Load Scheduling For Smart Energy Management in Residential Buildings with Renewable Sources

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***Abstract*— Demand Response is a promising technique that could be implemented effectively on the foundation laid by Smart Grid. Decentralization of power generation with the advent of renewable power sources will benefit the user as well as the central network along with reduction in dependence on conventional sources of energy. Energy management at the consumer end by controlling the loads will help the consumer also to participate and share the responsibility in proper management of energy. Among the various methods through which this could be done, load scheduling from the consumer end is an excellent option. This paper proposes an Off-line Load Scheduling Algorithm that aims at maximizing the energy savings along with the reduction in cost of energy consumption. This algorithm tries to shift loads to off-peak hours and hours with lower electricity cost thus relieving the utility grid from peak demand at the same time providing economic benefit to the consumer.**

Keywords—Demand Response; Smart Grid; Load Scheduling Algorithm; Distributed Generation

I. INTRODUCTION

Electrical power systems across the globe are undergoing transformations owing to the challenges they face in matters of production, reliability and efficiency. Fast deterioration of conventional power resources makes urgent call for replacement with alternative renewable sources. Existing power grids with vertically integrated structure shall not support this on a commercial basis. Apart from hydro and perhaps wind power, non-conventional energy resources are not available in abundance hence making them unfit for mass production. Moreover, the highly scattered nature of their availability and lack of reliability definitely eliminate the possibility of a centralized production but with decentralization of the existing network and along with the introduction of distributed generation certainly throws light to a feasible solution. Numerous power networks across the world have already taken initiatives in this direction. Small-scale generations within the consumer premises, industrial or domestic, are receiving encouragement from utility grid even in the form of economic incentives. Once installed, distributed generators have proven beneficial to both the suppliers and consumers along with the strengthening of grid reliability. With the aim of enhancing the efficiency of such a decentralized network, conventional power systems have been experiencing transition from centralized supply side management to decentralized supply and demand side management. Therefore, load management under the new operating environment becomes more difficult than that under the conventional environment. Currently, the electrical energy consumption is not efficient in most buildings mainly because of consumers' ignorance. Grid overloading especially during peak hours has become common which may even ultimately result in grid failure. Besides, this also results in the wastage of a large amount of resources. An attention from the load end by adopting techniques such as Demand Response (DR) could bring about definite improvement in this aspect. The wastage of energy can also be controlled in a more efficient manner if the utilization is being managed from the consumer side rather than from the supply side. The total effect of this demand response will be huge and will have a greater impact on reduction of the supply-demand gap. This project aims at implementing demand response by scheduling the loads from the user end with the target of minimizing the dependency on utility grid during the peak hours and maximizing the utilization of the available renewable energy resources.

II. NEED FOR LOAD SCHEDULING

A hike in the purchase of electrical appliances following a rising standard of living causes a growing demand for energy in domestic buildings. Inefficient use of these appliances causes wastage of energy. One way to tackle this is to give feedback to the consumers on their behaviour, which may lead to a reduction in this wastage. Another way to reduce energy consumption is the application of demand side load management. The first method, even though makes the users realize their unhealthy trend of energy utilization, will not suggest any proper method for them to follow so that they could rectify the issue. Therefore, the best way to ensure the solution is to adopt the technique of DR. The implementation of DR could be carried out through different methods among which valley filling and peak load shaving is the ones, which directly affect the peak demand reduction. In order to accomplish this load shaping, the loads have to be scheduled properly by the user so that heavily rated loads are not turned on unnecessarily during peak hours. The loads are to be scheduled keeping in mind that the user's comfort is not hindered. Meanwhile, those loads which do not directly affect the basic comfort concern of the user or the loads which could be run at any time of the day may be scheduled considering the energy availability and wastage constraints.

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Adoption of DR technique in smart grids and its impact in reducing the peak demand is discussed in [1]. The concept of demand side load management is gaining importance. Various methods are available to implement it such as peak clipping, load shaving, valley filling etc. that tries to relieve the grid from peak hour overloads [2]. Dynamic pricing is another way to have a control on load commitment that offers economic benefit to the consumers if they utilize the utility efficiently. This method encourages users to shut down heavy loads during peak hours and utilize grid during off-peak hours by charging distinctly and dynamically. Real-time price based DR is presented in [3]. Reference [4] designs and implements system architecture for autonomous demand side load management through admission control where the technique of peak load shaving is adopted. Load management after identifying the schedulable loads like thermostatically controlled household loads was presented by P.Du and N.Lu in [5]. Game theory and optimization algorithms are employed to have appliance commitment in buildings [3], [6]. Scheduling loads based on priority and optimization algorithms [7], [8] has also received much attention and the work done in this paper lays its basics on this research area. This work proposes an off-line scheduling algorithm that operates on an hourly basis and is designed to be implemented in a building, which consists of essential loads, facilitated with a utility grid connection and equipped with renewable power sources. It incorporates dynamic pricing technique, typically the Time of Use method and brings about DR.

III. Off-line Load Scheduling

Load scheduling at the consumer end for energy management is a feasible option once it is designed and executed with appropriate care suitable for the load environment. The present work tries to manage loads in a building that is supported by Hybrid Renewable Energy Systems (HRES) consisting of solar panels, wind turbines and battery along with an uninterrupted grid connection. The renewable power generators were designed to have an installed capacity of 20% of the total connected load in the building. A set of 4 solar photovoltaic (PV) modules each of power rating 150 W_p, 5 wind turbines each of 500 W rated power output and a battery bank consisting of 4 units of 100 Ah each were considered. The modelling of these components of the HRES was done as illustrated in [9]. With the model in hand, hourly renewable energy availability was estimated considering forecasted solar irradiation and wind velocity data for a day under the assumption that these values would remain constant for a particular hour. With this renewable energy forecast available in prior, the off-line scheduling algorithm was developed that was built in steps starting with categorization of the loads, load prioritization and then incorporation of tariff plans at a later stage.

A. Load Categorizaton

Home appliances are initially classified into three categories, namely, appliances with real-time energy consumption mode, appliances with periodic nonreal-time energy consumption mode, and appliances with nonperiodic nonreal-time energy consumption mode [8]. The energy consumption of the first category of appliances is directly related to consumer behaviour, which means that after the consumer turns them ON, the appliance must be energized until they are shut down. The energy consumption of this type of appliances cannot be scheduled and they must run immediately to satisfy the consumer's requirements. Lights, fans, desktop PCs and television are examples. The energy consumption of the second category of appliances is periodical and fluctuant when they are in use. Air conditioners and refrigerators are examples. They could be scheduled based on maintaining the set value of temperature i.e., they need to be energized only when the temperature violates the upper or lower limits. Battery embedded devices such as laptops shall also be considered under this category. The third type of appliances consumes energy non-periodically and does not have any specific time to run. However, they must serve their course before certain deadline. Plug-in Hybrid Electric Vehicles and pool pumps come under this category. The first category devices could be energized purely based on consumer behaviour whereas the other two categories are schedulable loads hence are exploited in the development of the scheduling algorithm.

B. Load Prioritization

The appliance commitment can be based upon the necessity of energy consumption by that appliance at any point of time. Again, the need or urgency of an appliance over the others should be considered for an even and efficient scheduling. This can be ensured by allocating priority to the devices dynamically considering their status [8]. This is applicable only to the second and third category appliances as the first category cannot be scheduled and must run immediately. Fig.1 is the flowchart depicting implementation of the subroutine for priority allocation for the different categories of appliances.

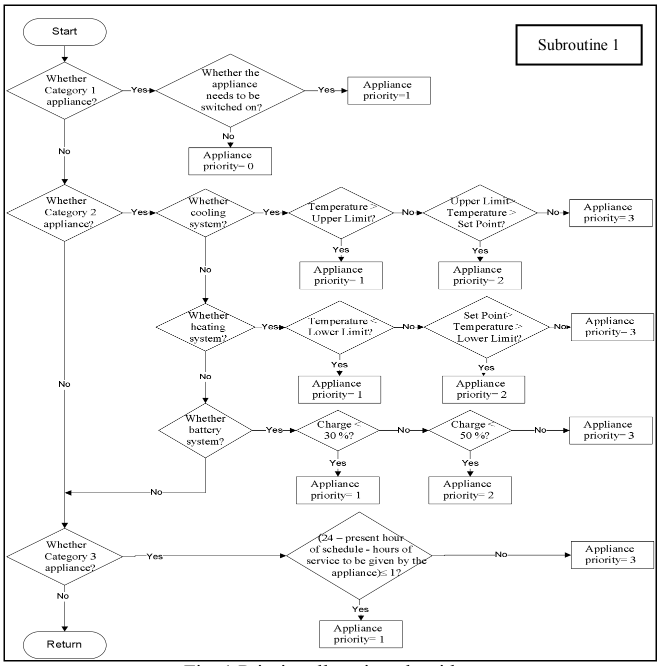

Fig. 1 Priority allocation algorithm

C. Off-line Scheduling Algorithm for Various Cases

The residential building under consideration is equipped with essential loads, a utility grid connection, and an HRES. The scheduling algorithm is developed with the aim of maximum utilization of the available HRES thus minimizing the energy consumption from the utility grid and hence minimizing the total cost of consumption. The basic idea of the algorithm is as mentioned next. If the appliance has high priority, it should run immediately in order to satisfy the consumer's comfort. All appliances with middle and low priorities are rescheduled based on the renewable sources' output prediction or the electricity market price forecasting. Algorithm was developed for any electricity tariff plans, fixed or variable. Cases with and without the incorporation of storage battery are also taken into account. This paper discusses the flow of logic pertaining to a basic flat rate tariff as well as a variable tariff plan.

Fig. 2 demonstrates the implementation of a function for load scheduling without a battery in the system for a flat rate tariff. Flat rate plan employs the same cost of energy irrespective of the time or degree of consumption. Since there is no economic benefit in shifting the loads to different time slots, the focus is made mainly on the utilization of the available renewable power. High priority appliances are run irrespective of the energy availability while middle and low priority devices are scheduled according to it.

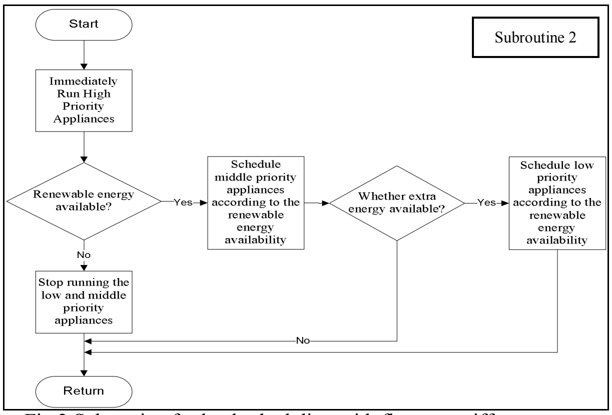

Fig.2 Subroutine for load scheduling with flat rate tariff

Variable tariff plans charge differently based on the time of utilization. This definitely encourages the consumer to schedule heavy loads during off-peak hour slots with the aim of economic savings. The algorithm developed here is designed to schedule the loads according to any Time of Use (ToU) tariff plans. This algorithm takes into account cost rate plans with any number of cost slabs and then schedules the loads accordingly. The initial step taken while dealing with multiple cost slabs is to count the number of cost slabs in the plan and to form an array of the costs in descending order. The total number of these different costs, which is same as the size of the formed array is denoted as 'Ncs'. An index variable 'i' is used to refer to each of the array element which will also indicate whether the hour of schedule is a high cost hour or not. If 'i' has the value 1, then the hour is a high cost hour, if 'i' has a value 2, then the hour has the next highest cost, and so on. If 'i' has the value 'Ncs', it is the least cost hour. As the number of cost slabs increases, the advantage is that the cost will be minimal for the least cost hours and maximum utilization of these hours can help in effective scheduling to have a minimum cost per day. The method adopted for scheduling in case of ToU cost rate plan is elaborated in Fig. 3.

The cases discussed yet do not take into account the presence of storage device in the system. As the renewable power is highly fluctuating and since there are times at which there is excess of energy availability, battery storage is inevitable. The prime matter to be taken into account while dealing with battery is that whether it should supply the loads or it should rather be charged. In some situations, it might be ideal for the battery to stay floating. After deciding upon the functionality of battery, then the scheduling algorithm can make necessary additions and deletions to get the desired outcome. Figs. 4 and 5 illustrate the sub-functions to carry out the decision making process on fixing the battery functionality.

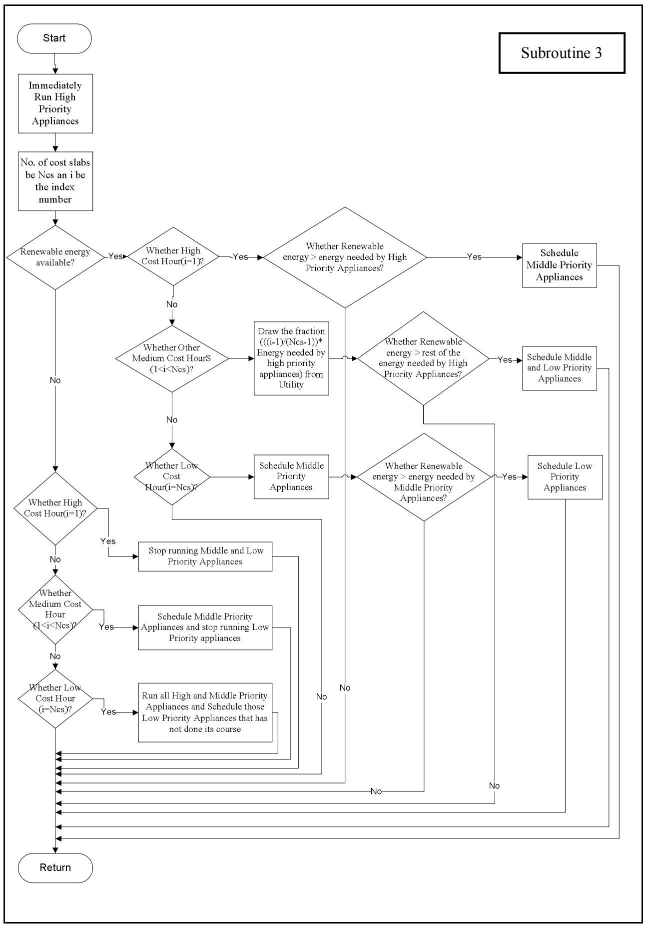

Fig.3 Subroutine for load scheduling with ToU variable tariff plan

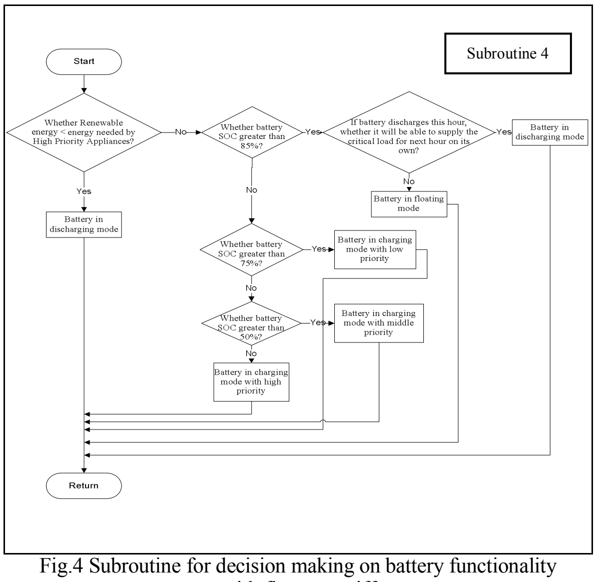

Fig.4 Subroutine for decision making on battery functionality with flat rate tariff

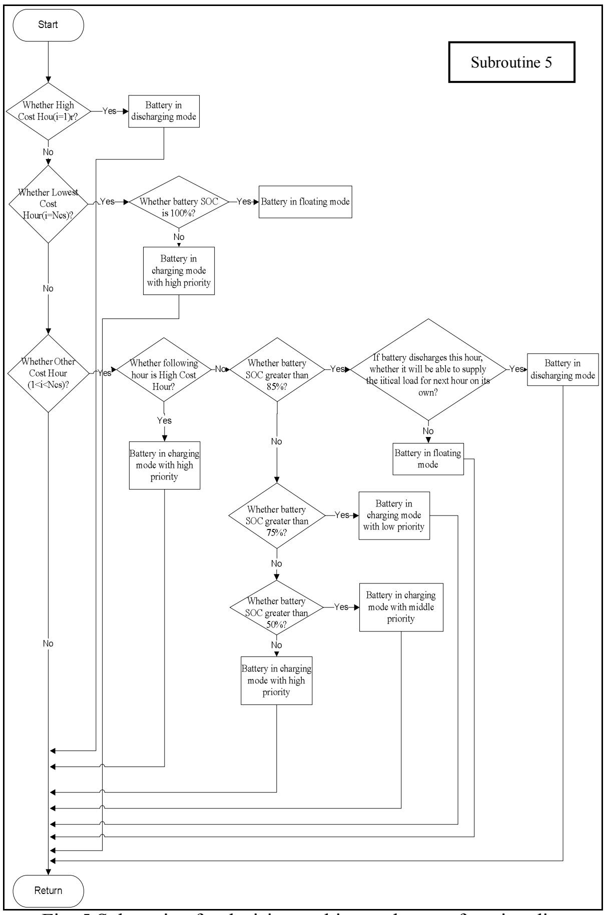

Fig. 5 Subroutine for decision making on battery functionality with ToU variable tariff plan

With the inclusion of storage battery, the load scheduling begins with the decision making on the battery functionality. Later, the loads are scheduled based on the battery status and renewable power availability for each cost rate plan. Figs. 6 and 7 depict the subroutines for load scheduling including the storage battery for flat rate plan and variable plan respectively.

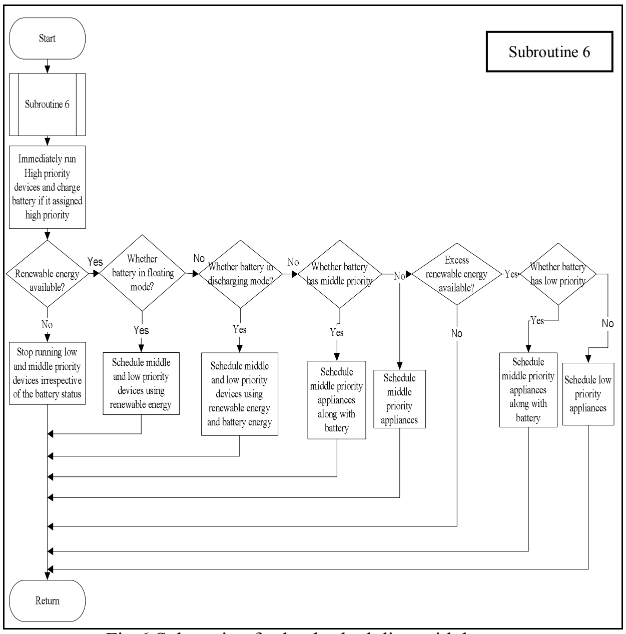

Fig.6 Subroutine for load scheduling with battery for flat rate tariff plan

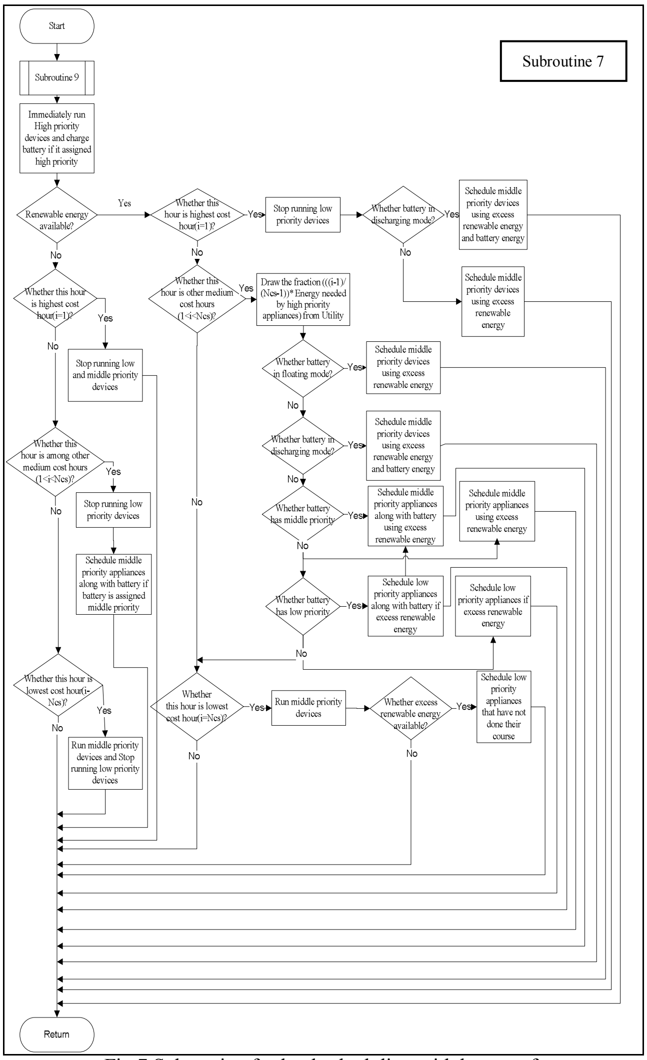

Fig.7 Subroutine for load scheduling with battery for ToU variable tariff plan

D. Overall Program Flow

With the sub-functions developed for the numerous possible cases the complete off-line scheduling algorithm was developed which is illustrated in Fig.8.

Initially the tariff plan has to be assigned and the availability of battery storage in the building has to be checked. Then the load scheduling process begins with load categorization. Once this is done, the iteration process begins. The variable ‘Tschedule’ denotes the iteration count. If the scheduling commences for 6 a.m., Tschedule shall be assigned the value 1. After generating load schedule for that hour, iteration count gets incremented and the scheduling for the subsequent hour begins. For each hour, the loads are prioritized as explained in Fig.1. Subroutine 1 executes the process. Renewable power availability for the considered hour is estimated. Next the load scheduling is carried out for the selected case by executing the subroutines corresponding to it. The loop is iterated 24 times corresponding to each hour of the day. When the variable Tschedule exceeds 24, the loop is terminated for the day. The scheduling is carried out assuming that the grid power is available throughout the day without interruption. The algorithm finally generates load schedule for each hour after considering the conditions pertaining to that hour.

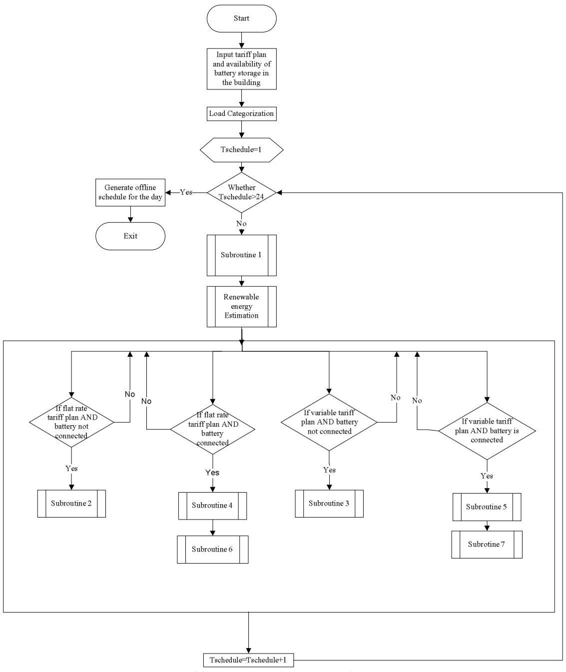

Fig.8 Off-line load scheduling algorithm

IV. RESULTS

The developed algorithm was coded and simulated in MATLAB. It is taken care to include appliances belonging to all three categories so that the effect of application of the algorithm becomes more distinct. They include both schedulable and non-schedulable loads. Table 1 gives the details of the connected loads in the building along with their time of utilization, which was used to form the load curve with manual operation.

TABLE I CONNECTED LOAD AND TIME OF UTILIZATION

Load	**Number of Units Connected**	**Time of Usage**
CFL[a]	20	6 a.m. – 8 a.m. 6 p.m. – 11 p.m.
Ceiling Fan[a]	8	10 a.m. – 4 p.m. 7 p.m. – 8 a.m.
Desktop PC	1	10 a.m. – 1 p.m. 2 p.m. – 5 p.m.
Television	1	8 a.m. – 10 a.m. 7 p.m. – 11 p.m.
CD Player	1	7 a.m. – 8 a.m. 2 p.m. – 4 p.m.
Mixer Grinder	1	6 a.m. – 7 a.m. 6 p.m. – 7 p.m.
Air Conditioner	1	Full day
Refrigerator	1	Full day
Space Cooler	1	Full day
Laptop	1	9 a.m. – 12 p.m. 4 p.m. – 6 p.m. 10 p.m. – 11 p.m.
Water Pump	1	6 p.m. -- 7 p.m.
Washing Machine	1	7 p.m. -- 8 p.m.
Pool Pump	1	4 p.m. -- 10 p.m.
Dish Washer	1	9 p.m. -- 10 p.m.
Vacuum Cleaner	1	7 a.m. -- 8 a.m.
Iron	1	7 a.m. -- 8 a.m.

[a.] Number of units committed were different for different hours

To prove the effectiveness of the developed algorithm, it was tested for various cases.Initially, the skeletal system was considered and analysed. It constituted just the loads in the building with utility grid as the sole source of power with flat rate tariff. The consumer behaviour was taken into account for appliance commitment. The timings for which different loads were committed based on which the load curve and cost of energy were obtained are given in Table 1. The load curve obtained with this data is depicted in Fig. 9. With the given load curve, the total daily cost of energy to be paid to the utility grid was estimated to be Rs.290.16 under a flat rate tariff of Rs.3.00 per unit in the absence of local renewable power generation. After considering the installed HRES, the net renewable power availability estimated is shown in Fig.10.

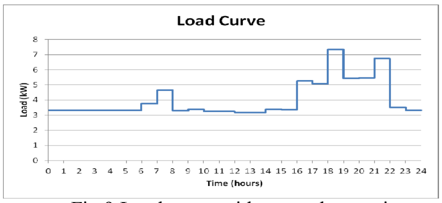

Fig.9 Load curve with manual operation

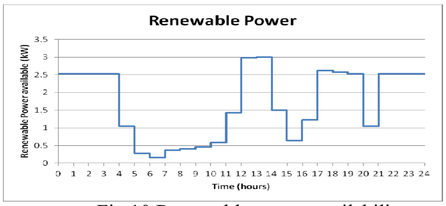

Fig.10 Renewable power availability

After integrating the renewable sources, different cost rate plans were introduced in the system and the algorithm was evaluated for each case. Results adhering to a flat rate plan and a variable plan (listed in Table II) are discussed here.

TABLE II COST RATE TARIFF PLANS

Tariff Plans	**Cost Slab**	
	Time of Use	***Cost per unit (Rs.)***
Flat Rate	--	3.00
Time of Use Variable Tariff	High Cost (7a.m. – 9a.m 6p.m.-10p.m.)	4.00
	Medium Cost (4p.m.-6p.m.)	2.50
	Low Cost	1.00

The performance of the algorithm was evaluated in terms of load shifting, amount of grid power drawn and cost of electricity to be paid to utility per day with the two tariffs for different cases. Figs. 11 and 12 demonstrate how load is shifted from peak hours to off-peak hours for different cases with and without algorithm under two different tariffs. Figs. 13 and 14 show that the algorithm helped to reduce the power drawn from the utility grid and whenever grid power was required, it was majorly during off-peak hours and that meant low cost hours in the presence of tariff plan. Figs. 15 and 16 illustrate the cost of electricity that was to be paid to the utility grid. In all cases with the application of algorithm, the total cost per day fell evidently and the peak cost incurred for any hour of the day stayed way less than that with manual decision on appliance commitment.

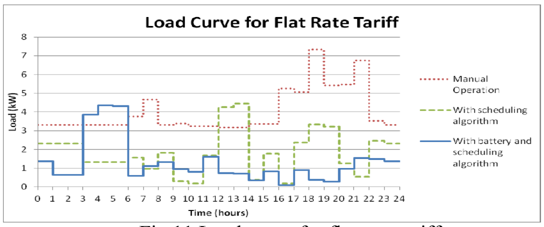

Fig.11 Load curve for flat rate tariff

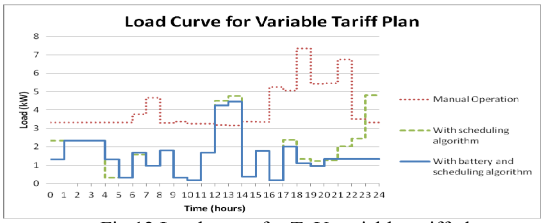

Fig.12 Load curve for ToU variable tariff plan

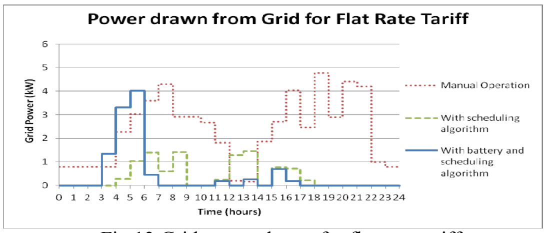

Fig.13 Grid power drawn for flat rate tariff

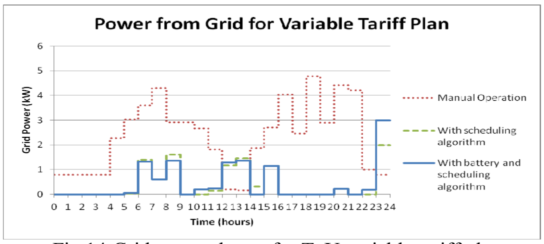

Fig.14 Grid power drawn for ToU variable tariff plan

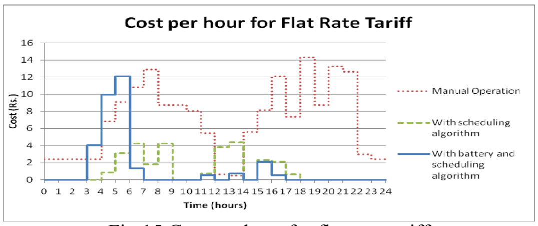

Fig.15 Cost per hour for flat rate tariff

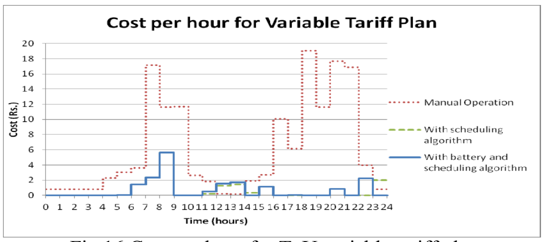

Fig.16 Cost per hour for ToU variable tariff plan

Table III compares and summarizes the cost to be levied in different cases and it could be inferred that the application of the developed off-line scheduling algorithm effectively helped in minimizing the cost of energy consumption with efficient utilization of renewable power sources, which is enhanced by the presence of storage battery.

TABLE III COST COMPARISON SUMMARY

Availability of Renewable Energy	Availability of Variable Tariff Plan	Availability of Storage Battery	Implementation of Scheduling Algorithm	Cost per day (Rs.)[b]
No	No	No	No	290.18
Yes	No	No	No	168.78
Yes	No	No	Yes	31.65
Yes	No	Yes	Yes	28.45
Yes	Yes	No	No	148.28
Yes	Yes	No	Yes	17.49
Yes	Yes	Yes	Yes	16.46

[b] To be paid to the Utility Grid.

CONCLUSION

Demand Response is an efficient tool in bringing about energy conservation, reduction in wastage of energy and proficient utilization of the utility grid without stressing the existing transmission and distribution network. It is beneficial to both utility and consumer. An attempt to implement DR through scheduling loads at the consumer end has been made in this work. This was achieved by designing and developing an off-line scheduling algorithm applicable for appliance commitment in a building that is facilitated with renewable power generators as well as utility grid connection. It also considered the availability of dynamic pricing scheme by incorporating ToU variable tariff plan for electricity cost. The offline scheduling algorithm at the consumer end successfully resulted in the saving of energy or money or both wherever possible. It also promotes the use of renewable sources of energy that exemplifies the decentralized nature of the current electrical network.

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