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Load Scheduling for Residential Consumer loads using Mixed Integer Linear Programming

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ABSTRACT

As compared to traditional flat electricity rates, real-time electricity pricing methods have the potential provide the economic and environmental benefits. Real time pricing gives consumers the option of reducing their electricity bills by responding to pricing that varies depending on the time of day. Load scheduling for the residential consumer loads is carried out using mixed integer linear programming (MILP). The proposedoptimization-based model in this paper aims to reduce the total electricity bill also ensuring the consumer comfort. The objective is to minimize both electrical peak load and electricity cost subject to various constraints. Proposed method effectively minimizes the energy consumption cost for day-ahead time horizon according to the forecasted electricity price using mixed integer linear programming Residential users can profit from the usage of renewable energy to improve energy efficiency and reduce their reliance on the grid while lowering their electricity bills. To efficiently control the load, a solar PV system is connected along with utility supply to feed theresidential loads. The optimization is also carried out in the presence of RES. The usefulness of the suggested model in greatly decreasing power costs and peak load is demonstrated by simulation results considering different scenarios.

Keywords : - Cost, Load Scheduling, MILP, Peak loads, Real time pricing

1. INTRODUCTION

Increased energy use has resulted in issues such as depletion of energy resources and pollution as a result of the energy production process [1]. Smart optimization models must be used in order to respond to ever-increasing energy demand while also reducing the environmental impact of energy generation [2-3]. Consumers can change their demand in reaction to supply by using real-time pricing, which uses a time-varying price based on the wholesale price of electricity and the cost of power generation. Consumers, on the other hand, are finding it difficult to manually schedule their increasing number of electrical appliances for shifting uses in response to hourly varying electricity prices [4][5]. Cost reduction is not the only objective that needs to be minimised during scheduling of consumer loads [6]. Methods for balancing peak demand and supply in an electrical grid with a large number of variables and customers that are cost-effective needs to be considered [7]. In addition, modern renewable energy integration can benefit both the utility and the consumer [8]. The notion of microgrids provides a good opportunity to manage by persuading users to schedule and control their own maximum demand, The reduction of electricity bills and peak-toaverage ratio (PAR) in load demand [9] utilising Mixed integer linear programming is carried out in [2][6][10]. Cost minimization and peak to average ratio subjected to constraints such as minimum and maximum energy consumption levels, average consumption level in each time period to be achieved over the entire day, user time preference and consumption ramping limits [2]. An active controller responds to a combination of internal set points and the external signal from the market, with the energy tariff varying over time as the stimulus for reaction from demand and in-home generation resources. In these work MATLAB is used to carry out load scheduling optimization of residential consumer devices using Mixed Integer Linear Programming (MILP). Each load has its individual power rating, varying energy requirement per day & user time preference. Each load is mathematically formulated and represented by a vector to go through optimization algorithms. Objectives include cost minimization, reduction of peak to average Ratio, lowering electricity price expenditure, improving load rate & user satisfaction degree. All objectives are prioritised as per the user and subjected to various mathematical constraints. Renewable energy source (PV) is integrated with these set of residential loads, for carrying out optimization. The simulation model developed is tested to verify its effectiveness for different scenarios. The paper is organized as follows, literature review is discussed in section II, problem formulation along with optimization algorithm is discussed in section III, simulation results are highlighted and discussed in section IV and V respectively, and section VI concludes the paper.

2. LITERATURE REVIEW

A Multi Objective Mixed Integer Linear Programming (MOMILP) model for minimizing electrical peak load and electricity cost individually and concurrently while taking into account the users' preferences in a residential area with five houses utilizing TOU rates is proposed in [1]. Mixed Integer Linear Programming (MILP) is used in [2] to determine the most appropriate time to use home appliances, taking into account the time varying electricity price and the varying energy demand peaks, and to compare the energy cost reduction results with and without the use of renewable resources, specifically photovoltaic modules. In [3] a new concept named cost efficiency a metric regarding the consumer's consumption efficiency to its electricity expenses is proposed. The cost efficiency can vary with different consumption patterns, and is sensitive to behaviors of load shifting. In terms of demand response, a MILPbased load scheduling optimization is used to schedule appliances to avoid problems emerging from the penetration of electric vehicles during peak hours [4]. In [5,] the fuzzy goal programming technique is discussed, as well as the application of soft user time preferences, the extension of the sequential processing constraint, and the introduction of 2 new constraints that limit the delay between two closely connected appliances. To solve the household energy scheduling optimization problem, a two-stage Mixed Integer Linear Programming (MILP) method was used [6].The scheduling problem is solved for all seasons and four unique pricing schemes to evaluate the potential for optimizing the total cost. A comparative study between Symbiotic Organisms Search (SOS) and Cuckoo Search (CS) algorithms, studying a public survey on Demand Side Management (DSM) [7]. The interior point method and a genetic algorithm are used to simulate customer's 24- hour power utilization scheduling [8] with PV and storage. The load scheduling problem is formulated as a combinatorial optimization problem constrained by the MD limit on a microgrid and its performance is also analyzed [9]. In [10] a MILP based smart appliance scheduling framework is proposed, capturing all relevant appliance operations, extended to incorporate renewable energies, battery and the multi-objective optimization with respect to energy consumption and CO2 footprint. In this paper, load scheduling is implemented to a set of loads with individual power rating, user time preference and per day energy requirements, using MILP. Real time pricing is received from the power grid with cost reduction and peak to average ratio (PAR) reduction as primary objectives. Advanced MILP techniques like Exact method and price updation method is summarized and compared. Solar PV and storage is further integrated in the network and optimization is carried out. Storage used can be charged via solar or grid as desired, and discharged accordingly to meet the objectives.

3. PROBLEM FORMULATION AND OPTIMIZATION APPROACH

A real time price signal obtained from the power serving utility and Indian energy exchange one day ahead, for a single home consumer with a collection of loads with distinct individual power ratings, user time preference and daily mandatory energy requirement are the data used in optimization Power ratings of a device specify the kilowatt rating of the device neglecting any other losses. The devices are classified as fixed, time shiftable and power shiftable device. If an appliance is always ON at any given time it is referred as fixed device. A device with binary power rating is the one that is either OFF or ON at a given time, drawing the same magnitude of power while ON and is called a time shiftable device. A device that can be OFF and ON while having different power rating at a given time is termed as a power shiftable device. User time preference is the data regarding the start time, end time and operational time. Start time is the time after which the device is permitted to operate, operational time is the time that the device has to draw power to meet its daily energy requirement, the end time describes the time after which the device is not allowed to run. The mandatory energy requirement is the minimum amount of energy the user wants the device to accept in one day. The objective in load scheduling is to mitigate the total cost of electricity incurred with the RTP rates and reduce the Peak to Average Ratio of the residential consumer, subjected to user time and energy preference as major constraints. Mathematically a device can be represented as a vector with dimensions exactly opposite of the pricing vector sent by the utility. The pricing vector consist of per KW rates of electricity. Device vector with a non-zero element at a particular position of the vector indicates that it is operational at a time slot corresponding to the same position. A fixed device will have only "1s" suggesting that it is always ON. Thedevice vector for a time shiftable device has binary elements only, "0" representing OFF state and "1" stands for ONstate. A power shiftable device vector has the same type of elements as time shiftable device vector additionally containing intermediate elements (less than 1 and greater than zero) representing a dimmed state. For the simulation purpose in linear programming, all functions and constraints are related to a variable x with the form $a\ Tx$ + b.

These linear optimization techniques can be divided into three main types: continuous, integer and mixed-integer. The continuous linear method optimizes variables that are generally real numbers. It is solved using algorithms, which generate iterated values of the variables until a solution is found. The integer programming method is similar to the continuous one, but includes an additional constraint that states that some or all the optimization variablesneed to be integers. The programming technique used in this paper is the mixed integer one because most of the loads to be scheduled are ON/OFF type loads (they are either ON or OFF). It is characterized by the fact that it combines with continuous and discrete variables. Mathematically speaking, the mixed integer technique search for a vector x that maximize or minimize an objective function under a set of constraints [2]. The formal mathematical expression is given in equation (1)

$\max, \min(C^t * x)$
Subjected to

$$Aeq * x = Beq$$

As Equality constraint (1) and (2)

$$A * x < B \quad (3)$$

As Inequality constraint and Bounded by Lower and Upper Bounds

$$lb \leq x \leq ub \quad (4)$$

The 4 equations above will be applied to load Scheduling optimization problems such that: ‘’x’’ represents a load, and the number of elements in x are equivalent to the number of time slots for which scheduling is to be obtained(24 for 24 hour Real time pricing and 96 for 15 minute real time pricing for 1 day), the values of elements will majorly be 0 “lb” or 1 “ub”, where 0 represents that the load is OFF and 1 states that it is ON. ‘’C’’ is the cost vectorset by the load serving utility, it is real time vector whose dimensions are same as transpose of vector x. Elements of C will be per KW or MW real time rates of power obtained from Indian Energy Exchange (IEX) , as given in Figure1.

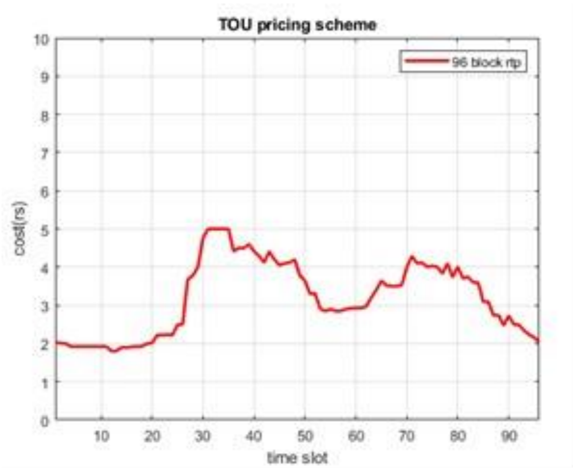

Fig -1: IEX price rates for 96 time slots of 15 minutes each for one day

“Aeq” will represent the preferred load status multiplied by rating of that particular load, its dimension will be same as “C (Transpose)”, for equality constraint “Beq” will represent the per day KWh requirement for that particular load. It will have dimensions obtained by multiplying Aeq and x for equality constraint “A” is denoted for preferred load status multiplied by rating of that particular load, with same dimensions as C transpose for inequality constraint. “B” will represent the per day KWh requirement for that particular load. It will have dimensions obtained by multiplying Aeq and x for inequality constraint for cost minimization of a given load represented.

$$\min(C^t * x) \quad (5)$$

Subjected to constraints given in equation 2, 3 and 4.

Table -1: Appliance User time and energy preference

Appliance	Rating inkw	PreferredStart time	Preferred End time	Per daykwh
Hair dryer	1	9	20	3
Washingmachine	0.5	9	18	2
Dishwasher	1	11	19	3
Cloth Dryer	0.5	19	22	1
Constant lighting load (CLL)	0.5	1	24	12
Fridge	0.5	1	24	12
Electronics	0.1	10	17	0.7

The table 1 includes the various household devices with their ratings user time preferences and per day energy use.

In unoptimized usage the consumer will have total control over all appliances, without any knowledge of the varying price set by the utility. This operation will cause a higher cost of electricity per day and may cause a high Peak to Average Ratio. Thereby stressing the utility nor benefiting the consumer. In case of unoptimized usage, it is assumed that the user turns ON the load at the very first time slot of his mentioned time preference set in optimization case. The unoptimized scheduling by the consumers is shown in Figure 2, while optimized usage for 7 appliances is shown in Figure 3.

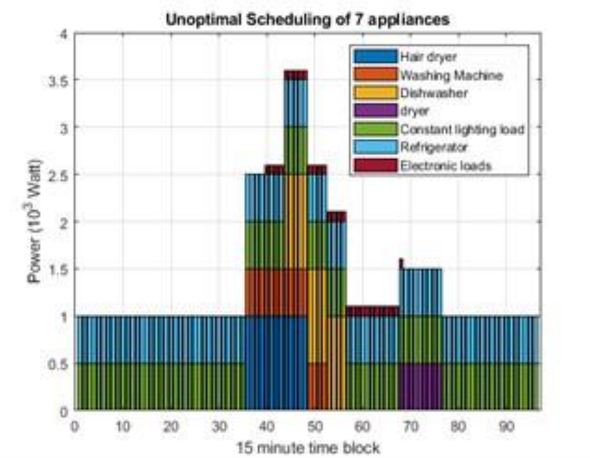

Fig -2: Unoptimized Usage by consumer

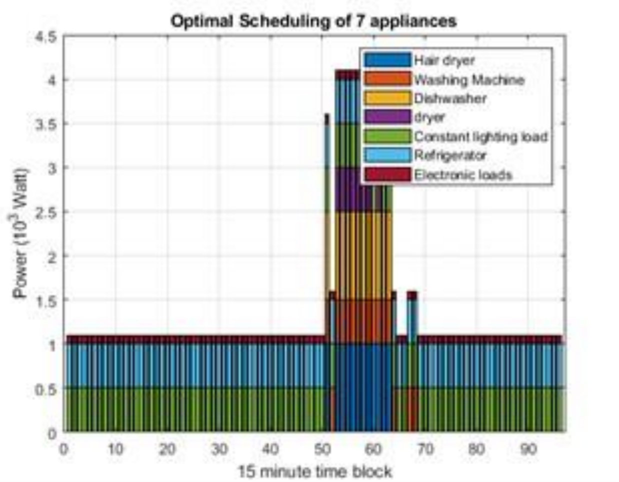

Fig -3: Scheduling of 7 appliances for cost minimization with equality constraint

Objective such as total cost incurred, load rate, peak to average ratio, user satisfaction degree and energy expenditure is computed the data and the optimization carried out. The Exact method of load scheduling involves conventional MILP optimization of loads with cost mitigation as the primary objective, followed by shifting operation of the device vectors (preferably low priority devices) obtained from MILP in order to find values of various objectives for each combination, and form a fitness function. A fitness function is shown below for 3 devices each shifted by d1, d2 and d3 respectively for calculating Electricity price expenditure, cost, PAR and Load rate.

$$conc(d1,d2,d3) = \frac{EPE(d1,d2,d3) * cost(d1,d2,d3)^{PAR(d1,d2,d3)}}{LR(d1,d2,d3)} \quad (6)$$

Further the minimum value of fitness function in (6) will correspond to the best shifting combination. The trade off between Peak to Average Ratio and Electricity Cost is shown in Figure 4. The point at the shortest distance from the origin correspond to the best shifting combination.

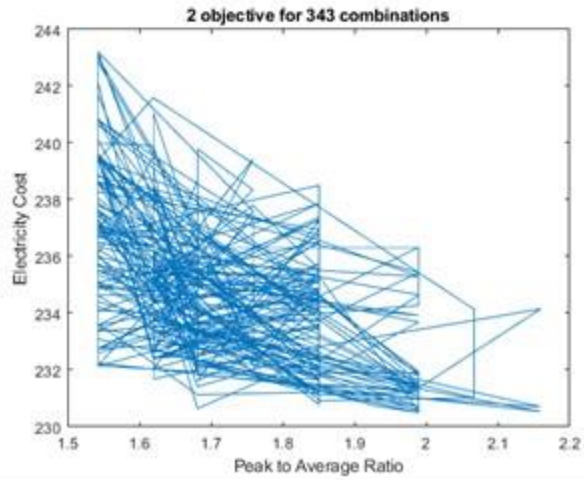

Fig -4: Electricity cost vs Peak to average ratio for 343 combinations of 3 appliances in a set of loads each shifted by 7 hours

Price updation method needs the devices to be ranked based on priority, such that MILP is used for first device with original price signal "f" sent by the utility to result into a output vector "x31", while the second device will undergo MILP with a different price signal "f2" such that the timeslots preoccupied by first device will seem "expensive", optimization will schedule this device at some other time slot for minimising cost and lowering the PAR, hence this method will mimic a Multi-objective Approach, as shown below

$$f2 = f + (k * (f .* x31')) \quad (7)$$

The importance of Peak to Average Ratio is determined by the value of constant "k". Therefore, the price will be updated after each device has undergone MILP leading to a scattered device placement (Lower PAR). The Variation of Electricity cost with Peak to Average Ratio for different values of "K" in price updation method is as shown in Figure 5. Price Updation and Exact method use MILP as a multiobjective tool for achieving simultaneous reduction in Cost and Peak to Average Ratio. price Updation with a computational time of less than 10 seconds for 7 devices ranked on priority, is better than Exact method which needs about more time for trying out all the shifting combinations for only 3 devices. Also, in Price updation only needs a change in the value of "k" to decide which objective is more important, while in exact method the fitness function has to be reformulated. Exact method is better at creating a diverse range of combination (with dissimilar Cost and PAR) to choose from, while price updation offers more than 2 scheduling outputs with same Objective value (Cost or PAR) and hence Figure 5 the curve is not smooth.

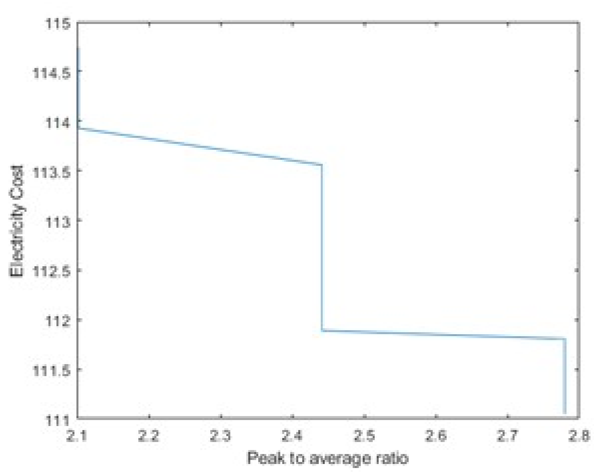

Fig -5: Cost incurred vs Peak to Average Ratio for 35 values of K(0 to 0.35)

PV energy can be used for in conjunction with grid, in order to meet with energy requirements. The PV energy is proportional to the irradiations available for the panel and hence it is maximum around 12 pm, the variation of energy generated by a 1kw peak solar panel, corresponding to respective time slot as illustrated in Figure 6.

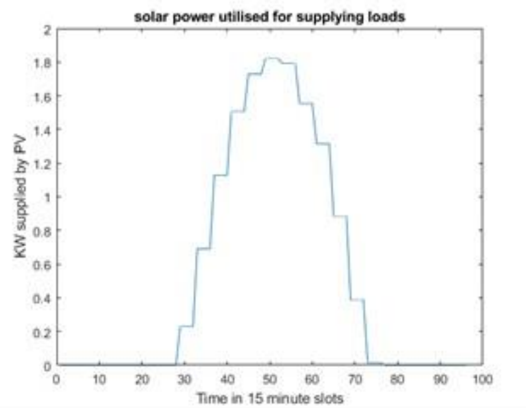

Fig -6: Solar Power Generated for corresponding time of day

4. SIMULATION RESULTS

Scenario 1: Only Grid Power is available
In this case, only grid power with a real time price signal is used for scheduling devices to reduce Cost and Peak to average Ratio. No solar electricity or storage is considered as seen in Figure 7.

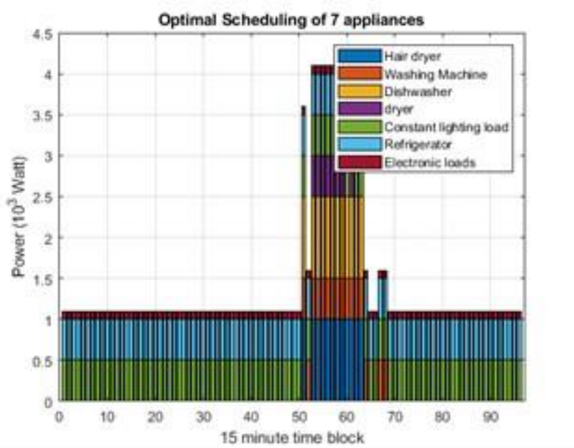

Fig -7: Load Scheduling with only Grid power

Scenario 2: Only PV Power is availaible
In this case grid power and storage is not available. Solar PV is only available for Load optimization. The scheduling here is done to maximize solar usage but it will increase the PAR, however there can be another method using the same technique as in Price updation leading to a lower PAR. In this case the energy generated by PV is not sufficient to meet all loads, therefore only 4 loads are scheduled as reflected in Figure 8.

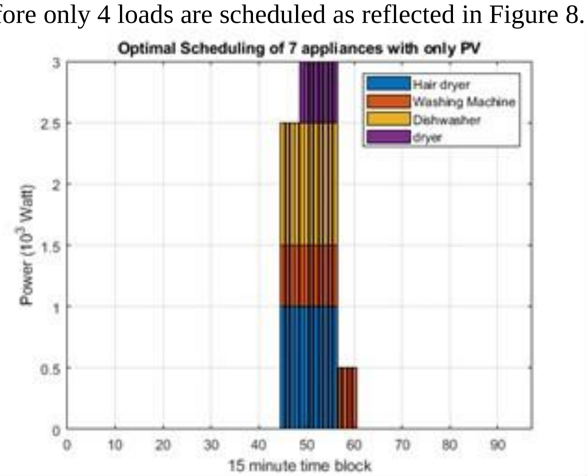

Fig -8: Load Scheduling using only PV power(able to run only 4 loads)

Scenario 3: Grid and PV power available, without storage Grid power is used for optimization, and solar power is fed instantaneously as no storage is available. Solar PV is considered as a negative load, hence lowering the power consumption from the grid and the total cost required for one day as shown in Figure 9.

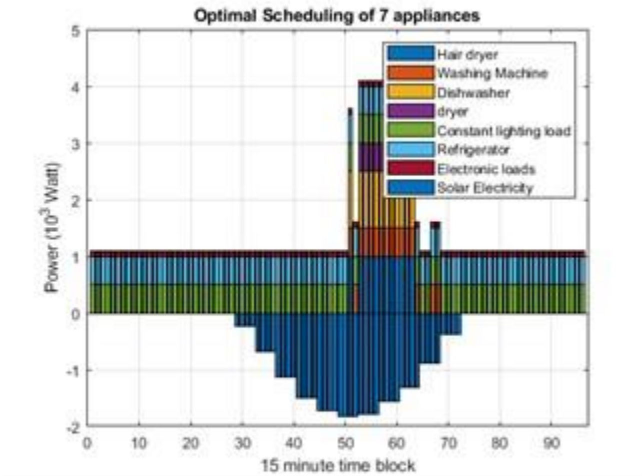

Fig -9: Load Scheduling with grid and PV power

Scenario 4: Grid, PV and Storage System Power
A combination of Grid, PV and Storage is considered for scheduling the 7 devices using a multi-objective approach. Here 2 cases are considered
Scenario 4.1 Storage is used as a load, and will charge itself only with no contribution to lower peak to average ratioas illustrated in Figure 10.

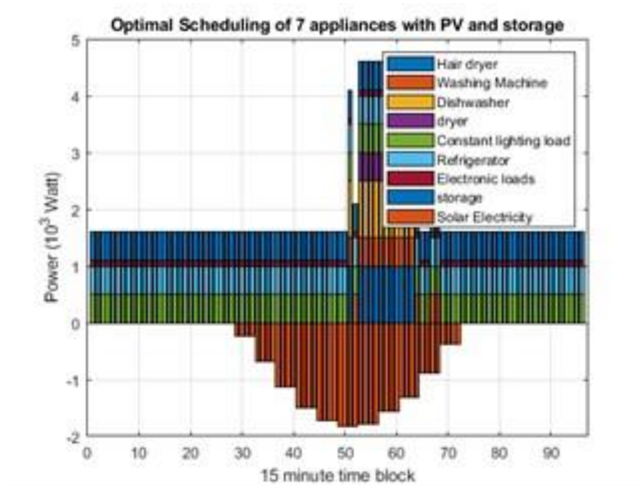

Fig -10: Load scheduling for grid and PV power with no discharge of storage

Scenario 4.2: Storage is used for charging and discharging
Storage is charged initially and whenever instantaneous load exceeds a certain limit (in this case 1.5 times the average load), it will discharge in order to lower the peak to average ratio as shown in Figure 11.

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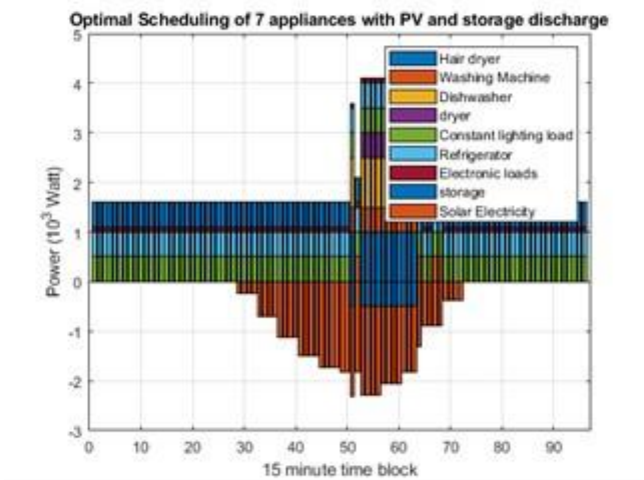

Fig -11: Load scheduling for grid and PV power with discharge of storage

5. RESULTS AND DISCUSSION

Scenario	Cost in Rs	PAR
Unoptimized	117.8603	2.5062
Only Grid	105.8150	2.9199
Only Solar (able to meetonly 4 device KWh)	-	-
Grid + Solar	63.14	1.8878
Grid + Solar +0.5kw Storage (no discharge)	101.4495	1.6630
Grid + Solar + 0.5kw Storage (with discharge)	92.5771	1.2349

Table -2: Comparison of all scenarios with respect to cost and PAR

The scheduling of high-powered shiftable household appliances can help to reduce distribution system losses. Scheduling time shiftable loads reduces peak load consumption during the grid's most heavily laden periods and improves the peak to average ratio. The effectiveness of the suggested system may be demonstrated by analysing the effects of day ahead task scheduling-based demand side management systems using cost as objective and consumer preferences. All of the aforementioned goals can be achieved simply by scheduling the loads. PV with storage system if integrated can be used to reduce utility demand and the peak to average ratio.

6. CONCLUSION

To optimize the electricity cost and peak to average ratio, a collection of residential loads is scheduled using Mixed integer linear programming (MILP) with respect to a reference price signal given by the power serving utility. Three methods of optimization for load scheduling are compared based on their performance. In conventional MILP problem minimization of cost is the only objective and will provide the minimum cost, peak to average ratio is calculated after the load vectors are stacked. Further these vectors can be shifted by some value without violating the user time preference by exact method of optimization to reduce peak to average ratio, but it increases the electricity cost from minimum. The computational time consumed is high as compared to other methods. In price updation method the computational time is less, but variation of objectives with constant “k” is not smooth. Integration of solar PV and storage for obtaining 4 possible scenarios helps to reduce cost and peak to average ratio (PAR), as compared to unoptimized cost and PAR thus benefiting the consumer and the power utility. All scenarios with cost and PAR optimization are compared to know the effectiveness.

7. REFERENCES

[1]. Hamed Shakouri G. Aliyeh Kazemi “Multi-objective cost-load optimization for demand side management of a residential area in smart grids”, Sustainable Cities and Society, Vol, 32, ,pp 171-180, March 2017.
[2]. Mohamed Amine Rafkaoui, Dr. Ahmed Khallaayoun Mr. Rachid Lghoul “Optimal Scheduling of smart homes energy consumption in conjunction with solar energy resources”, Al Akhawayn University In Ifrane, School Of Science And Engineering Honors Capstone Report, 2016.
[3]. J. Ma, H. H. Chen, L. Song and Y. Li, "Residential Load Scheduling in Smart Grid: A Cost Efficiency Perspective," in IEEE Transactions on Smart Grid, vol. 7, no. 2, pp. 771-784, March 2016.
[4]. A. Can Duman, Önder Güler, Kaan Deveci, Ömer Gönül “Residential Load Scheduling Optimization for Demand-Side Management under Time-of-Use Rate”, Istanbul Technical University Istanbul, Turkey, 2018.
[5]. Honggang Bu “Scheduling smart home appliances using goal programming with priority”, North Dakota State University ProQuest Dissertations Publishing, 2016.
[6]. M. H. Amini, J. Frye, M. D. Ilić and O. Karabasoglu, "Smart residential energy scheduling utilizing two stage Mixed Integer Linear Programming," 2015 North American Power Symposium (NAPS), 2015, pp. 1-6.
[7]. R. Çakmak and İ. H. Altaş, "Optimal scheduling of time shiftable loads in a task scheduling based demand response program by symbiotic organisms search algorithm," 2017 Saudi Arabia Smart Grid (SASG), 2017, pp. 1-7.
[8]. Chao-Rong Chen and Ming-Jen Lan, “Optimal Demand Response of Smart Home with PV Generators” Electrical Engineering, National Taipei University of Technology, Taipei 106, Taiwan.
[9]. S. Q. Ali, S. D. Maqbool, T. P. I. Ahamed and N. H. Malik, "Load scheduling with maximum demand and time of use pricing for microgrids," 2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS), 2013, pp. 234-238.
[10]. K. C. Sou, J. Weimer, H. Sandberg and K. H. Johansson, "Scheduling smart home appliances using mixed integer linear programming," 2011 50th IEEE Conference on Decision and Control and European Control Conference, 2011, pp. 5144-5149.