Application Of Low Cost And Reliable Home Energy Management System Using Generalized Reduced Gradient Nonlinear Solver Method

Muhammad Sarmad, Nedim Tutkun, Samran Saleem
Istanbul Aydin University, Department of Electrical & Electronics Engineering
Beşyol, İnönü Cd. No:38, 34295 Küçükçekmece/Istanbul, Turkey
Phone: +902124441428/22502
Email: samchohan49@gmail.com, ntutkun@ticaret.edu.tr, samranch11@gmail.com

***Abstract*—Electricity bills are a big cost for residential owners. With system efficiency improvement the cost of electricity bills can be reduced and it can bring significant benefits to house owners. Energy management systems play an important role in system operation and control. Electricity utilities base their charges on different factors but important are demand and consumption. If the irregularities during consumption are controlled, then it can play an important role in power generation. Demand side management is responsible for lower energy demand which in turn avoids the cost of utilities, building new generators and saving the environment from pollution as well. There are some DSM techniques to optimize this consumption for both commercial and domestic users. In this research, the process used to solve this problem is Generalized Reduced Gradient Non-linear solver method. The load factor is basically the ratio between average load and peak load. In domestic residential, load factor remains very low due to unscheduled load consuming the power more during the peak hours. This system contains the load profile of a residential building under consideration. Proposed design will help improve the energy consumption by reducing the usage of shift-able loads during peak hours and transfer in different hours to reduce the load factor. The designed system is optimized using Excel solver, which is responsible to perform Generalized Reduced Gradient Non-linear solver method. After applying the optimization technique, the simulation result shows the significant improvement in load curve, which can provide benefits for both generating sectors and consumers.**

Keywords—Energy management, Demand side management, Load factor, Power scheduling, Excel solver.

1. INTRODUCTION:

A well-managed energy management system was introduced by Faisal Baig in (2013) [1]. He proposed a two-part method. One is the power management centre (EMC) which contains a graphical interface. EMC displays operating time data and maintains user log data and equipment control. The second part of this approach is to edit uploads using a single knapsack problem.

Shareef at el in 2018 at IEEE have proposed a system that often creates fair use schedules by looking at a number of factors, such as energy costs, environmental concerns, upload profiles, and consumer comfort. With the introduction of smart meters, performing control using Energy management systems with Demand response enabled machines has become possible [2]. A research paper developed by Mahapatra & Nayyar last year proposed a new way to improve the construction of homes by incorporating the concept of green construction to reduce the use of energy by a resident in their home. Their research has shown that the effect of various programs on large-scale reductions through the Optimization based residential energy management (OREM) process shows a decrease in energy consumption showing a 35% reduction in total electricity debt [3].The short-term opportunity to implement an energy management system is not limited to individual consumers. However, with the integration of several consumers there is great potential. Manufacturers of Smart home energy management system need to communicate in order to integrate and ensure smooth interaction at home [4]. Home energy management systems optimize energy consumption by automating the connection between load and energy source [5] [6]. Through graphical response, one can realize the energy consumption. Smart home requires energy management system to optimally utilize the energy [7]. Several methods are used now a day for energy management including demand-side management (DSM), load scheduling, and many more [8].

2. PROPOSED METHODOLOGY

In the proposed method, of whom the flow chart is given in fig1, the first stage is to figure out the nature of the load if it is shift able/non-shift able. The non-shift able load cannot be scheduled. It will remain the same. Shift able loads are further categorized in fully and partially shift able. According to the given data, a whole load schedule as given will be labelled in Excel. After that optimization tool will be applied to that objective which is to maximize the load factor. In this research, the Generalized Reduced Gradient Non-linear Solver method is applied to maximize the load factor. It is a constrained Non-linear Programming method. A generalized reduced gradient algorithm is proposed exploiting the staircase structure of the Jacobian matrix of the dynamic equations by using some priority principles on the partition of the variables into basic and independent sets for each time period when a re inversion is needed, and for choosing a substitute basic variable when change-of-basis occur for regularity reasons. After finding the best schedule for shift able loads it will replace the binary on/off section and set a new schedule which will improve the load factor which will be demonstrated by the load curve representation. The program terminates if the objective function is improved. Demand side management includes improvement of load curves and load factor [9]. DSM can be implemented in two ways either direct or indirect load control. In direct control the utility can save energy by switching off the load of specific consumers. While in in-direct control the utility applies some techniques like load time scheduling, thermal storage method and many more [10].

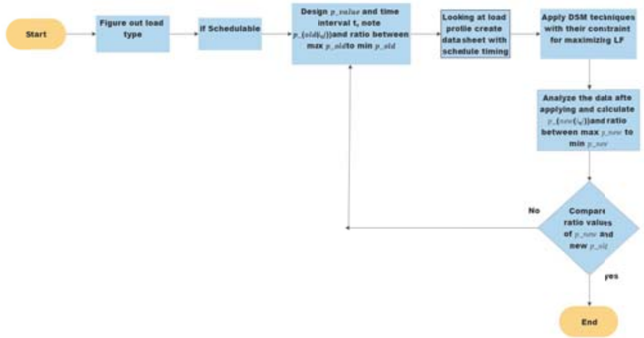

Fig 1: Flowchart of Proposed System

2.1. LOAD FACTOR & LOAD CURVE

The load factor is one of the most important factor in Energy systems. Basically, it is the ratio of the sum of maximum load/demand of the system to the total connected load on the system. Its value remains less than 1. This factor in the power system explains how much energy is being used during a specific period versus how much would have been used during that time interval. A system is considering well consumed if its value is very close to 1. It can be improved by improving the distribution of load during the different time intervals.

Load Factor = Average Load X 24 Hours / Peak Load X 24 Hours (1)

Load curve/load profile provides information of demand at a specific interval. This graphical representation of load provides a lot of useful information regarding consumption and generation need for the specified interval. This provides great help in scheduling the load consumption more efficiently. It is an important factor in deciding to generate the capacity of the system. It estimates generating cost and help out in deciding operation schedules of power station. Maximum power is the power indicated at the top of the curve. A load curve of 24 hours from midnight to noon is shown in fig 2.

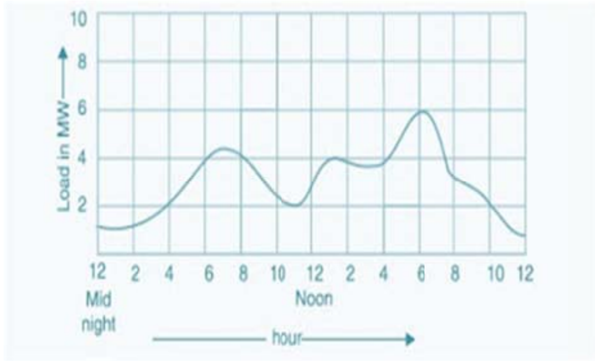

Fig 2: Load Curve of a Household for 24 Hours

2.1.1. OBJECTIVE FUNCTION

For all possible DSM techniques used for optimal schedule finding problem either to maximize the load factor or to reduce the cost of utility. In this problem, load factor improvement will be done by some non-linear problem solve technique using Excel solver. The objective function for load factor which has to be improved is as follows.

$$LF_{max} = LF_{max} = \left[\left[\sum_{i=1}^{N}\sum_{j=1}^{J} \mathrm{P}_{(i,j)}\, \mathrm{t}_{(j)}\right] / \sum_{j=1}^{J} t_{(j)}\right] / \sum_{i=1}^{N} \mathrm{P}_{(i,k)} \quad (2)$$

for $\mathbf{LF_{max}}$ – the maximum load factor value, $P_{(i\,j,)}$ – power demand of the load type i at the time interval j, for **i** = 1,., N, and j = 1,., J, N – the total number of load types, J – the total number of time intervals, $\mathbf{P_{tot\,j()}}$ – the total demand power for all types of loads, where j denotes time interval number, **k** – time interval of the maximum demand of all load types i = 1,., N, over all intervals j = 1,., J.

2.1.2. LOAD SHIFTING TECHNIQUE

Objective function can be optimized either by equality or inequality constraints. Load shifting technique just shift the peak load without changing the total power consumption.

Equality constraints

$p_{new(i,j)} = p_{value}$ for t range $\{t_k\,, t_h\}$ (3)

Inequality constraints

$p_{new(i,j)} \geq p_{old(i,j)}$ for t range $\{t_0\,, t_k\}$ and $\{t_h\,, T_{tot}\}$ (4)

$p_{new(i,j)} \leq p_{value}$ for t range $\{t_0\,, t_k\}$ and $\{t_h\,, T_{tot}\}$ (5)

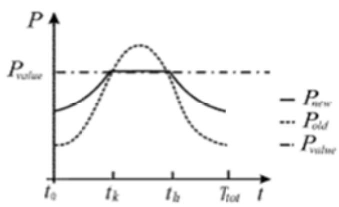

Fig 3: *Load shifting Parameters*

Table 1: Load profile of household

Appliance	Operation range (h)	Operation time (min)	Average power (kW)
Fully Time Shift able			
Dishwasher	1-24	120	1.80
Washing machine	1-24	120	0.80
Clothes dryer	1-24	60	2.50
Partly Time Shift able			
Iron	16-22	60	1.00
Vacuum cleaner	9-13	120	0.50
Oven	15-20	120	2.00
Hair dryer	6-10	60	2.10
Toaster	6-10	60	1.20
Electric kettle	6-10	60	2.10
TV	6-24	660(11hr)	0.10
Air conditioner	8-24	600(10hr)	1
Non-Time Shift able			
Fridge	1-24	1440(24hr)	0.15
Indoor lighting	7-8, 19-24	480 (8hr)	0.20
Outdoor lighting	1-7, 19-24	780 (13hr)	0.10

3-RESULTS AND DISCUSSION:

Table 1 include a household load profile which includes all common appliances that are being used in every home. Some of the appliance have to operate in specific hours or use 24 hours. These appliances are non-shift able appliances. Some of the have no specific time to operate these are shift able and partially shift able appliances. Using optimizing technique, the load factor which represent the behaviour of system that how well system is consuming energy and how much is being wasted in loses. Results achieved with the help of generalized reduced gradient non-linear solver method are discussed in this section.

The schedule of fully shift able loads and load curve values before applying optimization technique give down in Table 2.

Table 2: Schedule of Fully shift able loads before applying optimization technique & system load curve

Sr. No	Time (Hrs)	Base Load	Dish washer	Washing Machine	Clothes Dryer	Time (Hrs)	Base Load	Old Load Curve (watts)
1	**1**	250	1	1	1	**1**	250	5350
2	**2**	250	1	1	0	**2**	250	2850
3	**3**	250	0	0	0	**3**	250	250
4	**4**	250	0	0	0	**4**	250	250
5	**5**	250	0	0	0	**5**	250	250
6	**6**	250	0	0	0	**6**	250	5750
7	**7**	250	0	0	0	**7**	250	350
8	**8**	250	0	0	0	**8**	250	1350
9	**9**	250	0	0	0	**9**	250	1850
10	**10**	250	0	0	0	**10**	250	1850
11	**11**	250	0	0	0	**11**	250	1350
12	**12**	250	0	0	0	**12**	250	1350
13	**13**	250	0	0	0	**13**	250	1350
14	**14**	250	0	0	0	**14**	250	1350
15	**15**	250	0	0	0	**15**	250	3350
16	**16**	250	0	0	0	**16**	250	4350

17	**17**	250	0	0	0	**17**	250	1250
18	**18**	350	0	0	0	**18**	350	350
19	**19**	450	0	0	0	**19**	450	450
20	**20**	500	0	0	0	**20**	500	500
21	**21**	450	0	0	0	**21**	450	450
22	**22**	350	0	0	0	**22**	350	350
23	**23**	250	0	0	0	**23**	250	250
24	**24**	250	0	0	0	**24**	250	250
Capacity			**1800**	**800**	**2500**			
Runtime			120	120	60			

The Table 3 shows the same details but for partially shift able loads. The highlighted blocks are the time frame in which these loads can only be scheduled. Capacity shows how much power consumption is done by that appliance and runtime shows how many minutes the devices have to operate.

Table 3: *Schedule of Partially shift able loads before applying optimization technique*

Time (Hrs)	**Base Load**	**Iron**	**Vacuum Cleaner**	**Oven**	**Hair Dryer**	**Toaster**	**Electric Kettle**	**TV**	**Air Conditioner**
1	250	0	0	0	0	0	0	0	0
2	250	0	0	0	0	0	0	0	0
3	250	0	0	0	0	0	0	0	0
4	250	0	0	0	0	0	0	0	0
5	250	0	0	0	0	0	0	0	0
6	250	0	0	0	1	1	1	1	0
7	250	0	0	0	0	0	0	1	0
8	250	0	0	0	0	0	0	1	1
9	250	0	1	0	0	0	0	1	1
10	250	0	1	0	0	0	0	1	1
11	250	0	0	0	0	0	0	1	1
12	250	0	0	0	0	0	0	1	1
13	250	0	0	0	0	0	0	1	1
14	250	0	0	0	0	0	0	1	1
15	250	0	0	1	0	0	0	1	1
16	250	1	0	1	0	0	0	1	1
17	250	0	0	0	0	0	0	0	1
18	350	0	0	0	0	0	0	0	0
19	450	0	0	0	0	0	0	0	0
20	500	0	0	0	0	0	0	0	0
21	450	0	0	0	0	0	0	0	0
22	350	0	0	0	0	0	0	0	0
23	250	0	0	0	0	0	0	0	0
24	250	0	0	0	0	0	0	0	0
		1000	**500**	**2000**	**2100**	**1200**	**2100**	**100**	**1000**
		60	120	120	60	60	60	660	600

Table 4 contains all important parameters which are involved in this problem. Most important of the load factor which is our objective to be optimized is shown in that particular scenario. The value of load factor is 0.2684. Maximum demand for the household is 5750 watts and minimum is 250 watts both are highlighted to look prominent. Average load demand is also calculated which is 1543.75 watts. All these parameters are calculated before applying optimization to the system.

Figure 5 shows the load curve of the system. In which complete variation of load consumption is shown graphically. As per looking at the graph that it's maximum goes 5750 watts and minimum up to 250 watts. It is quite clear from this representation that variation between maximum load consumption and minimum load consumption is very large. It shows that the power consumption in this system needs improvement. For that optimization technique would be used. In this case we use Generalized Reduced Gradient Non-linear Solver. It is performed using excel solver.

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Table 4: System Parameters before optimization

Load Factor	0.26
Maximum demand	5750
Average demand	1543.75
Units	37050

The results of load curve are given below.

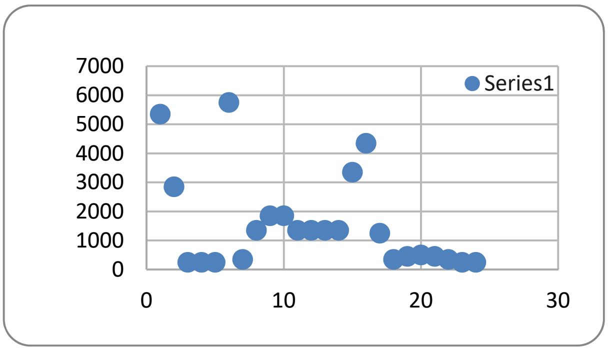

Fig 1: *Load/Demand Response before Optimization*

Showing Load at y-axis and hours along x-axis.

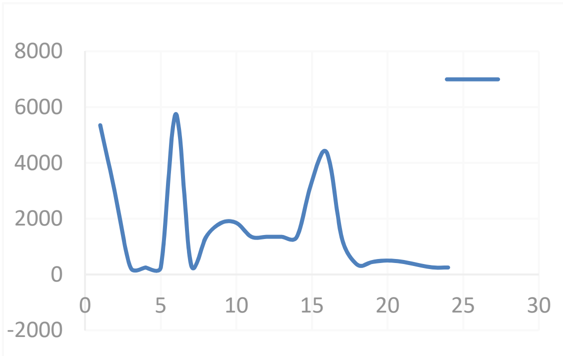

Fig 5: *Load Curve before Optimization*

So all information parameters and details are obtained for that load profile of household. Now we applied our proposed optimization technique. This process is being carried out in Excel solver. Excel solver has some special built in solving methods and this optimization is being done through this tool as well. Information about that and also constraints section and more related to this task is shown in figure down fig 6.

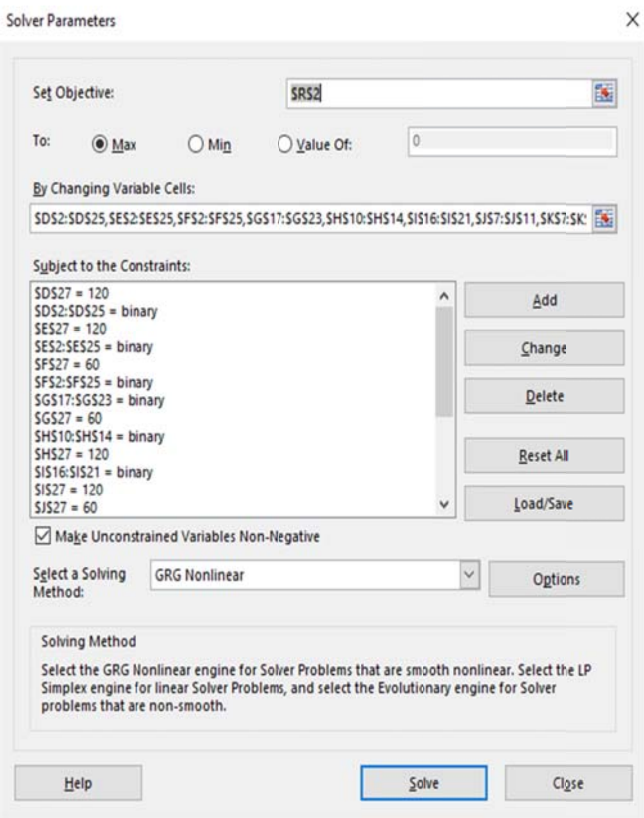

Fig 6: Excel Solver Parameter Set for Optimization

Optimal output received for the problem will be mention now step by step. We can compare both before and after results of the problem down below. As firstly as we had constructed a table of schedule of all fully schedule-able loads. In the table 5 the same parameters after applying optimization technique are shown.

Table 5: Schedule of Partially shift able loads after applying optimization technique

Time (Hrs)	Base Load	Iron	Vacuum Cleaner	Oven	Hair Dryer	Toaster	Electric Kettle	TV	Air Conditioner
1	250	0	0	0	0	0	0	0	0
2	250	0	0	0	0	0	0	0	0
3	250	0	0	0	0	0	0	0	0
4	250	0	0	0	0	0	0	0	0
5	250	0	0	0	0	0	0	0	0
6	250	0	0	0	0	0	1	1	0
7	250	0	0	0	0	0	0	1	0
8	250	0	0	0	0	0	0	1	1
9	250	0	1	0	0	1	0	0	0
10	250	0	0	0	1	0	0	1	0
11	250	0	0	0	0	0	0	0	1
12	250	0	0	0	0	0	0	0	1
13	250	0	1	0	0	0	0	0	1
14	250	0	0	0	0	0	0	1	0
15	250	0	0	0	0	0	0	0	0
16	250	0	0	0	0	0	0	1	1
17	250	0	0	0	0	0	0	1	1
18	350	0	0	0	0	0	0	0	1
19	450	0	0	1	0	0	0	1	0
20	500	0	0	1	0	0	0	1	0
21	450	1	0	0	0	0	0	1	1
22	350	0	0	0	0	0	0	0	0
23	250	0	0	0	0	0	0	0	1
24	250	0	0	0	0	0	0	1	1
		1000	**500**	**2000**	**2100**	**1200**	**2100**	**100**	**1000**
		60	120	120	60	60	60	660	600

Maximum demand for the household was 5750 watts and minimum was 250 watts when we calculated according to first schedule which was before optimization but as we apply optimization the schedule changed and because of these values also change. Now maximum demand for the household is 2850 watts and minimum remain 250 watts both are highlighted to look prominent. Now as we can analyse both the variation of load demand decrease prominently which is an evidence that our rescheduling help system to improve energy consumption remain whole constraints unchanged. Important parameters such as maximum demand, average demand and unit consume are given in Table 6. Most important thing to be noticed by doing all this how much it effects the Power factor which was our main aim as well as our objective to be maximized. Load factor improvement can be seen in the table 5 recently the load factor was low due to irregular usage of power. Its value was 0.2684 before applying optimization, but after optimization the value of load factor is improved to 0.5416. Improvement is almost 50% after applying optimization which provide us better scheduling of load to be consumed in a day.

Table 6: Schedule of Fully shift able loads after applying optimization technique & new load curve of system

Sr. No	Time (Hrs)	Base Load	Dish washer	Washing Machine	Clothes Dryer	Time (Hrs)	New Load Curve (watts)
1	1	250	1	0	0	1	2050
2	2	250	1	1	0	2	2850
3	3	250	0	0	0	3	250
4	4	250	0	0	0	4	250
5	5	250	0	0	0	5	250
6	6	250	0	0	0	6	2450
7	7	250	0	0	0	7	350
8	8	250	0	0	0	8	1350
9	9	250	0	0	0	9	1950
10	10	250	0	0	0	10	2450
11	11	250	0	0	0	11	1250
12	12	250	0	0	0	12	1250
13	13	250	0	0	0	13	1750
14	14	250	0	0	0	14	350
15	15	250	0	0	0	15	250
16	16	250	0	0	0	16	1350
17	17	250	0	0	0	17	1350
18	18	350	0	0	0	18	1350
19	19	450	0	0	0	19	2550
20	20	500	0	0	0	20	2600
21	21	450	0	0	0	21	2450
22	22	350	0	0	1	22	2850
23	23	250	0	0	0	23	1250
24	24	250	0	1	0	24	2150
Capacity			**1800**	**800**	**2500**		
Runtime			120	120	60		

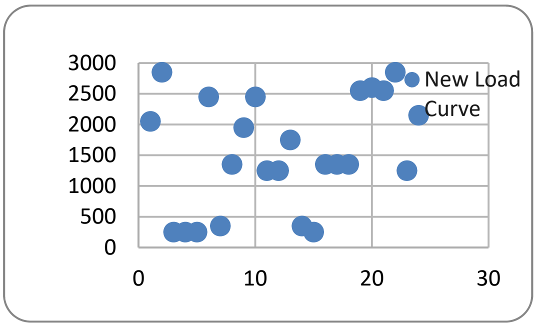

Fig 7: Load/Demand Response after Optimization

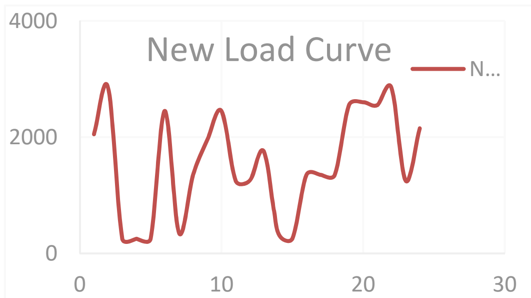

Fig 8: Load Curve after Optimization

The results of load curve are given above. Showing Load at y-axis and hours along x-axis.

Table 7: System Parameters after optimization

Load Factor	**0.54**
Maximum demand	2850
Average demand	1543.75
Units	37050

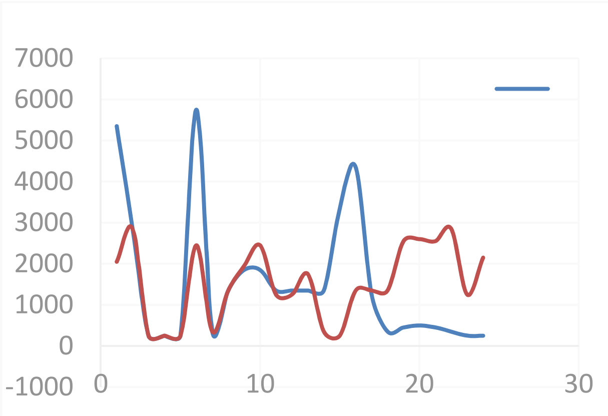

Fig 9: Load Curves Before and After Applying Optimization

The results of load curve are given below. Showing Load at y-axis and hours along x-axis. As mention before an optimization applied to the system improves the improvement of load consumption. It can be graphically represented with load curve. As we can analyse from figure that the variation between maximum and minimum load is reduced which in result improves the load factor as well. Blue waveform shows the load curve before applying optimization and orange waveform shows load curve after optimization.

3. Conclusion:

The proposed system is completely capable of optimizing and scheduling of load usage in a household. It's very important to optimize the usage to save energy from the utility as well as a consumer point of view. In third world countries like Pakistan and Bangladesh energy crisis is big issue and a lot of researches are under work to improve that as much as possible. In this research a very important factor of energy system known as Load Factor. It's the ratio between averages to peak load at any instance. Due to bad infrastructures and uneven distribution is some major cause that the load factor remains very low. Its value shows the condition of system that how optimal it is and how well it is consumed. According to most researches it values remain 25% to 30% in common household system but in this research it was also elaborated the same percentage of 25% can be seen before optimization. But after applying optimization technique load factor is improving and goes to 56% which can be seen in results section. A lot of complex systems have been proposed to obtain this objective. But using an Excel solver makes the system simpler and easier to change for different load profiles. That can be improved if we use the energy smartly proposed method is built to help out in this regard.

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