 hours) then the total cost comes out to be Rs. 185. There is always a scope to schedule the appliances in a more cost effective way. For example if the above appliances are scheduled in the order App1 (0 to 2 hours), App2 (2 to 4 hours) and App3 (4 to 5 hours) then the total cost comes out to be Rs. 155. So there is always a scope to find out the most cost effective way keeping in mind that the total load does not exceed the maximum load capacity of the supplier.

Another drawback of random scheduling is that some appliances may not be scheduled within the time frame although the total load does not exceed the maximum load capacity of the supplier. For example if the above appliances in the order App1 (1 to 3 hours), App2 (3 to 5 hours) then App 3 will not have any space to get itself operate on.

Hence we can conclude that if the appliances are scheduled arbitrarily there is a possibility of paying excessive cost that could have been minimized. Also appliances may not be scheduled although there is a scope for doing so.

4. System Architecture

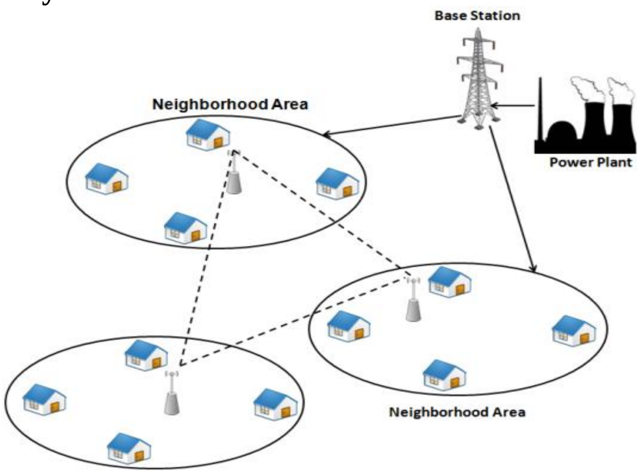

Figure 1: Power Distribution

Each power plant is connected with many base stations which controls the power that is being supplied to the consumers. Each base station provides power to many consumers. Many nearby consumers are placed under the jurisdiction of a neighborhood area which is under the control of a scheduler with a wireless sensor.

1) Power Supplier: There is only one power plant with many base stations attached to it. Each supplier is capable of supplying power up to a Maximum Load. This maximum load is predefined for each base station and is communicated to the scheduler for calculation. Different power supply plant has different production capacity and hence the maximum load capacity of each supplier varies accordingly. Each power plant is provided with a temporary electric charge storage device (ECSD) which is capable of storing huge amount of energy. The current flows from the power plant to the base station via the ECSDs. If there is any unused electricity which is stored in the Electric Charge Storage Devices, the consumer can directly consume electricity from the ECSDs prohibiting the power supplies to produce new electricity.
2) Consumers: There are many consumers in the system. Each consumer consumes power from one particular base station. Each consumer is equipped with a smart meter which collects the hourly consumption pattern of the consumers. Also users can input the details of the appliances to be scheduled into the smart meter.
3) Scheduler: The scheduler is a computer along with scheduling software. It also contains a wireless sensor which is capable of sensing data from the nearby consumer smart meters. It collects information from the smart meter of each consumer. It also contains the information about the maximum load capacity of each power supplier.

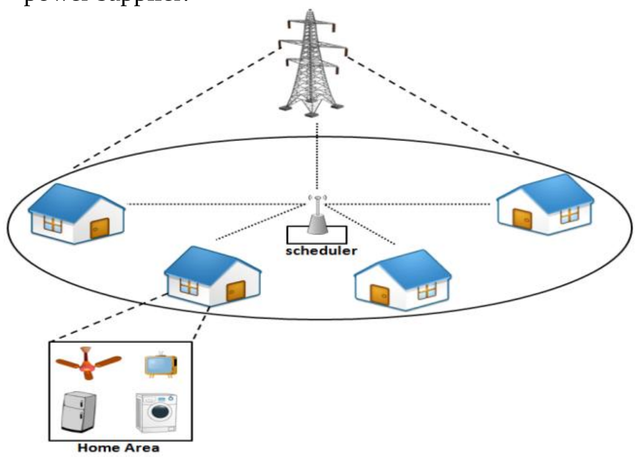

Figure 2: Working of Scheduler

For the ease of scheduling, we have divided the entire system architecture into three areas:

a) Wide Area: All the consumers along with their base stations and the power plant form the wide area. All the base stations are connected to the power plant. The base station controls the power supply to each consumers connected to it.
b) Neighborhood Area: A group of nearby consumers forms the neighborhood area. Each neighborhood area is equipped with a scheduler which sends and receives information to the consumer smart meters. The schedulers can communicate among themselves and also with the base station connected to it.
c) Home Area: The appliances in a consumer house along with the home smart meters forms the home area. All appliances are connected to the home smart meter. The smart meter receives the scheduling information from the scheduler.

5. Appliance Scheduling

We consider that there is only one Power Supplier. Each base station is connected to that power supplier. The appliances in a consumer house are classified into three types:

a) Non-Elastic: Those appliances which do not have any scope for scheduling are known as non-elastic appliances. For example, an appliance whose duration is 5 hours and preferred interval is 5-10 hours should be scheduled from

5 to 10 hours as there is no room for scheduling to achieve better results.

b) Elastic: Those appliances which can be scheduled for better results are known as elastic appliances. They are further classified into two types:
   - Continuous: Those appliances which operate continuously for 'h' hours are known as continuous. For example a washing machine should continuously run for 'h' hours until the job is totally done; else if it is interrupted the total process will start from the beginning.
   - Discrete: Those appliances which do not have any constraint to operate continuously for 'h' hours are known as discrete. For example a food oven can be used in different time slots.

A. Methodology

Step 1: At first each consumer is asked to fill up a table either online or offline. The table consists of the following attributes.

Appliance	Preferred Interval	Duration	Unit/hr	Type

Step 2: The non-elastic appliances are scheduled first and the total load is deducted from the maximum load capacity of the scheduled time slots. For example, the preferred interval of operation of a refrigerator is 6 PM to 11 PM and the duration is 5 hours. It consumes 5 units per hour. The maximum load capacity of each hour as provided by the power station is 20 units per hour. Since there is no scope to schedule the refrigerator, it is forcefully scheduled between its preferred interval and the maximum load capacity is reduced by 5 units to 15 units. This modified load capacity will be used later for final calculation.

Step 3: All one hour slot specified in the preferred interval column of each appliance is marked as contention slot. For example, if the preferred interval for App1 is 0 to 5 hours and App2 is 5 to 7 hours, there will be 7 contention slots.

Step 4: A group of continuous contention slots are combined into a super group or slot. For example, if the preferred interval for App1 is 0 to 5 hours and App2 is 5 to 7 hours, there will be 7 contention slots and since the contention slots are continuous, a super group will be formed of 0-7 hours and 2 appliances.

Step 5: All the appliances in a particular super group is then scheduled using ILP.

B. ILP Formulation

The ILP formulation is made for each super group. Let
h=number of hours in the super group
c=number of continuous appliances in the super group
CO_i = cost per unit for ith hour
For each continuous appliance in a super group:
Let 'a to b' hours be the preferred interval and'd' be the duration, then there will be (b-a)-(d-1) variables.
Y_{jh} be the variable for jth appliance if hth hour is the starting hour of the appliance.
$\sum_{h=a}^{b-d}\{\sum_{i=h}^{h+d-1} COi\}$ indicates the total cost for one continuous appliance

So Total Cost for 'c' continuous appliance = $\sum_{j=0}^{c}\sum_{h=a}^{b-d}\{\sum_{i=h}^{h+d-1} COi\}\, y_{jh}$

For each discrete appliance:
Let d=number of discrete appliances in the super group and 'a-b' be the preferred interval, then there will be 'b-a' number of variables.
x_{jh} be the variable for jth appliance for hth slot
$\sum_{h=a}^{b-1} CO_h$ represents the total cost for one discrete appliance

So Total Cost for 'd' discrete appliance $=\sum_{j=0}^{d}\sum_{h=a}^{b-1} CO_h\, x_{jh}$
Total Cost TC = Total cost for 'c' continuous appliance + Total cost for 'd' discrete appliance
We need to Minimize Total Cost TC subject to the following constraints:

For each continuous appliance 'i'
$\sum_{h=a}^{b-d} y_{ih} = 1$

For each discrete appliance 'i'
$\sum_{h=a}^{b-1} x_{ih} = d$
For each hour slot 'i'
P_i Σ Contributing variables for discrete appliances + P_i Σ Contributing variables for continuous appliances <= ML_i
Where P_i is the total power consumed by that particular appliances in slot 'i' and ML_i is the Maximum Load capacity of slot 'i'

6. Experiments

In this section, we report the simulation studies we have performed to determine the runtime performance of the ILP formulation and the advantages of the ILP formulation over the contemporary method of consumption. In most cities around the world, each consumer randomly schedules the appliance without paying attention to the cost effectiveness of the schedule. There may be more than one way to schedule the appliances out of which the customer may not choose the cost effective schedule. We will consider two scenarios (a) the consumer randomly schedules the appliances i.e. the contemporary method and we name this as *random process*. Next we will compare it with (b) our ILP formulation and we name this process as *ILP process*. The total cost obtained from the *ILP formulation* and the *random process* is taken into account. Also it is shown that by following our *ILP formulation* the overloading problem can be reduced by a significant margin as compared to the *random process*.

A. Experiment Results

Table 3: Appliance Details of Experiment

Appliance	Preferred Interval	Duration	Unit/hr	Type
App 1	06-16	10	5	Non Elastic
App 2	7-9	1	15	Discrete
App 3	7-12	2	10	Continuous
App 4	8-12	3	5	Discrete
App 5	0-5	2	10	Continuous
App 6	2-5	2	10	Discrete
App 7	0-5	1	15	Continuous
App 8	18-23	2	15	Continuous
App 9	20-23	2	10	Discrete
App 10	19-23	1	20	Discrete

In our first experiment, we assume that customers randomly schedule the appliances. The details of a customer appliance table are given above in Table III. At first the non elastic appliance is scheduled and the Maximum Load capacity of 06-16 hours is reduced to 15 units. We suppose that the customer schedules the appliances randomly according to the table given below:

Table 4: Result after random scheduling

Appliance	Scheduled Interval
Appliance 1	06-16
Appliance 2	8-9
Appliance 3	10-12
Appliance 4	8-11
Appliance 5	1-3
Appliance 6	2-4
Appliance 7	1-2
Appliance 8	19-21
Appliance 9	20-22
Appliance 10	18-19

Now before applying the IPL, we must mark the contention slots and form the super groups in order to schedule the appliances within that particular super group. After finding the contention slots, 3 sub groups have been identified. Each subgroup contains three appliances to be schedules. The non-elastic appliance is scheduled first and hence the IPL formulation is done using $ML_i = 15$ for i=6 to 16. After scheduling the non-elastic appliance the IPL formulation is done one three different subgroups whose result is as shown in the table below:

Table 5: Result after ILP scheduling

Appliance	Scheduled Interval
Appliance 1	06-16
Appliance 2	7-8
Appliance 3	9-11
Appliance 4	9-12
Appliance 5	3-5
Appliance 6	3-5
Appliance 7	0-1
Appliance 8	18-20
Appliance 9	20-22
Appliance 10	22-23

The hourly cost provided by the supplier is given in the table VI below. The graph in Figure 3 below shows the power comparison between random process and ILP process. It is evident from the graph that the total power never exceeds the maximum load capacity. On the other hand if the appliances are scheduled randomly, the total power exceeds the maximum load capacity on three points (1-2 hours, 8-9 hours and 20-21 hours).

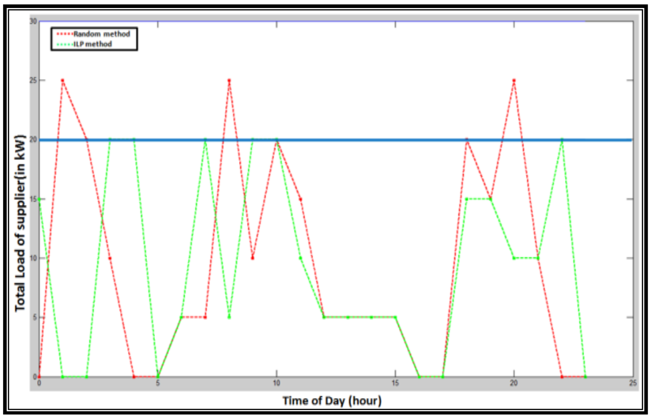

Figure 3 : Power comparison between ILP and random method

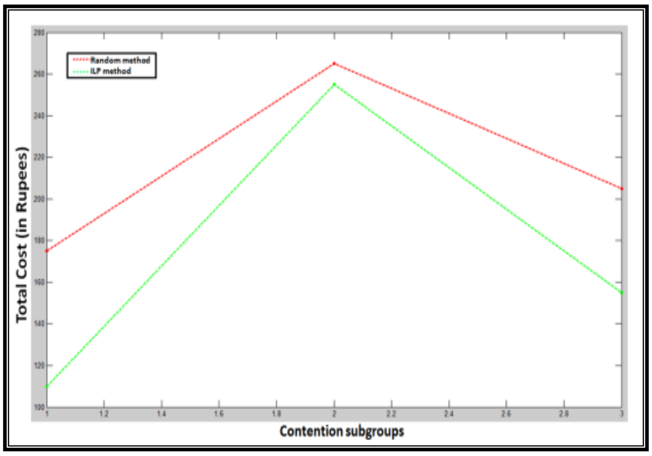

Figure 4 : Cost comparison between ILP and random method

In the second experiment, we compare the cost of random method and ILP method. The graph shown in Figure 4 shows the cost comparison between random process and ILP process for three different subgroups. In each super group, the cost of random method is much more than that of the ILP method. So, it can be concluded hereby that the total cost of consumption in ILP method of scheduling is relatively lower than that of the random method of scheduling. It is also evident from the graph that the ILP cost will always be less than the random process cost.

7. Conclusion

From the above experiment results we may conclude that the ILP method has several advantages over random or normal method of scheduling. Firstly the ILP method will try to schedule the maximum number of appliances within the particular time slot such that the maximum load capacity is never exceeded. Secondly, using ILP, the cost at the consumer end is reduced highly compared to the heuristic and normal method of scheduling. Furthermore, ILP reduces the chance of overloading since we use the maximum load capacity as the constraint in the mathematical formulation. In case the total load exceeds the maximum load capacity the damage caused will be minimal as scheduler will prohibit the consumers from scheduling further appliances.

In future households will have access to multiple power suppliers each having varying rates per unit. The future scope of this thesis paper is to schedule the appliances of consumers with multiple power suppliers. Multiple power suppliers with varying power suppliers provide incentives to the customers and the customers can thereby adhere to a particular scheduling process to avoid unnecessary payment.

Table 6: Hourly cost per unit

Hour	*Cost per unit*	*Maximum Load Capacity*	*Hour*	*Cost per unit*	*Maximum Load Capacity*
0-1	2	20	12-13	4	20
1-2	3	20	13-14	2	20
2-3	4	20	14-15	2	20
3-4	2	20	15-16	3	20
4-5	2	20	16-17	4	20
5-6	3	20	17-18	2	20
6-7	2	20	18-19	2	20
7-8	3	20	19-20	3	20
8-9	4	20	20-21	4	20
9-10	2	20	21-22	2	20
10-11	2	20	22-23	1	20
11-12	3	20	23-00	4	20

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