A Novel Integrated Approach of Energy Consumption Scheduling in Smart Grid Environment With The Penetration of Renewable Energy

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Abstract- In the future era, Smart grid provides phenomenal solutions for the consumers, in order to use the energy in more easy and efficient method. In this work, a new Demand Side Management scheme is proposed for users with renewable energy sources and storage facilities. Here an optimal scheduling for home appliances is determined using stochastic dynamic programming for consumers with smart meters. Simulation results demonstrates the effectiveness of the approach with the mathematical model. Results are worked out in Generic Algebraic Modeling System with Gurobi optimizer as a solver which exhibits significant reduction of electricity bills for the users with the usage of renewable energy sourse and battery storage.

Keywords Demand Side Management, demand response, smart meter, optimization, solar energy.

1. Introduction

Smart grids play a vital role in the transformation of present day energy grid in order to achieve security and efficiency of supply in electricity markets [1]. Moreover smart grids facilitate interconnection of new sources to the power grid [2]. Furthermore it has an essential part in the transition to low carbon energy sector, preserving a clean, efficient environment with the sustainable use of renewable energy resources [2,3]. The deployment of Demand Response (DR) schemes in the smart grid refers to the process of encouraging consumers to reduce the peak demand and resulting in lower electricity costs [4,5]. Inaccurate forecasts of renewable energy sometimes necessitates fast generation to avoid load fluctuations and wastage of transmission and generation assets [6] . As the global energy demand is expanding day by day with technology improvement, there is a need of alternate energy source for solving environmental constraints.

Among the various renewable energy resources, solar energy has driven the worldwide sector attention since it is abundant and inexhaustible in nature. Integration of renewable energy resources to smart grids is a challenging task. The control of power for optimum and reliable utilization of renewable sources is complex. It has to satisfy the grid conditions along with isolation conditions under faults and disturbance, with the ability to identify islanding conditions. There is a need of Demand Side Management scheme (DSM) to balance the power flow among these sources. Many research studies have been carried out in energy consumption scheduling and the optimization in the present few years. The main facilitators for the smart grid deployment globally, are the active participation of the users with the integration of renewable energy sources, distributed energy storage and distributed energy generation. The combination of DSM [5] and renewable sources results in a system with improved energy efficiency, controllable loads and different initiatives. Domestic consumers play an important role for the improvement of grid efficiency by involving various demand side management techniques. In domestic applications, PV systems are more used due to their reliability and low maintenance [6].

In this paper authors propose an energy scheduling algorithm for residential consumers in a smart grid scenario, using stochastic programming. The users considered here are a group of houses with their goal of minimizing the energy costs daily and improve the efficiency of the grid. The residential houses considered here are equipped with Photovoltaic panels (PV) and battery to store the energy . A group of appliances on a daily routine basis for a normal middle class family scenario is considered .The usage of home appliances according to the user preferences and comfort basis of the users are also considered . The entire planning module works on a day plan (24 h) for scheduling and the pricing scheme is analyzed using one hour flat tariff basis .An energy consumption scheduling algorithm is done for 24 h time slot using GAMS and Gurobi optimizer for both single user and multiple users perspective. The proposed method is based on stochastic dynamic programming and simulation results with renewable energy incorporation is studied for summer and winter days. To achieve the effectiveness of the proposed methodology , comparison studies are made for various conditions with DSM strategy and without DSM.

In literature, several techniques have been carried out for new trend setting aspects in smart grid like DSM techniques for residential and industrial consumers. In [7] the authors had dealt with optimization of energy management in residential users using mixed integer programming. In [8] the author have proposed optimal scheduling in homes with context of micro grid to meet one day ahead expense. In paper [9] authors elaborately explains demand side management on a game theory approach to reduce the cost of the consumers. In paper [10] the authors proposes an scheduling scheme based on incentives by working on a distributed algorithm to minimize peak load and maximize the utility profit. In [11 - 13] the authors have proposed a distributed DSM favoring self consumption and reduce the energy load from the power grid, considering the user's comfort. In [15] the authors have proposed noncooperative and cooperative user model using integer linear programming to minimize the peak load .In [16, 17] an intelligent demand response model is approached using different tariff using heuristics optimisation.

In most of the DR programs in [18, 19] involves only the focus done with the interaction of utility provider and the user made without the different pricing schemes . In paper[20] a new game theortic approach is done in home management incorporating renewable energy sources, whereas different schemes are to be analysed and the conditions for different climatic results are exhibited in the study .In [21], general outlook of energy scheduling in smart grid environment is done using off line load scheduling. In paper [22] demand response model in smart grid approach is evaluated with the use of wind power as a general study.

Considering the above facts from the literature, different new approaches has been handled to bring various demand response schemes to the user's benefit. The aim of reducing the electricity bill , by shifting the load from non peak hours to peak hours , maximizing the utility profit with users comfort are done in the literature. The integration of renewable energy like solar PV with the battery system in the house premises handles advantages of saving the energy much more, which is important in DSM. Further the proposed approach involves energy consumption scheduling by stochastic dynamic programming which gives better results in reduction of cost compared with other models in the literature. In the paper we had solved the model with GAMS optimizer where the convergence of the model is given better results. Integrating of renewable energy with the energy scheduler unit using stochastic process optimization in different climatic conditions have provided good results when compared to the survey

The main advantage and the importance of the proposed work is in regard with the users to reduce their fiscal expenses ,without losing their comfort during the scheduled period of consumption in a day. It has been done by storing or producing the energy rather than getting energy from the power grid .The remaining section of the paper is arranged as follows: Section 2 provides an overview of the energy management system. Further, mathematical model and system methodology is elaborated in Section 3. Discussions of results are highlighted in Section 4. Finally, the conclusions are presented in Section 5.

2. Energy management System

2.1. System Configuration

In the proposed work, the paper is designed as a model for a group of residential cooperative users with renewable energy sources for the goal of improvising the grid efficiency and minimizing the cost .For the future , electric power grids can face some set points and DSM is an intelligent approach to move the electric grid from the above set points, promoting distributed generation. Thereby intelligent way of energy consumption scheduling of loads is very much required. The authors perform a new energy consumption scheduling dynamic programming approach with the integration of renewable energy sources. The Figure. 1 shows the system architecture of DSM in smart grid system. In this work, residential users are considered where they are equipped with Photovoltaic system (PV) and batteries for producing and storing energy . The user's handle group of appliances in a day which have been separated to different slots in accordance to peak hours and off peak hours . The usage of appliances by the users are determined in sets according to the consumer for this dynamic programming.

DR programs exhibits the tariffs for the utility to provide incentives to the users for rescheduling the usage patterns [23]. It enables the consumers to shape the load profile depending upon the pricing schemes adapted. Depending on incentive [23] and price based DR programs developed by the utility provider price schemes are involved.

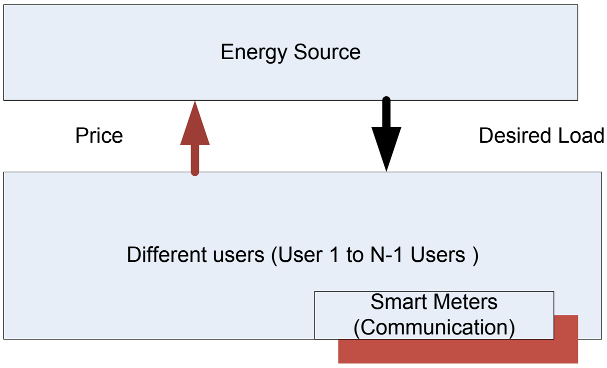

Fig. 1. Demand side management overview

Many pricing schemes like Time of Use (TOU), critical peak pricing, Real time pricing schemes are involved under price based incentive programs [24]. Different pricing schemes [24] are mentioned in Appendix B. The pricing schemes used in the proposed model are the price based programs of Time of Use pricing and hourly pricing schemes for comparison.

Optimization model is developed for the energy scheduling every day with the appliances and the power network. The integration of solar PV system is done by using Gurobi optimizer by learning methods depending on the climatic conditions. The analysis is done for PV power production both in summer and winter days. The tool used for the entire model is GAMS toolbox. It is a modelling tool software involved for complex mathematical formulation and programming .It has variety of high end performance with a complier .Different solvers have been used in practice, in this work Gurobi optimizer is used as a solver interfaced in Matlab.

The objectives of minimizing the cost by obtaining cost function is achieved by the solver with the use of Gurobi optimiser .The scheduling of the appliances is obtained using Gurobi optimiser G1.6 for optimisation in stochastic dynamic model. The GAMS software in this work uses the solver to obtain the cost function for scheduling the appliances. The solver is used in practice for considering different summer and winter loads exhibiting different load conditions in a formulated database inorder to reduce complexity , as the solution obtained by this tool exhibits less time for computation . The processor involved for this work is RAM 4MB and core i3.

The general overview of energy management system with the renewable sources integration is explained in Figure. 2. Our model exhibits a set of active users using renewable energy to react to change in their cost by changing their schedule enabling two way communication in between the smart meters and the central unit server. In the following section the system model with the results has been elaborated.

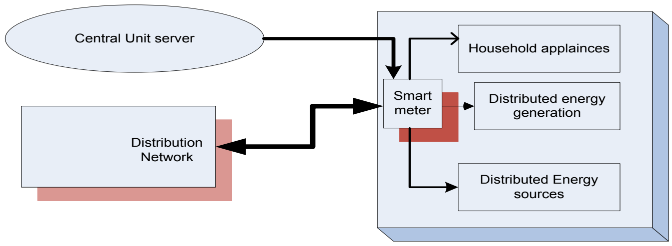

Fig. 2. Energy management-Overview

3. System Methodology

3.1 Energy Consumption Scheduling

Considering set of consumers enabled with smart meter and energy scheduler for the purpose of scheduling the appliances.The smart meter is been connected to each consumer through the utility with a network provider.Each consumer in a residential environment solves their energy minimization problem and thereby develops an energy scheduling vector for their energy consumption. In this procedure the consumer develops a cooperation to find their best schedule . The target of achieving to pay less is done by introduction of solar energy and battery as a supporting measure. As the usage of solar energy during summer time during peak hours is more .The basic procedure of the stochastic model is to minimize the cost with a energy scheduler for the period of 24 hours. Stochastic modelling is used in the system to achieve peak shaving during peak hours and they have been enabled with a set of nodes. The nodes created in the model are representing the scheduling of appliances .

This stochastic approach mainly is adapted to forecast the power model in future by prediction of nodes with one step forward. Thereby the prediction enables peak shaving successfully. The proposed stochastic model solves the problem in advance so that the different price slots are initiated for comparison. As in, at each stochastic execution , the first slot exhibits a time slot where the price band is obtained from the market provider with decision of scheduling is done with the appliances by the users with the usage of renewable energy.The optimisation model is based on the electricity pricing available for PV and the consumption of the energy in the next set of period.In general to narrow down it is to minimise the cost at a time slot t from all scenarios to the complete end process of scheduling done at the next stage with set of different constraints.

In the proposed model the integration of renewable energy with the DSM algorithm used for energy consumption scheduling of household appliances for residential users is done using stochastic dynamic programming. In this section the model is formulated with the optimization problem and further the constraints are analyzed mathematically with renewable energy. For scheduling of appliances by demand side management scheme , the domestic loads in the residential sector is classified as controllable and non controllable loads. The system model is represented in Figure. 3.

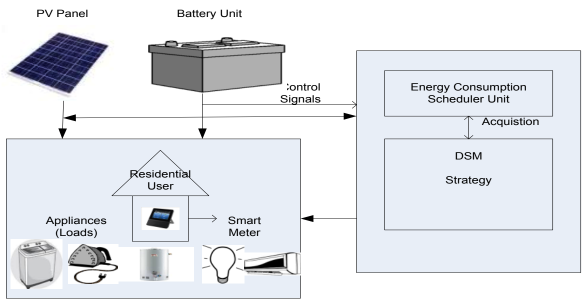

Fig. 3. Model Framework

The controllable loads are the loads which are possible to shift the load time or changing the operation, and also called as shiftable static loads or thermal loads. The noncontrollable loads are not possible to shift the operation load profile and they are also called as non shiftable loads. As these loads cannot be changed with time as e.g., TV is switched on based on the user comfort and need. Further all these load classification is given in Table1.

Table 1. Appliances Consumption profile and classification of loads in residential sector

Type of Appliance	Power (kW)	Duration (hr) every day schedule	Type of load
Washing Machine	2.3	2	Controllable
Cloth dryer	2.1	1	Controllable
Fridge	0.15	12	Critical (Nonshiftable)
Electric Heater	1.8	2	Controllable
Dishwasher	2.2	2	Controllable
Air conditioner	2	6(summer) 2(winter)	Controllable
Television	0.1	5	Controllable
Iron	1.8	1	Controllable (time shift able)
Illuminatio n(Lighting)	0.5	10	Critical
Fans	0.5	7	Controllable
Microwave Oven	2	2	Controllable

The Demand Side Management scheme contains the load need to be characterize every appliances , the operation period, the flexibility of operation period in order to minimize the cost. It invariably depends on the energy consumption scheduling algorithm reacting dynamically with every load depending on the load interface between the utility and the user. The major constraint is to improve proper scheduling of the appliances, by shifting the loads to non peak hours.The load parameters which are discussed in Table 1, are the required elements to configure the components in the scheduling strategy. Considering the total load priority classification for controllable and non controllable loads as $P_{Cl} = \sum_{i=1}^{11} P_{Cl}$ .The Table 2 exhibits the schedule execution of a residential user considered.

Table 2. Average Schedule execution of a user in residential domain

Type of Appliance	Starting time of operation	End time of operation	Parameter 1 (speed)	Parameter (temperature)
Cloth Dryer	08.00	12.00	1100 rpm	Not used
Dishwas her	06.00	16.00	Speed wash	Not used
Washing Machine	05.00	22.00	1200 rpm	90

3.2 Mathematical Model

The proposed model is to introduce renewable energy (solar PV) and battery storage in order to achieve reduction in energy bill using dynamic programming by energy consumption scheduler in a smart grid environment. Smart meters are installed in all the residential users and the goal is to allow the prosumers to store the energy using the sources and utilize them in peak hours.

The scheduling operation of appliances has to be managed in a household in order that the total electricity bill shall be minimized considering real time pricing. The need of smart meters installed in all the households would collect all electricity information of all the appliances. Depending on this energy scheduler unit provides an optimal solution for the utilization of the appliances. In this mathematical model ,addition of renewable energy with the energy scheduling unit is analyzed, by using two stage stochastic dynamic optimisation. In this process the scheduling operational unit with the constraints of PV unit and battery are made in a rolling procedure where the process is continued in a day (24hrs , 72 slots).

In the model , each residential user has set of appliances. The scheduling of the appliances , is considered as the total power preformed during the running time interval is equal to the predetermined energy, $P_{dt} = P_{Et}$. Stochastic dynamic programming model are used for the minimization of the cost considering noncooperative users both for single and multiple scenario. Further the analysis is carried out with the integration of solar energy and battery energy storage by developing the model by Gurobi optimizer for climatic conditions(summer and winter). GAMS solver are used as basic mathematical tool for performing the optimisation where the Gurobi optimizer solves the solution of handling the scheduling of appliances by interface with Matlab.

For the model, users house has equipped with PV panels(solar energy) and battery for electrical storage and develops a grid connection for the consumer to get electricity from the grid. The scheduling task of energy scheduling of appliances are considered for different appliances (11 appliances considered) during one day (24 hrs) which is subdivided with 72 slots of 20 minutes for each set of time T. The residential home appliances activities are scheduled by a set S_a . Each scheduling of appliance S_a is exhibited with a starting and a ending time. The consumers have the priority of sell and buy the energy at every time slot (24hrs, 11 appliances, 72 slots, 20 minutes) T for S_a. The proposed optimization using dynamic programming and GAMS solver with the mathematical model is derived in the further section. The performance action setting for each appliance is shown in Figure. 4.

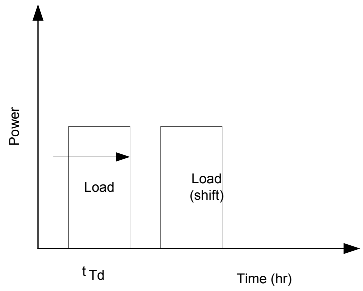

Fig. 4. Action setting for each appliance

3.2.1 Optimization Problem

The proposed work is to minimize the cost of the power obtained from the grid which are variable depending upon the peak and non peak hours tariff. The time pricing scheme is adapted here for the tariff analysis. The constant cost is adapted for the maintenance of PV unit and battery. The solar power is obtained from the region of Vellore, Tamilnadu , India for the detailed analysis [20]. The profile is based on the actual consumption pattern of a typical users of 3 residential homes in Vellore district. As the constant cost is independent of the schedule. The optimization problem is stated based on stochastic dynamic programming.

The objective function

$$C_{\Pi} = \min K[r_n(x_n) + \sum_{t=0}^{N-1} r_t(x_t, \alpha_t(x_t), y_t)] \quad (1)$$

The next state of the system using stochastic model is given as

$$x_{t+1} = f_t(x_t, u_t, w_t), \text{ at t=0 to N-1} \quad (2)$$

The rule of selecting x_t which is the first schedule state t in the system at every time period t is done with control action of u_t at the particular first state x_t .The control action for scheduling the appliances depends on the scheduling vector S. The scheduling strategy is done with each user as w_t. This process happens in a sequential form where a convergence limit of optimal schedule is obtained to reduce the cost .The optimal schedule for the appliances are given as S_a^* .This is a schedule parameter involved to minimize the cost by actively participating the energy consumption scheduling and incorporation of renewable energy. The cost function is the minimize the parameters using dynamic approach since it is solved based in a sequential form . The state of the model is given by three functions in the objective component where x_t is the first schedule state of the system over the t= 0,1... N-1 , α_t depends on the strategy over a time t (random strategy of scheduling the appliances depending upon the user constraints, y_t is the constraint developed for the battery and the PV unit with the integration with energy consumption unit.

$$C^*(x_0) = \min_{\Pi \in \prod} C_{\Pi}(x_0) \quad (3)$$

where Π handles all the optimal schedule of the appliances. $C^*(x_0)$ is the optimal cost value function as per the principle of optimality [1] . $\prod^* = \{\alpha^*_0, ...\alpha_{N-1}^*\}$ will be the optimal schedule for the optimisation problem for different time slots in a day (72 slots). The Figure. 5 shows the schedule process handled by stochastic programming to deal with uncertainty depending upon the probability of handling the strategy by the user.

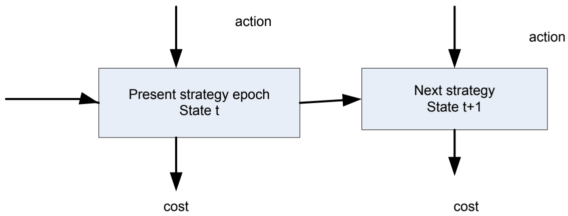

Fig. 5. Stochastic Optimization-Model Strategy

3.2.2 Constraints involved for Optimization

Scheduling :

Each appliance scheduling is considered as a activity S_a and which is carried out within a time slot for 24 hrs basis with starting and ending time.

$$\sum_{Stime}^{Etime} S_a^*, \forall a \in A \quad (4)$$

Each activity is divided into set of slots for 2 phases of peak and non peak hours, as the peak hour considered from 11am to 6pm and off peak periods are mostly in early morning and night hours like(4pm - 9pm)

Energy Balance from PV and storage (battery) constraints:

The energy flows in solar PV is represented by the following equations.

$$E_{load} < E_{PV} \begin{Bmatrix} C_b < C_{\max}, E_{Batt} = \beta_{i/p}(E_{load} - E_{PV}) \\ C_b = C_{\max}, E_g = E_{load} - E_{PV} \end{Bmatrix} \quad (5)$$

$$E_{load} = E_{PV} \{E_{Batt} = 0, E_g = 0\} \quad (6)$$

$$E_{load} > E_{PV} \begin{Bmatrix} C_B > E_{B\min}, \beta_{o/p}.E_{bat} + E_{PV} = E_{load} \\ E_B = E_{B\min,} E_{PV} + E_g = E_{load} \end{Bmatrix} \quad (7)$$

The battery level performance coefficient is given as $\beta_{i/p}, \beta_{o/p}$.The battery capacity performance energy level is given as $\beta_{\min} \le E_{Batt} \le \beta_{\max}$.The charge limit of the energy stored are calculated based on every hour for 72 slots considered. The energy balancing and battery constraints between the used and the produced energy is given as:

$$\alpha_t + \prod_t^{PV} + \sum_{r\in R} E_{B\min}^{Dch} = p_t + \sum_{a\in A}^{t=1\to 24} S_a + \sum_{r\in R} E_{Batt} \quad (8)$$

$$E_{con}^h = E_{PV}{}^h + E_{i/p}{}^h + B_k^h - C_k^h \quad (9)$$

B_k^h, C_k^h is the battery discharge and charge rate at hourly basis .From the energy balancing expression obtained from the model, $\prod_t^{PV}$ is the amount of solar power production made from the time slot. The electricity consumed at every point of time considers the total energy from the solar with the electricity from the grid minus the total amount of electricity sent to the storage is given in (9). Our goal is to minimise the electricity cost obtained from the electric grid. For the entire model, constant cost is been maintained for the solar and the battery backup. Two different scenarios is considered in the process for single and multiple users with set of home applainces.

The total optimisation problem with all the constraints and the mathematical model depicts the purpose of minimising the cost obtained from the grid. Thereby the cost obtained is independent of the schedule with a constant cost developed for maintaining of the solar PV and battery.

$$\min_{E_{batt}^h, E_{con}^h, B_k^h, C_k^h} \sum_{h\in H} C_{\Pi}(E_{i/p}^h) \quad (10)$$

subject to equations (4), (5), (6), (7), (8), (9) constraints

For the set of multiple users , the optimisation problem is stated as

$$\min \sum_n \sum_H C_{\Pi}(E_{i/p}^h, Users) \quad (11)$$

subject to the constraints of equations (4), (5), (6), (7), (8), (9) for each user.

The iterations taking place performing in the optimisation probelm for complete convergence with constraints is done in Appendix C.

The flowchart of the process is explained in Figure. 6.

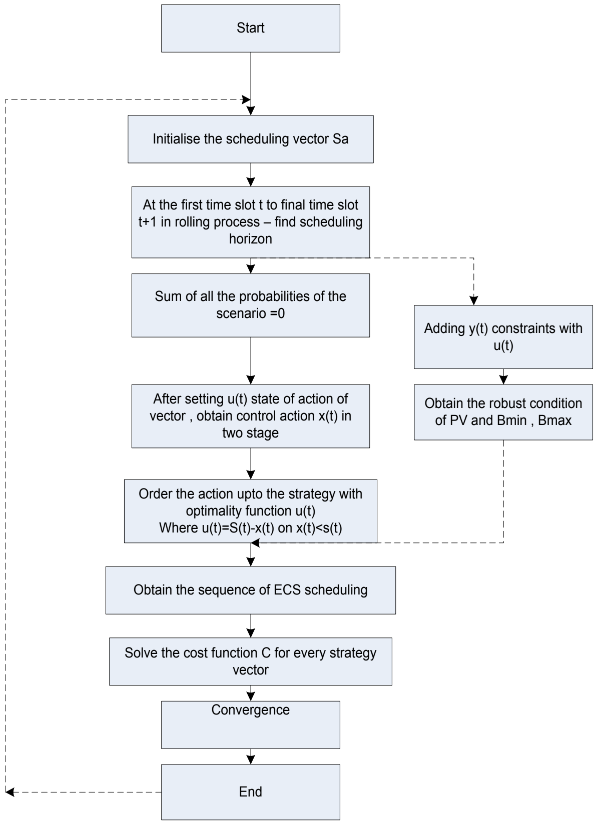

Fig. 6. Flow chart of the process

3. Results and Discussion

For the optimization process, the mathematical model is implemented using GAMS solver and later the modeling is done with MATLAB through Gurobi optimizer. In regard to evaluate the models considering for all the users bills and efficiency , prediction method is carried out for PV unit and battery storage unit.For the model of non cooperative users , we have analyzed the results with the case of single user and multiple user scenario and also considered the cases of climatic conditions. For the single user , we have considered one user in a normal middle class family , equipped with 10 household appliances (considering 9 shiftable appliances) and the house is connected to the power grid. Our simulation results were obtained by GAMS solver which is a mathematical programming tool for complex problems and the stochastic model is solved using Gurobi optimizer to arrive at optimal solutions of scheduling. For the first case, we have taken one house installed with solar PV and energy battery storage with the parameters of PV panel rating of 1kWh and battery capacity of 10kWh. The charging and discharging limits of the battery is equal to 10kWh. For general case two prices are considered for daytime D_p(1 to 15 hrs) and night time N_p(16 to 24hrs).

Different scenarios have been considered in the model with and without PV panel and storage battery, in order to discuss the difference in cost of the user's bill with the integration of renewable energy. In concern with the electricity prices for the model time varying tariff is considered and one hour tariff analysis is also done. Time of use tariff [18] is introduced globally in many electricity markets so that the cost varies with respect to the demand in peak hours. Each appliance works during a particular time interval e.g. Appliance 1: Washing Machine: from h=10 to h=12 ,Appliance 2 :Heater: from h =12 to h =15. Similarly for the entire proposed stochastic model 11 appliances is considered. Further ,the results have been compared with hourly pricing scheme including the climatic conditions also considered .Various load profiles is generated with DSM model for energy scheduling with the renewable sources. Figure. 7 is the load curve taken on a normal summer day for 2kW PV panel system used in the model. Indeed, to obtain the difference between energy consumption scheduler with and without renewable energy , different studies have been incorporated shown in Figure 8 and Figure 9.

Table 3. Multi user performance gain

Scheme	User 1- Cost/day in Rs	User 2(Rs)	User 3(Rs)
Hourly Pricing	109	82	84.5
TOU Pricing	112.5	87.6	88.5
Savings in a day	5.2	3.4	2.5

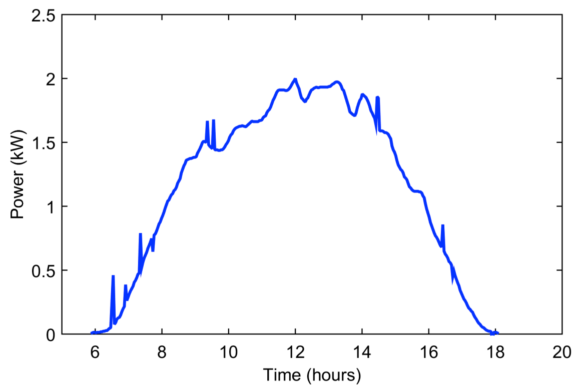

Fig. 7. Load curve for a day for 2 KW PV system

The results for the dynamic programming model is analyzed in a non cooperative multiple user scenario with the combination of Battery, PV panel. Simulation results are carried out to obtain the difference between energy consumption scheduling model both with and without the renewable energy sources model . Table 3 shows the results of multi user electricity bill for the particular TOU pricing (Time of use) , Hourly pricing and the cost is calculated in Rupees(INR).The day time price was D_p= 1.8 Rs(0.7cent) and the night time price was $N_{p.}$ = 1.2Rs (0.5 cent). As the hourly and TOU pricing are involved for the entire model. The table 3 exhibits the clear savings done by the users from this model incorporating renewable energy. Using GAMS solver results have been established for PV power and the load scheduling with DSM and without DSM ,considering the battery (state of discharge and charge)power in summer and the winter season .The contribution of PV and battery with DSM shows an intensive usage in high production time in a day considering user's comfort shown in Figure. 8 and Figure 9

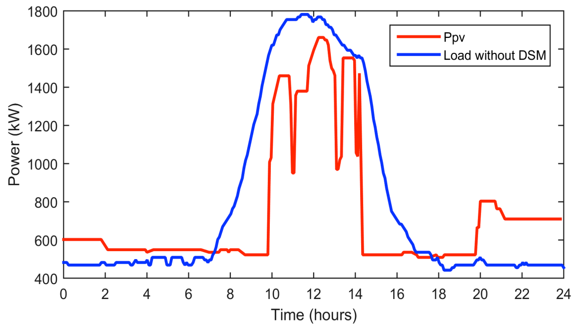

Fig. 8 (a). Without DSM-PV Power

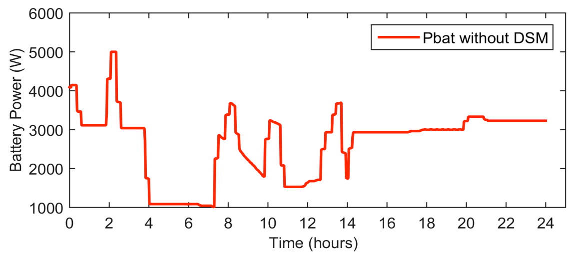

Fig. 8 (b). Without DSM-Battery power

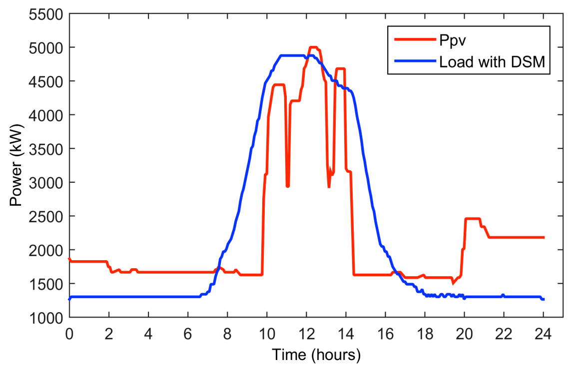

Fig. 9 (a). With DSM (energy scheduler) and PV power

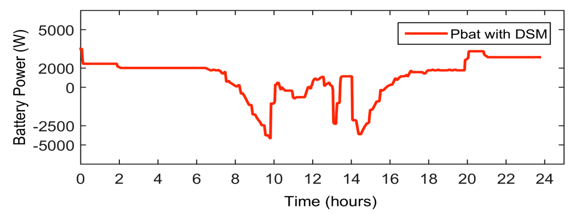

Fig. 9 (b). With DSM (energy scheduler) and battery power

The characteristics of the battery considered for one user for the limits is based on 4000Wh. The PV power and battery contribution are found using DSM strategy , where the cycles are increased to about 2% in summer. So using this strategy the PV contribution is increased about 12% in summer season where the user in future smart grids can buy sell and store energy effectively.

Simulated results of the energy consumption scheduling unit with the cost for the different cases is analyzed and shown in Figure. 10 and Figure 11. The results obtained establishes that the energy cost at the peak hours with the DSM model(energy scheduler unit) equal to 288 INR is reduced to 178 considerably by adding renewable energy.

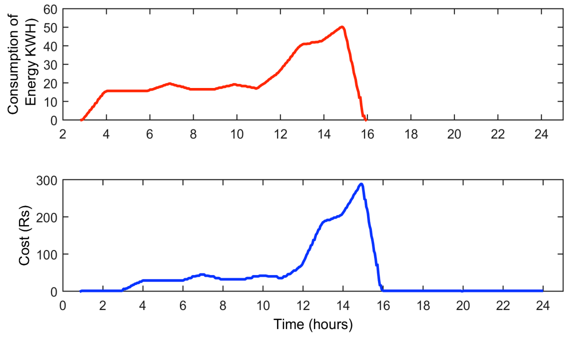

Fig. 10. With Demand Side Management (DSM) modelling with user 1 (TOU pricing scheme) for energy scheduling

From the results , there is about 4%decrease in the total cost and the savings per day is increased with the addition of PV power and battery storage unit. The programming is developed for n number of users, considering the climatic conditions , PV power utilization and pricing scheme. In Figure. 12, where the case is considered for 5 set of users ,the cost is very much decreased to 5% of the total cost for per day.

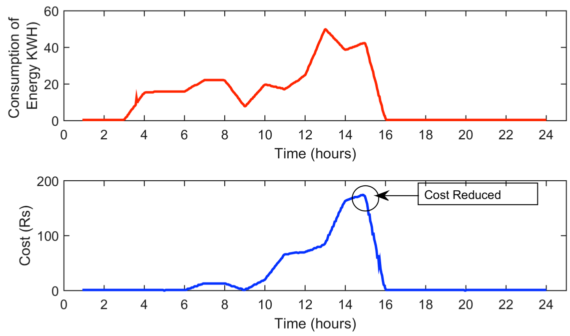

Fig. 11. With Demand Side Management (DSM) modelling with user 1 (TOU pricing scheme)for energy scheduling considering renewable energy(winter season).

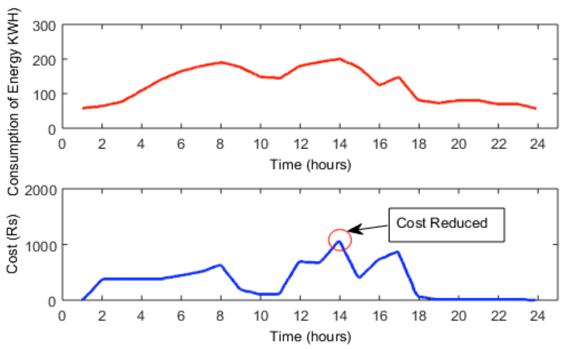

Fig. 12. With Demand Side Management (DSM) modelling (hourly pricing scheme)for energy scheduling considering renewable energy(summer season)

For multiple users , we have considered 10 houses with 7 shiftable appliances installed with PV and battery. The parameters and constraints are the same as the single user consideration but the charging and discharging limits is considered to be 70kWh.Pricing scheme is also the same as the single user and the comparison is made with the two pricing schemes. Different results have been obtained for multiuser scenario and the consideration is taken for summer days . The results obtained shows that the cost is considerably decreased from Rs 200.8 to Rs 178 by using renewable energy.

Table 4. Performance Gains of the Model

Parameters	Users			
	User 1	User2	User 3	User 4
Pricing scheme	TOU (summer)	TOU	Hourly pricing (winter)	Hourly pricing
Without DSM (Cost in Rs)	300	350	252	292
With DSM - Energy scheduler unit	272	331.5	241.3	272.4
With DSM and without addition of Renewable energy	288.3	325.2	230.8	254.6
With DSM and addition of renewable energy	173.4	280.5	225.6	212.5
Savings in a day	8%	6.5%	5.9%	7.2%

Observations of results made with the comparison for two pricing scheme incorporating renewable energy in the model shows significant savings in a day are tabulated in Table 4 .For multiuser scenario, users follow both the pricing scheme and to show the analysis better, case studies in summer and winter has been done. By this model, cost is reduced to about 7% in average of a day by adding the renewable energy based on the characteristics of the power management strategy made with PV and battery power using stochastic model.

4. Conclusion

In this paper demand side management control strategy is done by developing an energy consumption scheduling unit with the consideration of renewable energy (PV) to save the electricity cost of the users. For better analysis different pricing schemes were considered with climatic conditions. The model is analyzed by stochastic dynamic optimization using Gurobi optimizer and GAMS solver for solving different scheduling process . The simulation results show the effectiveness of the system model under different simulation scenarios by reducing total electricity cost with users comfort . The model can be exhibited further to industrial sector by considering scheduled and non scheduled tasks for future works.

Appendix A

A.Nomenclature

C_{Π}	Cost function
S_a	Scheduling vector for appliances
α_t	Strategy at every time slot for scheduling
x_t	First schedule state of the system
y_t	Constraints for energy balancing unit
u(t)	Utility control action at every state (t+1)
E_g	Total power interchanged with the grid
A	Set of scheduling appliances
E_{PV}	Solar power generated
E_{load}	Actual power by the loads
E_{Batt}	Power by the battery storage system
$E_{B\min}$, $E_{B\max}$	The maximum and minimum level charge of the battery system
β	Battery level performance coefficient
$\prod_t^{PV}$	Amount of solar power production
E_{con}^h	Energy consumed for each hour in the slot

Appendix B

B. Pricing Schemes

I.Incentive Based Programs	II .Price Based Programs
Direct load control	Time of Use Pricing
Interruptible load	Real time Pricing
Demand Bidding	Inclining Block Rate
Emergency Demand Reduction	Critical Time pricing

Appendix C

C.Iterations involved for one set of users

To solve the optimisation problem the following iterations steps are involved to move to next strategy with the set of constraint

$$\min\{\sum_{a\in A}[r_t \cdot p_{i,t} + \sum_{t_0+1}^{\beta_k, C_k}(C^*(x_0))]\} + \min\{\sum_{t_0+1}^{\beta_k, C_k}(C^*(x_0)), y_t.\alpha_t)\} \quad (12)$$

$$\sum_{t=x_i}^{t_0-1} p_{i,t} + \sum_{t=x_i+1}^{x_n} p_{i,t} = H_i \quad (13)$$

The multiple operation task is given as $p_{i,t}$.The sum of all probabilities of the energy scheduling is considered in stochastic model

$$\tau = t_0 + 1, \ldots N \text{ for } y_\tau \geq 0, \sum_{s_i} p_{i,\tau} \leq y_\tau$$

Here the iterations steps are involved in the model to obtain the convergence with an unique schedule to reduce cost.

References

[1] Amin, S. Massoud, Bruce F. Wollenberg. "Toward a smart grid: power delivery for the 21st century." IEEE Power and Energy Magazine, vol. 3, no. 5, pp. 34-41, 2005.

[2] Kärkkäinen, Seppo. "Integration of Demand-Side management, Distributed Generation, Renewable Energy Sources and Energy Storages." Report Task XVII Integration of Demand-Side management, Distributed Generation, Renewable Energy Sources and Energy Storages, vol. 1, pp. 77, 2008.

[3] Pina, André, Carlos Silva and Paulo Ferrão. "The impact of demand side management strategies in the penetration of renewable electricity." Energy vol. 41, no 1, pp. 128-137, 2012.

[4] Palensky, Peter, Dietmar Dietrich. "Demand side management: Demand response, intelligent energy systems, and smart loads." IEEE Transactions on Industrial Informatics, vol. 7, no. 3, pp. 381-388, 2011.

[5] Strbac, Goran. "Demand side management: Benefits and challenges." Energy policy, vol. 36, no.12, pp. 4419-4426, 2008.

[6] Shaahid, S. M., M. A. Elhadidy. "Economic analysis of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions—A step to clean future." Renewable and Sustainable Energy Reviews, vol. 12, no. 2, pp. 488-503, 2008.

[7] Xiao, Jin, et al. "Near optimal demand-side energy management under real-time demand-response pricing." Network and Service Management (CNSM), 2010 International Conference on. IEEE, pp. 527-532, 2010.

[8] Di Zhanga, Nouri J. Samsatlib, Nilay Shahb, and Lazaros G. Papageorgioua. "Optimal scheduling of smart homes energy consumption with microgrid." ENERGY 2011 : 1st First International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, pp. 70-75, 2011.

[9] Mohsenian-Rad, Amir-Hamed, et al. "Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid." IEEE Transactions on Smart Grid, vol. 1, no. 3, pp. 320-331 2010.

[10] Barbato, Antimo, et al. "House energy demand optimization in single and multi-user scenarios." IEEE International Conference on Smart Grid Communications (Smart Grid Comm), pp. 345-350, 2011.

[11] Castillo-Cagigal, Manuel, et al. "A semi-distributed electric demand-side management system with PV generation for self-consumption enhancement."Energy Conversion and Management, vol. 52, no. 7, pp. 2659-2666, 2011.

[12] Matallanas, E., et al. "Neural network controller for active demand-side management with PV energy in the residential sector." Applied Energy, vol. 91, no.1, pp. 90-97, 2012.

[13] Palma-Behnke, Rodrigo, et al. "Energy management system for a renewable based microgrid with a demand side management mechanism." IEEE symposium on Computational intelligence applications in smart grid (CIASG), 2011.

[14] Samadi, Pedram, et al. "Optimal real-time pricing algorithm based on utility maximization for smart grid." First IEEE International Conference on. Smart Grid Communications (SmartGridComm), pp. 415-420, 2010.

[15] Barbato, Antimo, et al. "Cooperative and non-cooperative house energy optimization in a smart grid perspective." IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2011.

[16] Dam, Q. Binh, Salman Mohagheghi, and James Stoupis. "Intelligent demand response scheme for customer side load management." IEEE Energy 2030 Conference, pp. 1-7, 2008.

[17] Gudi, Nikhil, Lingfeng Wang, and Vijay Devabhaktuni. "A demand side management based simulation platform incorporating heuristic optimization for management of household appliances." International Journal of Electrical Power & Energy Systems, vol. 43, no.1, pp. 185-193, 2012.

[18] Samadi, Pedram, et al. "Utilizing renewable energy resources by adopting DSM techniques and storage facilities." Communications (ICC), 2014 IEEE International Conference on. IEEE, 2014.

[19] Narimani, Afsaneh, et al. "Financially optimized scheduling of electric energy storage in presence of renewable energy resources." Power Electronics for Distributed Generation Systems (PEDG), 2015 IEEE 6th International Symposium on. IEEE, 2015.

[20] Zhu, Ziming, et al. "A Game Theoretic Optimization Framework for Home Demand Management Incorporating Local Energy Resources." Industrial Informatics, IEEE Transactions on 11.2 (2015): 353-362.

[21] Radhakrishnan, Asha, and M. P. Selvan. "Load scheduling for smart energy management in residential buildings with renewable sources." Power Systems Conference (NPSC), 2014 Eighteenth National. IEEE, 2014.

[22] Cicek, Nihan, and Hakan Delic. "Demand Response Management for Smart Grids With Wind Power." Sustainable Energy, IEEE Transactions on 6.2 (2015): 625-634.

[23] Deng, Ruilong, et al. "A Survey on Demand Response in Smart Grids: Mathematical Models and Approaches."

[24] Albadi, Mohamed H., and E. F. El-Saadany. "A summary of demand response in electricity markets." Electric power systems research 78.11 (2008): 1989-1996.

[25] Moura, Pedro S., and Aníbal T. de Almeida. "Multi-objective optimization of a mixed renewable system with demand-side management"Renewable and Sustainable Energy Reviews, vol. 14, no. 5, pp. 1461-1468, 2010.(18 earlier)

[26] Palma-Behnke, Rodrigo, et al. "Energy management system for a renewable based microgrid with a demand side management mechanism", IEEE symposium on Computational intelligence applications in smart grid (CIASG), 2011.

[27] Arulkumar, K., D. Vijayakumar, and K. Palanisamy. "Estimating Future Site of Grid PV System with Optimal Shade Analysis." International Journal of Renewable Energy Research (IJRER) 5.1 pp. 308-316, 2015.