An optimal Home Energy Management System based on Time of Use pricing scheme in Smart Grid

Fahad Nawaz, Gulzar Ahmad, IhsanUllah, Khalid Javed, Intekhab Khan, Wahab Khan

ABSTRACT: ------Smart Grid came to the fore with developing technology, getting the attention of mostusers,because it is the most efficient, reliable and user friendly technology. Smart Grid (SG) supports the concept of dual communication between the users and utility; thus, managing the energy demands of the user in a sophisticated way. The most authentic part of the Smart Grid is Home Energy Management System (HEMS), whose core incentive is to reduce the electricity expense of the consumers and minimize Peak to Average Ratio (PAR). Time of Use (TOU) pricing is that part of the HEMS, which mainly describes the electricity tariff for the consumers in a time horizon. For TOU pricing, the main initiative, which has to be taken, is the scheduling scheme for the home appliances. In this paper we proposed an authentic, reliable and cost-effectivemodel for scheduling of the home appliances in an optimal way. Our simulation model depends upon three cases with two different evolutionary algorithms i.e. Genetic Algorithm (GA) and Binary Particle Swarm Optimization (BPSO). This model completely describes the best scheduling for the home appliances with minimum delay, reducing the electricity bill in an efficient way. All the comparison is made in proper way for making trade-off between the two main algorithms.

Keyword---- Smart Grid, Demand Response, Home Energy Management System, Time of Used Pricing, Genetic Algorithm, Binary Particle Swarm Optimization, Appliance Scheduling Scheme.

1. Introduction

A smart grid is an integrated grid system that manages electricity generation and demand in a sustainable, compatible, sophisticated and economical way. SG is inundated with optimization techniques that lessen losses and voltage levels; increases reliability and improves management by using real - time measurements.SG operates on two-tier flow of electricity--information and Intel--to create an automated and distributed advanced energy dispensability network"[1]".

In older versions of grid, there is no two-ways flow of information, i.e., between the consumer and supplier. When energy consumption exceeds the grid capacity, it affects the grid maneuver, cost of production, user compatibility and reliability in the form of load shedding and black-out. Due to these hurdles, it is indispensable to changethe grid infrastructure.

The SG usestwo-way flow of information--cyber-security technologies, and computational intelligence--in asynchronizedway against electricity production, transmission, substations, distribution and consumption to accomplish a system that is clean, safe, secure, reliable, robust, efficient, and sustainable. This discourse caters to the cornucopia of energy system from generation to the apogee of utilization of the electricity "[2]".

There is a dearth of power generation despite the need increasing with each passing day. Therefore, there are different channels being exhausted to meet up the demands. So, smart grid uses renewable energy resources to balance this supply demand.Due toconstraints of flow of information and details of traditional grid, its efficiency on both the supply and demand side goes downhill"[3]".

As we are expecting a steep crescendo of energy demand, there would be a colossal leap from the fossil-fueled production to production based on renewable energy resources like solar, wind, and geothermal . Renewable power production gives a sustainable energy supply which is safe and clean. According to a research paper,United States household electricity consumption data divulges that 42% of all power consumption by dwellings is used by household appliances "[4]". Major factors and forces are using the markets, implementing new and reformed models to optimize technologies,reinvigorating them as the demand of energy touches new heights. New technologies are being devisede.g. intelligent and smart meters, advanced meter infrastructure, controllable

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appliances. New laws are being implemented and older ones are reformed giving access to users where they can check on the prices and energy usage. Finally, there are dynamic pricing schemes being proposed and some of them are implemented"[5]". Due to the scarcity of huge storage devices, electricity production and usage must be sustainably balanced in order to dodge load-shedding and tripping.

After SG came to the fore,dwellers can now reduce and manage the budget by efficient and smart scheduled use of electricity.With such way forward, different entities are coming forward with new in-home power consumption schemes.On the consumer front, they can reduce the cost by shifting the power consumption hours"[6]".With this shift of time, .the power consumption demand can be steeply reduced. The shift can be achieved by a Demand Response (DR) mechanism "[7]". Through DR mechanism, researchers have come up with schemes that decrease the peak-to-average ratio by convincing them to change the consumption hours from peak to low hours "[8]".A real-time pricing scheme costs each power consumer according to the time and units of power consumption. Price-based DRschemestake into consideration the reduced demand fluctuations as a mainstay, and both the consumers and suppliers take benefits from DR.

ADR schemesynchronizes the power supplier and the user demands"[9]". DR program, by decreasing the peak-to-average ratio of power demand, protects grid from number of perils including black-outs etc. It also decreases the need of costly power-generation plants which mainly operates for peak load periods, increasing the utility utilization and improving the smart grid sustainability"[10]".

Regarding some of the important properties of the human life, Artificial Intelligence (AI) techniques are used in human-made systems in order to make them intelligent and progressive in the research. The types of algorithms include Genetic Algorithm GA, Particle Swarm Optimization PSO, and Ant Bee Colony ABC etc. PSO and ABC algorithms are copied from the behavior of the birds and insects. They find the solution for the problem same as the pattern followed by the insects and birds for their own problems.

This paper is about providing a proper scheduled model embedded with the renewable energy sources in order to produce the cost efficient model for users. Our model provides an optimal schedule for the working of appliances, the shifting from high peak hours to off peak hours, utilizing the energy got from renewable energy sources, minimizing the utility bill of the end users in a fix time horizon. All these procedures are done by using two different types of algorithms i.e. GA and BPSO. The results which are obtained from the two algorithms are compared on the basis of energy consumption and cost minimization, to provide optimal algorithm for scheduling model.

2. Related Work

Smart Grid is the new emerging technology, which is a two way communication system, provides the optimal electricity to the consumers with the proper information about demand of the end users. SG combines the Information and communication technologies ICTs, engineering and management of the grids to provide an efficient power supply chain for the users. RES also plays a vital role in reduction of the power consumption from the utility grid. Home Energy Management system is now a days an emerging system for scheduling the working of appliances in optimal way. Researchers also used some of AI techniques for scheduling the appliances in automatic way in order to minimize the utility bills "[11]".

The main purpose of introducing HEMS is to minimize Peak to Average Ratio PAR by scheduling the appliances and cost minimization. A HEM is the combination of Smart Meters, Advance Meter Infrastructure AMI, Energy Management Controller EMS and some in home display devices.SG provides different types of pricing schemes like Time of Use TOU, Real Time Pricing (RTP) and Critical Peak Pricing (CPP) with the help of smart meters.

Demand Side Management (DSM) focuses on the influence of RES in order to minimize power usagein appropriate way. Home appliancesload is put as a feedback by the DSM and control actions are taken in order to cater to the demand of load consumption of the home. The shift-able devices are managed with the help of DSM. DSM technique overcomes all types of the complexities in the management of the loads which includes different characteristics of power consumption. The main purpose of DSM is to keep balance between the load curve and objective load curve "[12]".

The three different types of pricing schemes which are TOU, RTP, and CPP are discussed "[13]". Each pricing scheme has the information about the price of the electricity in advance in order to define the high peak hours and peak hours for the users. In our paper, we use TOU pricing scheme for our case in which the prices of the electricity varies from hours to hours depending upon the demand of the users.

The developments made in the communication and networking technologies of the SG are presented in "[14]". This paper shows a brief description of SG, smart homes and the devices used in smart homes and challenges for implementation of the Energy Management Systems. RES systems are mostly the type of generation systems which are unpredictable, for example the solar system is mainly based on the availability of the sun, while the wind mill depends upon the wind. So users can't depend fully on such type of sources. To get the maximum output from such RES, using GA is described in "[15]".

Demand Response DR Program provides the balance between the demand and supply. Most of the conventional homes are not familiar with the DR program while on the other hand the Smart homes have the proper information about DR, and have the required tools to take part in the DR. he overall working of the appliances in the smart homes are monitored, controlled and managed by HEMS in appropriate way "[16]". Three main types of Distributed resources are mainly described, which are: Distributed Generation, Demand Response, and Distributed Electricity Storage. All the above types are reconnected inside the grid representing radical change operation "[17]".

3. Motivation

To overcome the energy crisis in the world, the basic need is to minimize the use of the energy in homes and industries. Developers are introducing new and improved technologies to benefit user efficiently and to make the use of energy more sustainable. RES are defined to overcome energy crisis in homes and industries. Both the generation and consumption of energy should be balanced in an appropriate way for sustainable development.

For a residential area, the demand of users and productionof utility should be balanced. For this purpose, we need a two-tier system for communication between users and utility grid; such system is provided by the Smart Grid. Looking at micro level, SG provides the different pricing schemes for the end-user in order to manage the load,reducing the bills. SG stresses on the end-users to shift their heavy load from high peak hours to off peak hours. Most users are notcognizant of DR program, and they don't have much available resources to be a part of the DR program. Such types of users are not fit for the optimal usage of energy; hence, pay maximum bills. For all these problems, there should be a proper smart system referring to the three types of the pricing schemes which are discussed to overcome all the problems of customers.

The prime purpose of the proposed algorithm for scheduling the appliancesis to manage the energy consumption sustainably by appliances to reduce the electricity bill. The defined algorithms will schedule a pattern for the appliances working throughout the day and decides which appliance will turn on first and which would follow; it also defines the length of operational time of the appliances. The defined algorithms are very efficient and intelligent to fit in every environment easily. The impact of our proposed model on the power system is listed below.

1. Reduction of utility cost and PAR.
2. Provision of the two different types of the algorithms for the scheduling of the appliances in optimal
3. The working of our proposed system is defined and calculated.

4.Proposed Home Energy Management System

The mainstay of installing HEMS in home is to reduce the electricity bill and minimize the PAR by scheduling the operation of appliances sustainably. HEMS includes advanced metering infrastructure (AMI), Smart Meters (SM), Home Gateway (HG), Home Area Network (HAN), Central Control Unit (CCU), home appliances, and in-home display (IHD). The complete HEMS architecture is demonstrated in Fig. 1. This model stresses on minimizing bills of consumers by reducing the amount of the energy dissipated by the home appliances in proper way.

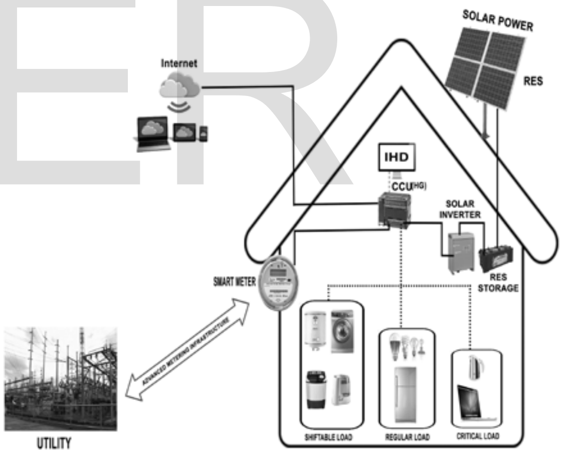

Figure 1: Home Energy Management System Architecture.

The proposed HEMS model communicates with grid and shifts the heavy load from the high peak hours to low peak hours. CCU is the core part of the HEMS which will communicate with the grid via smart meter and AMI to get the information about the price of electricity regarding each hour. CCU will then adjust the load according to the information and price provided by the utility. AMI infrastructure is designed for automation, bi - directional communication between smart meter and utility company. Advanced metering infrastructure (AMI) is responsible for both consumers and utility sides to transfer power utilization and power pricing information. SM will gather information of the end user load and electricity consumption and convey it to the utility almost in real time. SM is generally mounted outside of the homes. SM enables the communication between the HEMS and utility grid, which will describe the load consumption of the consumer to the utility and guide them about the load of the users with the help of Demand Response.

In this model, wejuxtaposeHome Gateway with CCU. Smart meter will provide the pricing scheme to the CCU with the help of HG, and all of the home appliances will communicate with the CCU through a HAN. This connection can be found in fig 2. Now taking this pricing scheme in to account, CCU will manage the load of the whole day. All the home appliances will communicate with CCU wirelessly with the help of Zig Bee, Z wave or wifi. CCU defines the optimal power pattern for each appliance. As our proposed model contain RES, so some of the energy requirements of the users can also be fulfilled with the help of energy, provided by RES, like solar panel which is also connected to the CCU. CCU will shift some of load from the utility to the RES minimizing the amount of energy drawn from the utility. In Home Display, is connected to the CCU which will update the users about the whole processto be controlled by the user any time.

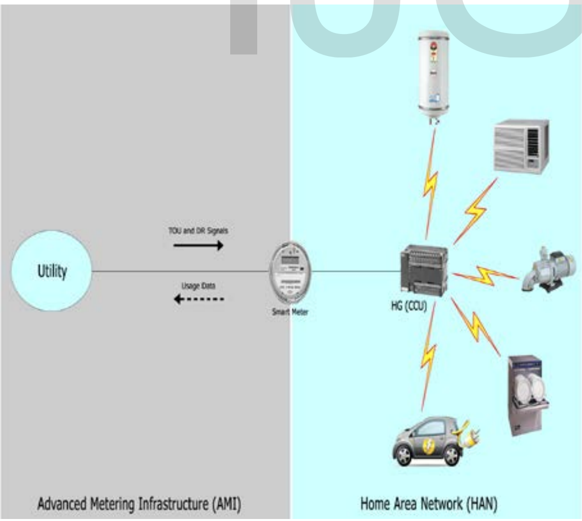

Fig. 2:Communication of the Appliances with CCU through HAN.

When HEMS is absent, electrical energy is assigned to the appliances without any specific pattern, while in case of HEMS;scheduled pattern is assigned to appliances, minimizing the overall expense. The purpose of providing power pattern for appliances is to minimize energy imported from grid by shifting heavy load from the high peak hours to low peak hours,thus, minimizing the energy demand and PAR.CCU works on principle of load shifting as represented in given fig. 3.

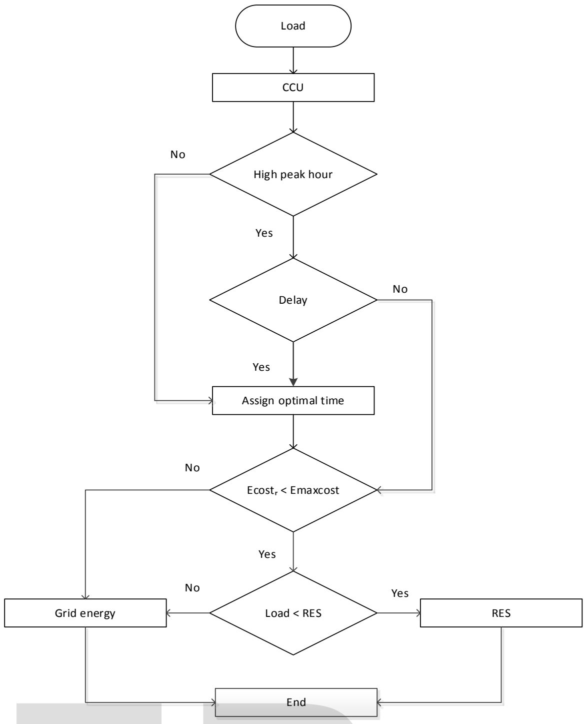

Fig 3: Home Energy Management System Model.

In our research, we are taking a time period of 24 hours. In this time period, each hour refers to a time slot i.e. T= {1, 2, 3… 24}. CCU is the main controller for providing energy to the appliances according to their needs in appropriate way.

4.1 Energy Consumption Model

In our research, we are working with three main types of load which are given under.

4.1.1 Regular load(R)

The Regular load cannot be changed or altered; they have fixed energy requirement, and have to ensure continuous supply of electricity e.g. lights. Regular load will bear no delay and the energy consumed by regular load can be calculated as:

$$\epsilon_{R,t} = L_R * \chi_{a,t}, \forall\, t \in T\,, \qquad (1)$$

$$A \in \{a_1, a_2, a_3, \dots\dots\dots a_N\}$$

Such that

$$\eta_R = 0 \qquad (2)$$

Where $\epsilon_{R,t}$ represent the energy consumed by regular load in time slot h. L_R represents the critical load, and $\chi_{a,t}$represent the appliance $a$status in specific time period t,if $\chi_{a,t}$=1, then appliance will be in working condition and if $\chi_{a,t}$ = 0, then it represents the appliance is not in working condition i.e. it is off and η represent acceptable delay for critical load.

$\chi_{a,t}$is a Boolean variable which is written as:

$$\chi_{a,t} = \begin{cases} 1 & appliance\ is\ on \\ 0 & appliance\ is\ off \end{cases}$$

4.1.2 Shiftable load(S)

The Shift-ableloads refer to the type of load which can be stopped from working any time. The set of Shift-able load which we are taking in this work isDish Washer, Vacuum Cleaner, Water Heater and Washing Machine.Energy consumed by the shift able load is calculated as:

$$\epsilon_{s,t} = L_{s,t} * \chi_{a,t} \quad (3)$$

The maximum possible delay is represented as

$$\eta = 24 - \alpha_a \quad (4)$$

Where $\epsilon_{s,t}$represent the energy consumed by shift able load $L_{s,t}$ and $\alpha_a$denotes the Length of Operational Time (LOT) of appliance a. As the CCU shifts the load from high peak hours to low peak hours, so all appliances belongs to this category can bear a certain amount of delay and is mathematically calculated as:

$$\psi 1 \le \eta_a \le \psi 2, \forall a \in R, S, C \quad (5)$$

Where

$$\psi 1 = 24 - \alpha_{max} \quad (6)$$

$$\psi 2 = 24 - \alpha_{min} \quad (7)$$

The main objective of our research model can be completed by managing the shifting of these shift able loads in proper way.

4.1.3 Critical Load (C)

Critical load is type of load which is available for users in case of emergency or guest situation when the user needs extra switches to consume energy. Such appliances have a highest priority so this category is delay free e.g. electrical kettle. Energy consumed by such load during time slot h is given by

$$\epsilon_{c,t} = L_{c,t} * \chi_{a,t}, \quad \forall t = T \quad (8)$$

$$\eta = 0 \quad (9)$$

Where $\epsilon_{c,t}$represent the energy consumed by critical load $L_{c,t}$ in time slot t.

In this model every appliance has fixed LOT. The energy prerequisite for all appliances are enumerated in kWh and defined as:

$$\epsilon_{a,t} = [\epsilon_{(a,1)}, \epsilon_{(a,2)}, \ldots, \epsilon_{(a,t)}], \quad \forall t \in \{1,2,\ldots,24\}, \quad a \in N$$

Where$\epsilon_{(a,t)}$ expresses appliance $a$power consumptionin given time slot t. The overall energy demand of household is:

$$\epsilon_t = \sum_{a=1}^{N} \epsilon_{(a,t)} \quad (10)$$

So total N appliances demand in a house for 24 hours can be defined as:

$$\epsilon_T = \sum_{a=1}^{N} \sum_{t=1}^{24} \epsilon_{(a,t)} \quad (11)$$

As in proposed model, we are also working with the installation of RES like solar panel, so home will fulfill its few demands from the energy obtained from the RES. The RES which we are taking in to account can fulfill the 30% of the needs of the energy, so the further energy demands can be fulfilled from the utility ,and the users will use the energy provided with the help of CCU which is the combination of energy from utility and RES. The amount of energy produced by the single photovoltaic cell in kW is defined as:

$$\epsilon_{RES,t} \quad \forall t \in \{1,2,3,4 \ldots \ldots \ldots 24\} \quad (12)$$

HEMS gets the amount of energy obtained from RES in 24 hours is given by:

$$\epsilon_{RES} = \sum_{t=1}^{24} \epsilon_{RES,t} \quad (13)$$

4.2 Energy Cost Model

Cost function defines the cost of consuming electricity by the household appliances in each hour. Generally, the cost of the same load can be changed at different time horizon. The cost model for the three types of load is given as under

4.2.1 Critical Cost Model

Cost model for critical load is:

$$C_c = \chi_t * L_c * EP_t \quad (14)$$

Where C represents the cost of critical loadχ_t represents the status of the appliance during time slut t, Lc represents the critical load and $EP_t$is the price of electricity set by grid for time slot t.

4.2.2 Cost model for Shift able load

Cost model for shift able load is derived as:

$$C_s = \chi_t * L_s * EP_t \quad (15)$$

4.2.3 Cost model for regular load

Cost model for regular load is derived as:

$$C_R = \chi_t * L_R * EP_t \quad (16)$$

The appliances working in time slot$t$will dissipate the cost of the energy. If we generalizeequation of cost for critical, regular or shift-able load is calculated.

$$C = \sum_{t=1}^{24} \epsilon_{Load,t} * EP_t \quad (16)$$

4.3 The Optimization Problem

For optimization, it is important how we dispense our loads. We have to distribute load in such a way that we can obtain the maximum profit out of the HEMS in 24 hours. The problem of optimization is defined as: Set of appliances, i.e., $A = \{a_1, a_2, a_3 \ldots a_N\}$, where allthe appliancesconsume energy differently in different time period.

CCU connects all the appliances together. The price of the electricity isdefined by the utility according to the time. The price of electricity will be different for each hour. Noticeably, each user wants to minimize their bill by reducing the amount of energy consumed by their appliances. The aim of our proposed scheme is to reduce the utility cost and is expressed as:

$$min\left(\sum_{\alpha=1}^{N}\sum_{t=1}^{24}\epsilon_{cost\ \alpha,t}\right) \quad (17)$$

Refers to:

$$1 \le t \le 24 \quad (18)$$

$$\sum_{\alpha=1}^{N}\sum_{t=1}^{24}\epsilon_{\alpha,t} \le \epsilon_{Grid} \quad (19)$$

$$0 \le \alpha_{\alpha} \le 24, \quad \forall\, \alpha \in A \quad (20)$$

$$\eta \le 24 - \alpha_{\alpha} \quad (21)$$

Where $\epsilon_{cost\ \alpha,t}$ is the cost of electricity paid by the user for time horizon t.

4.4 PAR Model

Optimal energy efficiency refers to use minimum energy by consumer at any specific time during high peak hours as well as low peak hours. To achieve reliable and efficient electric grid system, it is very important to reduce the PARby reducing peak hour demand. By using the energy optimally, it will minimize the PAR.

The daily peak and average energy consumed can be calculated by the following formula.

$$\epsilon_{peak} = max\left(\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{T,\alpha,t}\right) \quad (22)$$

$$\epsilon_{avg} = \frac{1}{T}\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{\alpha,t} \quad (23)$$

Peak to average ratio can be written

$$PAR = \frac{max\left(\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{T,\alpha,t}\right)}{\frac{1}{T}\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{\alpha,t}} \quad (24)$$

To minimize PAR the equation can be written as

$$min\,\frac{max\left(\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{T,\alpha,t}\right)}{\frac{1}{T}\sum_{t \in T}\sum_{\alpha \in A}\epsilon_{\alpha,t}} \quad (25)$$

4.5 Appliance scheduling using Binary Particle Swarm Optimization

BPSO is a technique which is based on heuristic population method that search solution to an optimization problem. In BPSO the optimization includes binary-coded decisions so this is a technique that will provide the best and the fittest value. In BPSO, the solution space is provided for particles; these particles will move through the solution space and find the best solution. The particle positions and velocities are randomly initialized first, and then particles will initially movein the solution space with velocity$V$, each particle move in iteration and dynamically update their positions and velocities according to these extremes i.e.$P_{lbest}$and P_{gbest}. The best optimal solution is then taken from the positions of the particle. Global best will be taken as a solution for optimization problem. The BPSO flow chart is given in the figure 4 below.

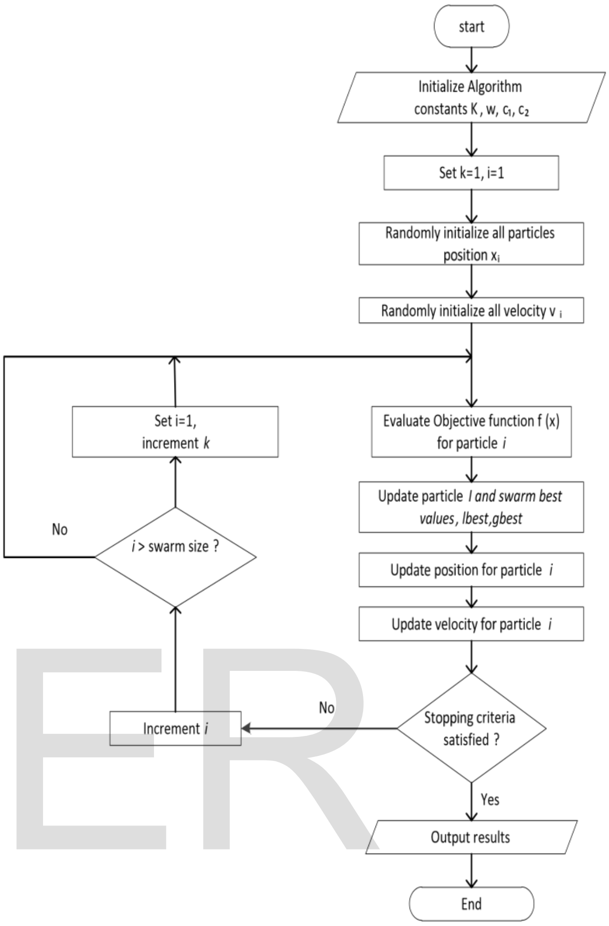

Fig4: Proposed Binary Particle Swarm Optimization.

For finding the objective function Fwe will determine both $P_{lbest}$and P_{gbest} and evaluate them. The particles position and velocities are updated with the help of equation.

$$V_i^{t+1}(j) = \omega V_i^{t}(j) + c_1 r_1\left(p_{lbest}^{t}(j) - \mathcal{X}_i^{t}(j)\right) + c_2 r_2\left(P_{gbest}^{t}(j) - \mathcal{X}_i^{t}(j)\right) \quad (26)$$

Where $i \in \{1,2,3 \ldots \ldots \ldots M\}$represents particles number, r_1 and r_2 represents range value, i.e., [0 1]. The constantc_1 represents the personal pull and $c_2$represents the best global position. ω Represents the weight of the particleis expressed by:

$$\omega = \omega_i + \left(\omega_f - \omega_i\right) * \frac{K^{th}\ iteration}{maximum\ \ iteration} \quad (27)$$

The range V_i^{t+1} is given as under.

$$V_i^{t+1} = \begin{cases} V_{max}, & if\ V_i^{t+1} > V_{max} \\ V_{min}, & if\ V_i^{t+1} < V_{min} \end{cases} \quad (28)$$

Particle position $\mathcal{X}_i^{t+1}(j)$ is updated with the help of below equation

$$\mathcal{X}_i^{t+1}(j) = \begin{cases} 1, & if\ Sig\left(V_i^{t+1}(j)\right) > \gamma_{ij} \\ 0, & otherwise \end{cases} \quad (29)$$

Where

$$Sig\left(V_i^{t+1}(j)\right) = \frac{1}{\left(1+exp\left(-V_i^{t+1}(j)\right)\right)} \quad (30)$$

This above equation reflects the sigmoid function. This sigmoid function will define the speed of the particle and mapped also, and the probability will defines coordinate value either 0 or 1.

4.6Optimization Approach Based on the GA:

GA is an empirical search algorithm based on ideas of genetics, which is used for the solution of both unconstrained and constrained optimization problems. Optimization problems are solved by the random search exploitation intelligently. Population is repeatedly modified in GA to find individual solutions. Individuals are selected randomly from current population and children's are produced from them for generating new generation. New population is produced by repeated crossover of the parent's chromosome. The process is repeated until iteration reaches the maximum generation. From these newly generated children chromosomes, best and fittest chromosomes are chosen as optimal solution for the problem.The length of the chromosome is denoted by N, which is directly related to number of household appliances which we are taking into account. Different methods are used for chromosome selection in crossover which includes simplex crossover, binary tournament selection, truncation selection and local selection etc. we implement binary tournament selection for crossover selection. The flow diagram of GA is shown in figure.5.

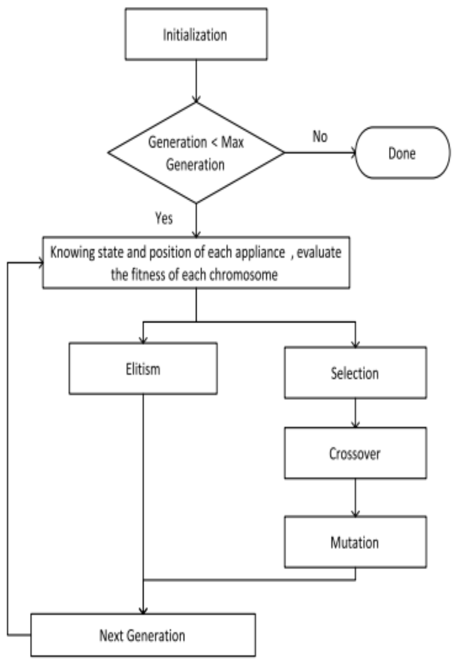

Fig.5. Flow diagram of Genetic Algorithm

The fittest chromosomes are evaluated from the population created. The newly evaluated chromosomes have better fitness levels are compared to the existing chromosomes. This process is referred as crossover. We are using one-point crossover technique.

Fitness function is used to evaluate the population. The N individuals are chosen on the basis of their fitness values, which are passed through crossover and mutation process for generating new fittest population. The fitness function of GA is given as follows

$$\text{Fitness} = \sum_{a=1}^{N} \sum_{t=1}^{24} \left(\epsilon_{t,a} * N\right) * \epsilon P_t^T, \quad (31)$$

$$\forall\ t \in \{1,2,3,4, \dots \dots \dots 24\} \quad (32)$$

Amongst these fittest chromosomes, only the best chromosomes are chosen as an optimal solution for optimization problem. All these process are monitored by CCU, which have the information about the energy consumption pattern for fittest chromosomes, and with the help of this information they can control the working of the appliances. The CCU shifts that best individual to the time slot where it costs minimum. Moreover, CCU shifts the acceptable load from utility grid to RES stored energy, where utility energy cost is expensive to the residential consumer.

5.1 Results and Discussions

We perform simulation of daily energy usage for different household appliances by which we check our proposed appliance scheduling scheme performance. The different parameters of our household appliances were shown in table 1.We perform simulations for three cases.

Group	Appliances	Power Consumption (KW)	Daily Usage (hours)	Power Rating (KWh) = KW *Hours
Shift able and Interruptible Appliances	Water Heater	1.5	4	6
	Dish Washer	1.2	1	1.2
	Vacuum Cleaner	0.8	2	1.6
	Water Pump	1	1	1
	AC	2	5	10
Shift able and un-interruptible Appliances	Electrical Vehicle EV	1.2	5	6
	Washing Machine	0.6	2	1.2
Regular Appliances	Refrigerator	0.6	18	10.8
	TV	0.2	10	2
	Lights	0.02	12	0.24

Table 1: Power Ratings of Different Home Appliances.

5.2 Time of Use Pricing Scheme:

We use Time of Use Pricing Scheme (TOU) for billing. The TOU pricing scheme contains a complete electricity tariff with different prices for different hours depending upon high peak hours, low peak hours and off peak hours. These prices are set by the utility grids. This electricity pricing tariff will helps out the consumers to utilize their loads according to the Tariff to shift their heavy loads from high peak hours to off peak hours to benefit them in managing their electricity bill. TOU pricing scheme is shown in fig 4 below.

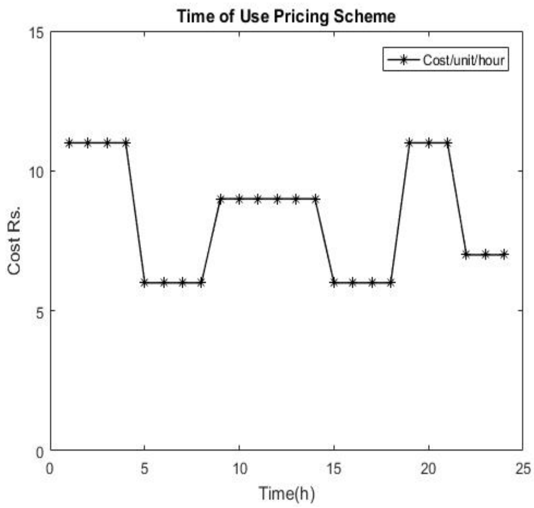

Fig.4: TOU Pricing Scheme.

5.3 Performance and Control Parameters of Algorithms:

In our research, we perform simulation by using two different algorithms which are Genetic Algorithm (GA) and Binary Particle Swarm Optimization (BPSO). Below we describes there performance and control parameters.

5.4 The control parameters of BPSO are detailed below:

5.4.1 Electricity Consumption:

The power consumed by the household appliances is referred as electricity consumption. This electricity is consumed in time slot h and measured in Kilo-Watt hour kWh.

5.4.2 Electricity Cost:

The electricity cost is defined as electrical energy consumed by the different appliances of the home in a specific time period. The electricity cost is paid to the corresponding utility grid in rupees (Rs).

5.5 The main control parameters of BPSO are discussed below:

5.5.1 Swarm:

To analyze the proposed BPSO algorithms performance, we use the number of particles which are known as swarm.

5.5.2 Velocity:

For finding the optimal solutions, the particles moves in a search space between the two limits of velocities, i.e. Vmax and Vmin.

5.5.3 Appliance status:

Appliance status shows either the appliances will operate or not. Below table 2 and table 3 shows the control parameters of BPSO and GA respectively.

Size of Swarm	Size of particles in (bits)	Velocity Range	Maximum Iterations	Status of appliances
200	8	[-4,4]	600	{0,1}

Table 2: BPSO Algorithm Control Parameters

5.5 The control parameters of GA are detailed below:

5.5.1Chromosome:

Chromosome is a string made by linking genes together having size of 6-bits.

5.5.2Population Size:
Set of individuals represents population size, which represents all possible solutions for given problem.
5.5.3Crossover:
The variation of programing from generation to generation, crossover operator is used. Crossover operator generates new population from current population with new elements.
5.5.4Mutation:
Mutation is the last step of the Algorithm purpose of which is to inject new information from old population to new population.

Population Size	Maximum Generation	Crossover	Mutation
100	200	90%	10%

Table 3: GA Control Parameters

6. Appliance Scheduling Schemes:

In this sector, we perform the simulation of the three different cases which are

1) Conventional Case
2) Smart Case
3) Smart Case with RES

Wewill compare their results in order to display the usefulness of our proposed scheduling algorithms. The energy consumption and the costs are the main attributes upon which we perform our analysis.

Case 1: Conventional Case:
The main scenario of this conventional case as discussed above is now shown in the fig 5, which shows the unscheduled load energy consumption profile.

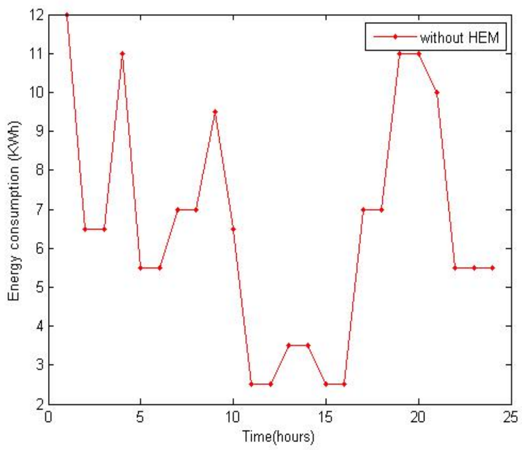

Fig 5: Unscheduled load energy consumption profile.

The energy cost for the above case is shown below in figure 6.

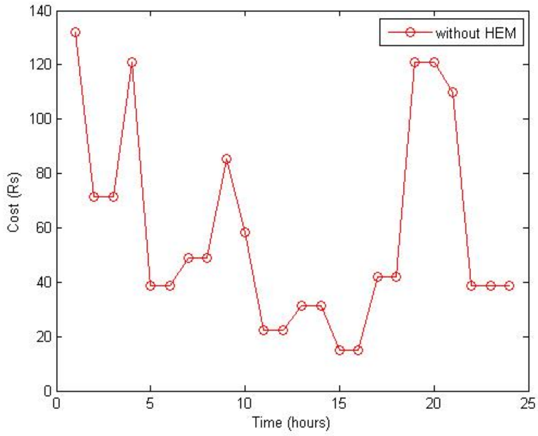

Fig 6: Unscheduled load energy cost profile.

Case 2: Smart Homes:
The Smart homes case refers to houses in which HEMS are installed. Here we use basically two HEMS scheduling Algorithms types. The first algorithm is BPSO and second one is GA. The CCU will switch the load from high peak hours to low peak hours because it is cost sensitive. In this case, the energy consumption of various household appliances in specific time period is shown in figure 7. In this case as we discussed that we use two different algorithms, so we plot a graph of figure 7 for both algorithms, which shows their comparison. The comparison in the figure 7 clearly reflects that BPSO is optimal algorithm for switching the load from peak to low peak hours thus minimizing the electricity bill and giving benefit to the consumer.

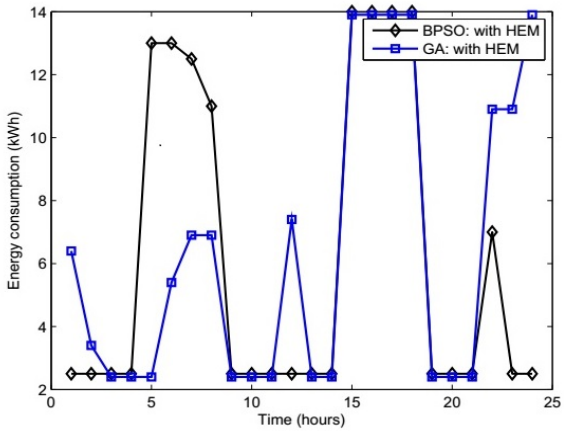

Fig 7:Energy consumption for case 2.

Now the corresponding graph of the daily cost of the electricity bill is shown in the fig 8.

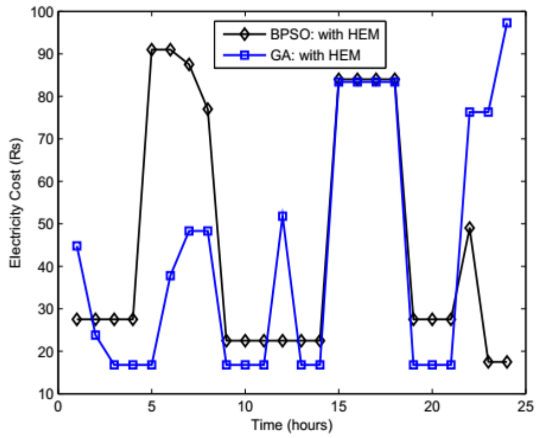

Fig 8: Scheduled load energy cost for case 2.

Now we are comparing the case 1 and case 2, i.e. the conventional homes and the smart homes. The comparison of the energy consumptions by the appliances in case 1 and case 2 are shown in the figure 9 and their corresponding electricity cost graph is shown in the figure 10.

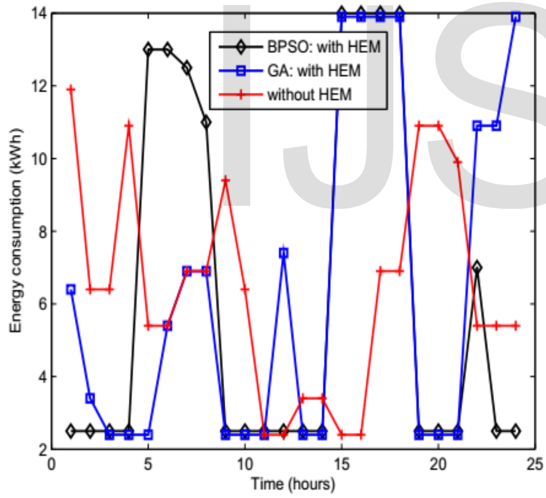

Fig 9: Energy consumption comparison between case 1 and case 2.

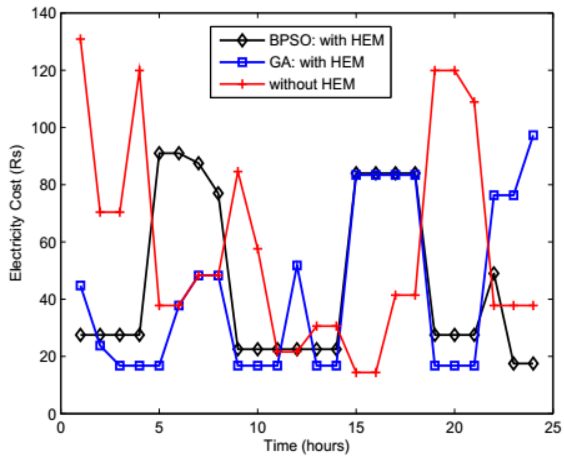

Fig 10:Electricity cost comparison between case 1 and case 2.

The above comparison clearly shows that smart homes are much beneficial as compared to the conventional homes, because the energy consumed by the smart homes are less than conventional homes due to the HEMS installed at smart homes and because of the less energy consumption in smart homes their relative electricity cost is also minimum as compared to the conventional homes.

The above figures also show the difference between the smart homes with HEMS installed with different algorithms. The energy consumed by the smart homes with BPSO algorithm is 26% lesser as compared to the conventional homes, while the energy consumed by the smart homes with GA is 21% lesser then conventional homes which clearly reflect the beneficiary level for the consumers towards installing HEMS for their appliances. The savings achieved by the smart homes with BPSO and GA as compared to the conventional homes are tabulated in table 4.

Case 3: Smart homes with RES system:

As discussed above, that in this case weare considering smart homes with RES installed. This RES installed consumers took more advantages by using 30% of energy from RES due to which the minimizing of the electricity bills could be achieved. This case is most beneficial by using RES with storage system, because whenever the prices of utility grid is high, then our CCU will automatically shifts the load from utility to the RES system thus minimizing the electricity bills. The energy consumption graph for this case is shown in the figure 11.

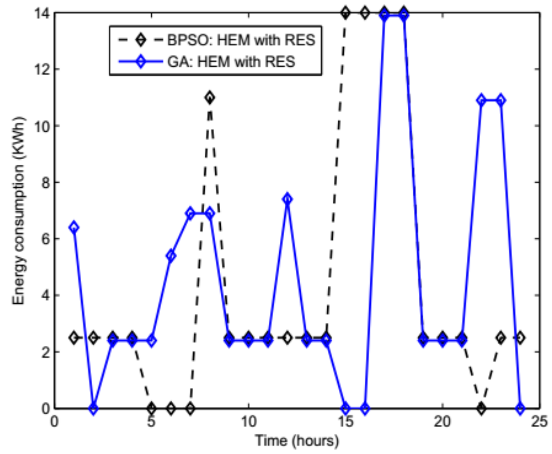

Fig 11: Energy consumption graph for case 3.

This graph clearly shows that energy consumed by the smart homes with RES systems installed at them are lesser because of the fact that during high peak hours, they shifts their load to the RES with storage system thus minimizing the electricity bills efficiently. The corresponding electricity cost graph of this case is shown in the figure 12.

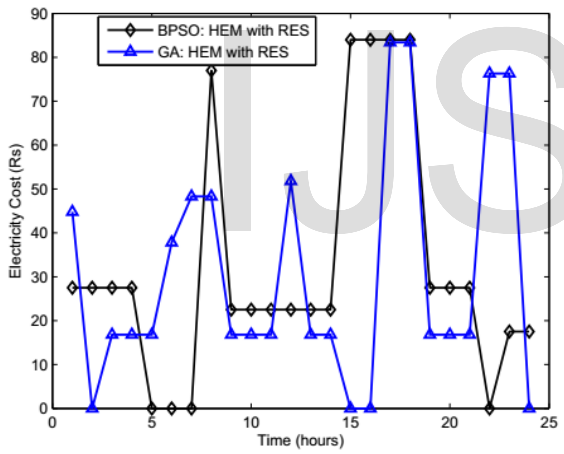

Fig 12: Electricity cost graph for case 3.

Figure 12 shows that cost in this case 3 is most efficiently lesser as compared to the other two cases because the CCU will shift their loads to the RES system in peak hours and after peak hours they will shift back their loads to the utility grid. For justifying this, we will compare this case with the other two cases. First we are comparing the energy consumption by the appliances in each case in a singles graph which is shown in the fig 13 and their corresponding electricity cost graph is shown in the figure 14 which are given below.

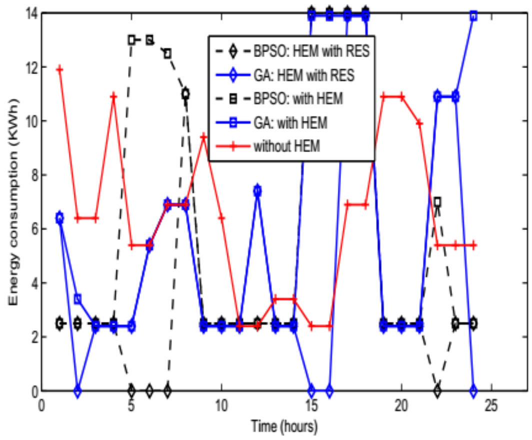

Fig 13: Energy consumption profile for all three cases.

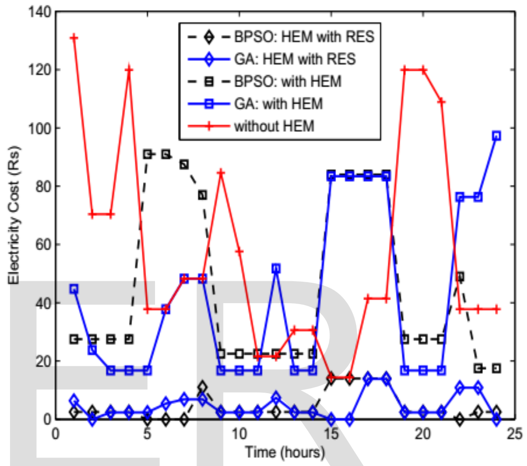

Fig 14: Electricity cost profile for all three cases.

These above two figures clearly shows that the energy consumed in case 3 is more effective than the other two cases i.e. case 2 and case 1, and similarly the cost profile is also beneficial in case 3. Now making the comparison between the algorithms used with HEMS, then it clearly shows that energy consumed by the smart homes with RES systems installed with BPSO algorithm is 43% low as compared to the conventional homes, while smart homes with RES systems installed with GA is 39% lesser then conventional homes which is also detailed in the table 4.

7.Balance between Performance Parameters:

This section compares all the above three cases on the basis of their performance parameters--their pros and cons-- in terms of energy consumption and cost. We simulate our result on the basis of three cases i.e. conventional homes, smart homes, and smart homes with RES system. The main comparison between these cases occurs due to load shifting in peak hours. HEMS looks for the optimal use of energy coming from the utility grid, by adjusting the working of appliances in optimal time and to minimize the utility bills. For minimizing the electricity bill or the energy consumption, HEMS compromise on the consumer comfort level up to some extent in the form of delaying the operation of the appliances in the peak hours. The traditional users did not compromise on their comfort level, having no HEMS or RES installed at their homes, so that's why they have to pay the maximum electricity bill. On other side, smart homes consumers have HEMS. Despite having minimum electricity bill, they did compromise on their comfort level. So there is a trade-off between first and second case in terms of user comfort levels and electricity bill. Now coming towards the third case, from the above discussions and figures, we come to know that in third case the users have to compromise very rarely and shortly on their comfort level and also have to pay the least electricity bill as compared to the other two cases which can be clearly shown in the figure 14. In detail when we study that third case, it shows that HEMS having BPSO are the best and efficient in use because they optimally use the energy without giving much delay in the operation of the appliances thus compromising barely on the comfort level of the users, while HEMS with GA algorithms are also optimal for managing the energy used by the appliances but the only difference in comparison with the BPSO is that it giving a little more delay in the operation of the appliances, thus compromising the comfort level of the consumers a little more as compared to BPSO.

Figure 14 clearly reflects the fact that using smart homes with RES systems, HEMS with BPSO, is more efficient to use RES storage system as compared to the HEMS with GA. HEMS with BPSO switchthe entire load from peak hours to low peak hours, while GA didn't switch the load completely from high peak to low peak hours. So, there is a trade-off between the HEMS with GA and HEMS with BPSO in terms of delay in operational time and cost minimization.

All the three cases with their electricity bills on 24 hours interval using the BPSO and GA are tabulated below in table 4. This clearly shows that using both the algorithms is beneficial in reducing the electricity bill, but BPSO is more efficient as compared to the GA.

Cases	HEMS	RES	GA	BPSO	Total Cost (Rs)	Savings
1	×	×	×	×	3564	0%
2	✓	×	✓	×	2815.5	21%
	✓	×	×	✓	2637.4	26%
3	✓	✓	✓	×	2167.9	39%
	✓	✓	×	✓	2030.8	43%

Table 4: Results obtained from Simulation

8. Conclusion:

In this paper we study the three main types of the users in detail; we apply HEMS architecture on them, using different pricing schemes trying to minimize the bills with the help of two different types of algorithms. We were also concerned with the comfort level of the consumers explaining all the pros and cons of each case in order to provide our consumers with the best option. The results clearly show the comparison between all different cases in detailed way, giving consumers the best optimal case in order to reduce their electricity bill. Our simulation results show that using BPSO with smart homes (case 2) and BPSO with smart homes also having RES (case 3) reduce the electricity bill by 26% and 43% respectively, and this is the best optimal case for consumers.

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