Home Electrical Energy Management System Using DijCostMin Algorithm

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Abstract. In the afternoon until night, an electrical load is increased, it happened because to increase the usage of electrical devices by customers. These conditions in which increased electricity consumption by buyers at the same time with the quantity a large power have not been able to handle properly by PLN as the supplier of electrical energy in Indonesia. The impact is the occurrence of the power outage in rotation, to reduce these all, needs to be setting the use of electric power appropriate, in order to achieve the purpose of balance between demand and supply for electricity energy; especially on the household sectors. One of the tricks is enacting the management of the load on the side of their customers or well known as Demand-Side Management (DSM) and apply dynamic pricing on electricity tariff from the peak time and non-peak time. Home Electrical Energy Management System (HEEMS) is a system for managing electrical energy-based method DSM and apply dynamic pricing. HEEMS allows users to manage and monitor the usage of electricity. HEEMS serves to do scheduling on the use of an electrical device DijCostMin Algorithm based on data planning the use of devices electricity or load forecasting entered by users. The method that proposed is a success and effective to reduce energy demand is about 22.69% when peak time and reduce bills of electricity is about 8.38%.

Keywords: Demand Side Management (DSM), DijCostMin Algorithm, Non-Peak Time, Peak Time.

1. Introduction
In the 21st century, the problem of energy conservation has come to the attention of many people, especially for academics and researchers. One the problem is PLN as the supplier electricity energy in Indonesia have not been able to handle properly customers demand of electrical energy at the same time in big quantity or well known as Peak Time Demand [1]. Many solutions which has been offered to handle the problem, example as implementing a load of management in the sight of customers or better known as Demand Side Management (DSM) which is dynamic pricing is one of the tools by DSM [2]-[3]-[4]. Most of the previous research on dynamic pricing to encounter the peak demand and does not preclude for it’s implemented in Indonesia [5]-[6].

In this work, we present a Home Electrical Energy Management System (HEEMS) lies under the umbrella of DSM, it allows the consumer to supervise and manage the power usage of the appliance [7]. HEEMS is a system for energy optimization to minimize the cost and to manage peak demand by scheduling the loads with consumer satisfaction [8]. Based on the literature the problem has identified
as MILP (Mix Integer Linear Programming), the complexity can be reduced by formulating in two steps as step (i) and step (ii) with necessary constraints [9].

The first step problem is to group the household appliances, and this group of appliances to be scheduled in a timeslot [10]. It’s to be ensured which total load demand should not exceed the “\( E_{max} \)” at any circumstance. In the subsequent step pick a specific list of an optimized set of household appliances which satisfies the given constraints and it will accommodate to a time slot. This paper contributes an efficient energy control and management scheduling system by considering the basic problem formulation in a home environment [11]. The second step problem is to schedule the formulated sets of devices in the previous step to minimize the sum cost, in this section we use DijCostMin Algorithm to solve the problem.

2. Literature Review

We consider a modern energy system installed at the end-user that can be examined, calculate, optimize, and manage the flow and use of energy. Figure 1 shows the considered system model where a HEMS module is connected with the smart meter at one end and to all the appliances at the other end. A smart meter is an intelligent device which calculates the power consumption and communicates with the utility simultaneously [12]. We assume that it receives the energy pricing signals from the utility over Power Line Carrier (PLC) and communicates the price values to HEEMS [13].

![Figure 1. System Model](image)

Smart meter and HEEMS are connected through the wired or wireless, and HEEMS communication through all appliance for data collection and load control can be performed with Zigbee to ease the users in use although the devices are can’t be reached to the internet [14]. The appliance will be grouping in two types of appliances: 1) Schedulable appliance, ‘A’ number of the total schedulable appliance which is fully flexible and can be turned on at a later time and the set become ‘\( S = \{A_1,A_2,A_3,\ldots,A\} \)’. 2) Real-time appliance, ‘B’ number of the total real-time appliance which has a low degree of flexibility depending on customer needs and priority [11]-[15]-[16]. So the set become ‘\( R = \{B_1,B_2,B_3,\ldots,B\} \)’. These devices have to be scheduled in any time slot based on customer choice of operation as shown in equation (1).

\[
T = \{t_1,t_2,t_3,t_4,t_5,\ldots,t_n\}
\]

where,

- \( T \) = total time slots,
- \( t_n \) = \( n^{th} \) time slots,
- \( n \) = number of slot per day.
So, based on the literature the problem can be defined as MILP or Mix Integer Linear Programming because there are any some states and constraints that should be fulfilled [17]-[18]. It caused there is any kind of electrical devices and also there are any more than one constraint that should be fulfilled like Emax, available timeslots, time of the devices to complete the task, and etc. The goals that want to be achieved is the scheduling of using electrical devices [19]. In this research to get the goals that we want to be achieved, we are using DijCostMin Algorithm. DijCostMin Algorithm is an algorithm that used to find the shortest path from one vertex to the others vertex on weighing graph. This algorithm is an algorithm that modified from Dijkstra Algorithm [20], but between DijCostMin and Dijkstra has some differences, especially on the steps to find the shortest path [11].

3. Methods
Let “Eapp” is the total energy required by the set of devices to complete their operation and should not exceed Emax. For the simulation purpose a total of ten household appliances (d1,d2,d3,d4,d5,d6,d7,d8,d9,d10) are considered. Among these ten appliances, two appliances are considered as Non-Schedulable (Real-time) appliances ‘R’ = {d1,d3} and the remaining eight appliances are schedulable appliances ‘S’ = {d2,d3,d4,d5,d7,d8,d9,d10}. And also, tariff ‘C’ of each time slots is

\[ C = \{C_1,C_2,C_3,C_4,C_5,C_6,...,C_n\} \]  

Where,
\[ C = \text{Total cost of time slots}, \]
\[ C_n = \text{Cost of n}^{th} \text{ time slots}. \]

For this case, we just make two groups of cost or tariff, first is Non-Peak Demand tariff = \{C_1,C_2,C_3,C_4,C_5\} and second is Peak Demand tariff = \{C_6,C_7,C_8\}. And then, for the ease of mathematical formulation, the binary variable \( V_{Sapp,n} \):

\[ V_{Sapp} .n = \begin{cases} 1, & \text{if Sapp-th device is ON in timeslot } t_n. \\ 0, & \text{otherwise.} \end{cases} \]

\[ \forall_{Sapp=1...A}, \forall_{n=1...N}, \]

Thus, the number of schedulable appliances which are turned ON at time slot \( t_n \) can be represented as:

\[ S_{S}^n = \sum_{S}^{A} (V_{Sapp} .n), \forall n \]  

Further, we define \( V_{Rapp,n} \) a binary variable for real-time appliances:

\[ V_{Rapp} .n = \begin{cases} 1, & \text{if Rapp-th device is ON in timeslot } t_n. \\ 0, & \text{otherwise.} \end{cases} \]

\[ \forall_{Rapp=1...B}, \forall_{n=1...N}, \]

Thus, in a given time slot \( t_n \), real-time appliances are tuned ON and can be represented as:

\[ K_{R}^n = \sum_{R}^{B} (V_{Rapp} .n), \forall n \]

3.1. Problem Statement
The target of this research to reduce the peak demand and the cost of energy consumption. The total cost the energy consumption of schedulable appliances and real-time appliances per day should be minimized by optimum scheduling scheme and the optimized path is shown in equation (5).

\[ V \min_{n} \sum_{n=1}^{N} \sum_{S}^{A} (S_{S}^n = 1 I_{Sapp} + \sum_{R}^{B} (V_{Rapp} .n \sum_{n=1}^{N} \sum_{R}^{B} = 1 I_{Rapp} .n) \]  

Where two function cost \( I_{Sapp} \) and \( I_{Rapp} \) in equation (5) represent the cost of Sapp\(^{th}\) schedulable device in \( n^{th}\) time slot and Rapp\(^{th}\) real-time device in \( n^{th}\) time slot, Thus, we have:

\[ I_{Sapp} = \frac{\delta_{S}^{B} \gamma_{S}^{B} \delta_{S}^{n} \gamma_{S}^{n}}{F_{S}}, \quad I_{Rapp} = \frac{\delta_{R}^{B} \gamma_{R}^{B} \delta_{R}^{n} \gamma_{R}^{n}}{\epsilon_{R}} \]
Where $p_{S,n}^{C}$ is the cost of a schedulable device during $n^{th}$ time slot and $p_{R,n}^{C}$ is the cost of a real-time device during $n^{th}$ time slot with $p_{S,n}^{C} = (P_{Sapp,n})(V_{Sapp,n})$ and $p_{R,n}^{C} = (P_{Rapp,n})(V_{Rapp,n})$, where $P_{Sapp,n}$ and $P_{Rapp,n}$ are the energy consumed in time slot $t_n$ by the Sapp schedulable devices and Rapp real-time devices.

As has been described in early, to reduce the complexity the problem will be divided become as two sub-problems, so it will be solved in two steps too.

3.2. Problem Solution

Since the problem was identified as MILP or more specifically is MIBP, it’s solved in two steps.

1) Step (i)

Step by step to solve the sub-problem 1 are summarized as:

1. Add the devices in set ‘R’ $\{B_1, B_2, B_3, ... B\}$ one by one into member of set L $\{D_1, D_2, D_3, ... D_y\}$ until $\sum_{R}^{n} = n^C \leq E_{max}$. Thus, the constraint in eq (16) is satisfied.

2. Adding the devices from set ‘S’ $\{A_1, A_2, A_3\}$ one by one into member of set L $\{D_1, D_2, D_3, ... D_y\}$ until demand for each device is satisfied for each timeslots.

2) Step (ii)

In this research, DijCostMin Algorithm is using to find the optimum solution to make the schedule devices for each timeslot. Step by step DijCostMin Algorithm to solve sub-problem 2 are summarized as [11]:

1. Calculate the cost for each node in each tier, i.e total energy consumed each set multiply with price in each tier.

2. Assign the path by doing permutation as much as $N$ factorial, which is $N$ is total tiers and it’s equal total timeslots, so it will never happen re-choosing the same nodes in next tier.

3. Assign the shortest path by judgment from a minimum of the total cost for every path.

4. Results

To verify the effectiveness of DijCostMin Algorithm in scheduling the home appliances to minimize the cost and manage peak demand in case the dynamic pricing is implemented. For simulation, we make a load scenario. We assign two of ten appliances as real-time devices ‘R’ = $\{B_1, B_2\}$ and it should be kept ON for all timeslots, and the rest as the schedulable devices ‘S’ = $\{A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8\}$. The following graphic (Figure 1) shows the demand of each appliance in each timeslot in the scenario.

![Figure 1. Graphic of Total Demand Energy Per Timeslots Without Algorithm vs Using Algorithm.](image-url)
Figure 2. Graphic of Total Demand Energy Per Timeslots Without Algorithm vs Using Algorithm.

Table 1. Comparison of Total Cost Between Non-Algorithm vs Algorithm

| Ts  | Cost Non-Algorithm (Rp) | Algorithm (Rp) |
|-----|-------------------------|----------------|
| T1  | 4.235,82                | 4.235,82       |
| T2  | 4.235,82                | 4.235,82       |
| T3  | 3.447,60                | 3.447,60       |
| T4  | 3.447,60                | 3.447,60       |
| T5  | 3.818,05                | 3.818,05       |
| T6  | 5.199,79                | 4.510,80       |
| T7  | 4.629,92                | 4.510,80       |
| T8  | 6.698,48                | 4.510,80       |
| Total per day | 35.713,08 | 32.717,28 |
| Total per 30 days | 1.071.391,40 | 981.518,40 |

Figure 2 shows the total demand energy per time slots if using the algorithm and isn’t, especially in time slot 6, 7, and 8 when it’s the peak demand occurs. The algorithm can reduce the demand of energy till 22.69% and also we can see from Table 2 the total cost per day and total cost per 30 days, scheduling based on the algorithm is cheaper than the conventional way with the same scenario and using modified dynamic pricing as explained before, so the algorithm can reduce bills of electricity till 8.38%.

5. Conclusion
This paper proposes a way to encounter the dynamic pricing if it’s implemented in Indonesia where the scenario using the modified dynamic pricing that adopted electricity tariff in Indonesia right now for an industrial tariff which divided into two tariffs; Peak Time Tariff and Non-Peak Time Tariff. Do scheduling the household appliance based on DijCostMin Algorithm can achieve the optimal result to make a cheaper bill of electricity till 8.38% and reduce peak demand for electricity in peak time based on the load scenario. However, for the future work, multiple home environments with more appliances
can be taken into consideration with real dynamic pricing and real-time load variations which are integrated with IoT.

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