

Renewable energy based dynamic tariff system for domestic load management

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ABSTRACT

To deal with the present power-scenario, this paper proposes a model of an advanced energy management system, which tries to achieve peak clipping, peak to average ratio reduction and cost reduction based on effective utilization of distributed generations. This helps to manage conventional loads based on flexible tariff system. The main contribution of this work is the development of three-part dynamic tariff system on the basis of time of utilizing power, available renewable energy sources (RES) and consumers' load profile. This incorporates consumers' choice to suitably select for either consuming power from conventional energy sources and/or renewable energy sources during peak or off-peak hours. To validate the efficiency of the proposed model we have comparatively evaluated the model performance with existing optimization techniques using genetic algorithm and particle swarm optimization. A new optimization technique, hybrid greedy particle swarm optimization has been proposed which is based on the two aforementioned techniques. It is found that the proposed model is superior with the improved tariff scheme when subjected to load management and consumers' financial benefit. This work leads to maintain a healthy relationship between the utility sectors and the consumers, thereby making the existing grid more reliable, robust, flexible yet cost effective.

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1. INTRODUCTION

A smart and intelligent energy management system is required to address the difference between generation and demand. There is a large volume of published studies describing the role of demand side management (DSM) in power system planning. Over the past decade, most research in this issue have emphasized the use of renewable energy sources (RES) and incline block tariff. These can be observed in the DSM approaches proposed by some authors [1]-[3]. Application of load management as an effective technique for handling the peak load management issues can be observed in the work of Logenthiran and Srinivasan [4]. However, for applying this solution in the practical work, peak load management cannot be the sole criteria. Incorporation of several other factors such as consumers satisfaction level and cost of energy are also required for developing an efficient energy management system (EMS) which has been demonstrated by the work of Xu *et al.* [5]. In recent days RES has gained importance in energy management system. authors in [6], [7], conclusively agreed to this and explained how by dispatching the shiftable domestic loads and available storage resources energy management solution can be achieved. In addition to the widely used RES, biomass can be used for self-generation in rural areas has been proposed by Naz *et al.* [8]. Despite the

simplicity of these models, Issi and Kaplan in [9] and Ahmad *et al.* in [10] found that it is necessary to determine the load profiles and power consumptions of home appliances individually for scheduling the load judiciously, which in turn helps to formulate a residential energy management problem under various practical constraints like human interaction, unavailable power supply and consumer preference. In contrast, Malik *et al.* in [11] and Nguyen *et al.* in [12] indicated that beside RES integration and load scheduling, efficient communication and optimization scheme is utmost important. Similarly, authors in [13]-[15] discussed several methodologies and future techniques to optimize energy consumption with minimum consumer interaction. Another possibility would be trading of self-generation among the prosumers and consumers which can help to increase grid stability [16]. Similarly, a contract-based energy trading scheme has been proposed by Zhang *et al.* [17] and the economic impact of demand response has been discussed by Conchado and Linares [18]. Several DSM approaches based on real time pricing has been proposed by the authors in their research articles [19], [20]. However, a number of studies [21] show that there are numerous challenges and restrictions in implementations of DSM. Even Govt. of India has taken various actions to implement DSM strategies [22]. Despite the numerous works carried out, mentioned in Table 1, no previous study has thoroughly investigated and analysed the consumers preference on the basis of RES availability and load profile. On the other hand, a search of the literature revealed that limited studies have focused on load analysis and tariff system. Since the impact of tariff on EMS is understudied, there is a need to develop an improved tariff system based on time of utilizing power, available RES and consumers' load profile.

Table 1. Summarized related work

Techniques	Aims	Attributes	Limitations
EA [4]	Cost reduction	Energy optimization in industrial, commercial and residential sectors	Complex system
GA [23]	Cost reduction	Optimization of energy consumption	Complex system and Consumers' preference is ignored
FP [24]	Cost reduction	Cost effective model with DG	PAR and Consumers' preference not considered
GA [25]	Cost and PAR reduction	Generic model	Consumers' preference is ignored
BPSO [26]	Cost and PAR reduction considering consumers' preference	Efficiency of BPSO	Time slots are divided into sub time slots, which is complex
Hybrid Technique (LP and BPSO) [27]	Cost reduction considering consumers' preference	DAP model	PAR reduction not achieved
GA, BPSO, ACO [28]	Cost and PAR reduction considering consumers' preference	Load scheduling by considering consumers' preference and RES	Complex system and better management are possible
GA [29]	Cost and PAR reduction	Model tested using radial residential network	Complex system and better management are possible
GA [30]	Cost reduction considering consumers' preference	Optimization of energy consumption on the basis of RES availability	PAR reduction not achieved
DP [31]	Cost and PAR reduction	Optimization of energy consumption on the basis of RES availability	Complex system and Consumers' preference is ignored
ILP [32]	Cost and PAR reduction	Load analysis using Day Ahead Pricing (DAP)	PAR reduction not achieved
Hybrid Technique (GA and PSO) [33]	Cost and PAR reduction	Considered Energy Storage System	Consumers' preference is ignored
GHSA [14]	Cost and PAR reduction considering consumers' preference	Analysis on the basis of Single and Multiple Homes	System is complex and time consuming
PSO [34]	Cost and PAR reduction	Efficient use of RES	Consumers' preference is ignored

In view of these shortcomings, an advanced energy management system (AEMS) has been proposed in this paper. The current study contributes to the expansion of the knowledge in this field by addressing four important issues. First, electricity cost has been reduced by introducing advanced three-part dynamic tariff structure. Second, grid stability has been maintained by minimizing peak to average ratio (PAR). Third, peak demand has been addressed by load shifting and valley filling. Fourth, consumer comforts and benefits have been maximized by integrating RES and designing a user-friendly application. Thereby an effective load management system based on load scheduling has been proposed which in turn encourages renewable energy usage reducing the adverse effects of carbon emission and ensures proper utilization of electrical power incorporating an advanced tariff structure.

2. PROBLEM FORMULATION

Identifying the gaps in the aforementioned literature work, we proposed a novel AEMS with RES integration to reduce PAR and electricity cost at user end, which is based on critical load analysis, consumers comfort level and proposed dynamic tariff structure. Secondly, we evaluated the proposed AEMS by performing extensive case studies and simulations. First, we applied multi-objective optimization techniques based on genetic algorithm (GA) and particle swarm optimization (PSO) to reach the optimum energy management solution. Further we analysed our AEMS with the effects of proposed three-part dynamic tariff structure. In addition, based on a hybrid combination of genetic algorithm and particle swarm optimization a new optimization technique has been proposed and found to perform better than the existing optimization techniques. Based on these aforementioned steps, an AEMS has been designed, developed and tested.

3. AEMS ARCHITECTURE

For efficient energy management with the existing grid, AEMS is of utmost important. According to utility perspective the primary task of AEMS is to manage the energy consumption, thereby reducing PAR and in consumers' perspective, it is to reduce cost of electricity. Here we have designed a model in matrix laboratory simulation and link (MATLAB/Simulink) platform considering five residential consumers with different load patterns. The utility companies sends useful day ahead forecasted information such as demand profile, tariff and also availability of RES through a smart application. This Microsoft.Net technology-based application has been developed for the benefit of the consumers so that they can plan their electricity usage based on their comforts and preferences. At the same time the application itself will suggest the most optimal solution to adopt for domestic consumers. A new advanced and flexible dynamic tariff structure has been proposed to ensure consumers preference. Based on the proposed tariff an optimum point has been achieved where usage of conventional energy and renewable energy results in reasonable electricity pricing and significant reduction in PAR.

Therefore, rest of this paper has been organised as shown in Figure 1. In section 3, modelling of different parts of the system will be discussed such as: i) demand forecasting, ii) RES and ESS, iii) proposed tariff, iv) Heuristic algorithm for optimization, and v) energy consumption model respectively. In section 4 and 5, we will present and discuss the results and conclusion respectively.

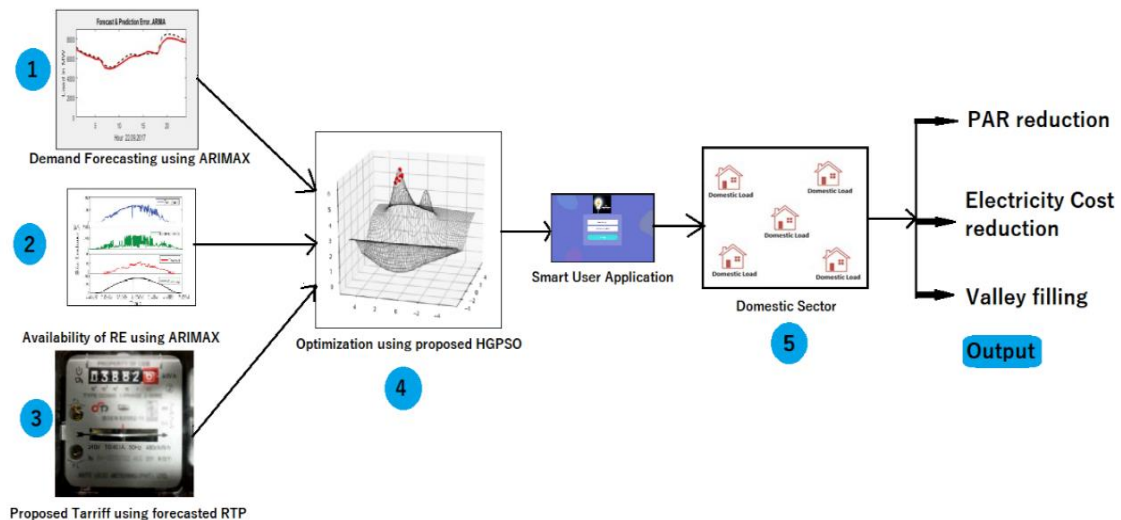


Figure 1. System modelling

4. SYSTEM MODELLING

The proposed AEMS incorporates the use of photovoltaic (PV) system as RES and energy storage system (ESS) to store electricity either from main grid at low price time or from RES for home appliances at peak price time. This in turn helps to reduce the carbon emission level. The entire system can be briefly described using a block diagram as shown in Figure 2.

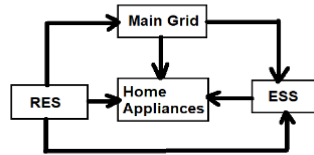


Figure 2. Basic block diagram of system

4.1. Demand forecasting

Demand forecasting is the initial and most important part of electrical power system, specifically load management system [35]. In this article, we have compared different forecasting tool and finally used auto regressive integrated moving average with exogenous variables (ARIMAX), a multivariate method to perform load forecasting, which is performing comparatively better than other techniques [36]. By using this classical method, we have achieved an almost error free forecasted demand profile [37], [38].

Auto regressive integrated moving with exogenous variables, here to design ARIMAX model for forecasting Y_t and X_t have been considered as two stationary time series. The transfer function model (TFM) can be written as,

$$Y_t = C + v(B)X_t + N_t \tag{1}$$

where, Y_t is response series, X_t is predictor data series, C is constant term, N_t is the stochastic disturbance, $v(B)X_t$ is the transfer function and B is back shift operator.

$$v(B)X_t = (v_0 + v_1B + v_2B^2 + \dots + v_kB^k)X_t \tag{2}$$

In ARIMAX, we deal with two different time series X_t and Y_t . The Transfer Function can be written as,

$$v(B)X_t = \left[\frac{w_h(B)B^b}{\delta_r(B)} \right] X_t \tag{3}$$

theoretically, $v(B)X_t$ has infinite number of coefficients. Where,

$$w_h(B) = w_0 + w_1B + \dots \tag{4}$$

$$\delta_r(B) = 1 - \delta_1(B) - \dots - \delta_rB^r \tag{5}$$

where, h is the number of terms plus one of the independent variables, r is the number of terms plus one of the dependent variables and b is the dead time.

$$N_t \text{ can be written as, } N_t = \left[\frac{\theta(B)\Theta(B^S)}{\phi(B)\Phi(B^S)(1-B)^d(1-B^S)^D} \right] a_t \tag{6}$$

Where, a_t is zero mean and normally distributed white noise. Therefore, TFM can be finally expressed as,

$$Y_t = C + (v_0 + v_1B + v_2B^2 + \dots + v_kB^k)X_t + \left[\frac{\theta(B)\Theta(B^S)}{\phi(B)\Phi(B^S)(1-B)^d(1-B^S)^D} \right] a_t \tag{7}$$

initially, the value of K and N_t must be specified to find out (b, r, h) . By observing and comparing the estimated impulse response function with some common theoretical functions (b,r,h) can also be identified to represent TFM. Several diagnostic checks are involved to check the status of residuals in the series and to conclude whether the model is adequate or not. Akaike information criterion (AIC) is one of them. A forecasting model is highly acceptable if the value of Akaike’s information criterion is small. Bayesian information criterion (BIC) and Schwarz information criterion (SIC) are also very effective in choosing the accurate model.

4.2. Availability of RES

Availability of RES: We assume that some of the consumers are equipped with PV system. We have used the given mathematical model to calculate the PV output (P_{PV}) at t .

$$P_{PV}(T) = GHI(t).A.\eta \forall t \ 0 \leq T \leq 24 \quad (8)$$

Where global horizontal irradiation (GHI) is (kW/m²). A is the area of solar panel and η is the efficiency of the PV system. The electrical energy generated (EPV) by the PV system in time duration Δt ,

$$E_{PV}(t) = P_{PV}(T).\Delta t \quad (9)$$

where T is the real time. This energy will be used for home appliances ($E_{PV.load}$) and energy storage ($E_{PV.storage}$).

$$E_{PV}(t) = E_{PV.load}(t) + E_{PV.storage}(t) \quad (10)$$

$$\text{Constraints: } 0 \leq E_{PV.load}(t) \leq GHI(t).A.\eta.\Delta t \quad (11)$$

$$0 \leq E_{PV.storage}(t) \leq GHI(t).A.\eta.\Delta t \quad (12)$$

4.3. Energy storage system (ESS)

The aim of ESS is to use RES and main grid electricity efficiently. ESS acts as a sink to store energy from RES and main grid at low price time and source for domestic appliances. The mathematical model of ESS is,

$$E_{ESS.discharge}(t) = E_{ESS.load}(t)(1 - mode_{ESS}(t)) \quad (13)$$

$$E_{ESS.charge}(t) = (E_{RES.charge}(t) + E_{MG.charge}(t)).mode_{ESS}(t) \quad (14)$$

$$mode_{ESS}(t) = \begin{cases} 1, & \text{if ESS is charged} \\ 0, & \text{if ESS is discharged} \end{cases} \quad (15)$$

$$E_{ESS.level}(t) = E_{ESS.level}(t-1) + E_{ESS.charge}(t).\eta_{ESS} - E_{ESS.discharge}(t)/\eta_{ESS} \quad (16)$$

here $E_{ESS.level}$ is the energy level of ESS after time t and η_{ESS} efficiency of ESS.

As we are considering our system as a day ahead system, therefore energy level of ESS must return to the initial level (EL_0) at the end of the day.

$$ESS_{level}(t) = EL_0 \quad (17)$$

Constraints: The ESS charge/discharge rate should not exceed the critical value and charge level of ESS should lie between minimum (EL_{min}) and maximum energy level (EL_{max}).

4.4. Energy consumption model

AEMS depends on several factors such as demand profile, availability of renewable energy, judicious tariff structure, consumers' flexible attitude and their direct participation in electricity trade market. Here, we have considered five different consumers and each home with set of appliances A and N is the total number of appliances. a_1, a_2, \dots, a_N are N number of domestic appliances used in a home. They are operated over a time period $t \in T$, where Suppose, S_{a1} is the starting time instants of appliance a_1 and F_{a1} is the finishing time instants of appliance a_1 . Therefore, operation time interval for scheduled appliances a_1 is $[S_{a1}, F_{a1}]$.

$$A \triangleq \{a_1, a_2, a_3, \dots, a_N\} \quad (18)$$

$$T \triangleq \{1, 2, 3, \dots, 24\} \quad (19)$$

Here, in this model we have considered conventional energy sources (CES) and RES to satisfy the demand. We have assumed, $\epsilon_{t,PV}$ as generated or available solar energy at time t , which should be known or forecasted. However, the price of the renewable energy is variable. Here, $\gamma_t.MG$ is denoting forecasted price of energy from main grid at time t , $\gamma_t.PV$ is denoting forecasted price of solar energy at time t .

We have considered ψ_{a1} as the operation time vector of appliance a_1 . Therefore,

$$\psi_{a1} = [\beta_{1Ga1}, \beta_{1PVa1}, \beta_{2Ga1}, \beta_{2PVa1}, \dots, \beta_{24Ga1}, \beta_{24PVa1}] \quad (20)$$

β_{tGa1} is used grid energy to satisfy demand of a1 at time t (known/forecasted).
 β_{tPva1} is used solar energy to satisfy demand of a1 at time t (known/forecasted).
 State of operation of an appliance a1 at time,

$$t, \phi_{a1}(t) = \begin{cases} 0 & \text{when appliance is not operating} \\ 1 & \text{when appliance is operating} \end{cases} \quad (21)$$

Consumer will place a day ahead request for a1 appliance in time interval [Sa1, Fa1], where [Sa1, Fa1] \in T. Consumer needs to specify aa and fa for availing the best suited tariff scheme. Here fa1 is the no. of switching ON of appliance a1. Total energy demand of a1 can be satisfied by CES and RES. Hence the total energy consumed by a1 can be determined as,

$$\sigma_{a1} = \sum_{t=1}^T \sum_{a_1 \in A} \alpha_{a1} (\beta_{Ga1} + \beta_{Pva1}) \quad (22)$$

similarly, the cost of the energy consumed by a1 over 24 hours can be calculated as,

$$\delta_{a1} = \sum_{t=1}^T \sum_{a_1 \in A} \alpha_{a1} (\gamma_G^t \beta_{Ga1}^t + \gamma_{PV}^t \beta_{Pva1}^t) \quad (23)$$

4.5. Load categorization

In this section, domestic consumers have been classified as active consumers and passive consumers. Active consumers are equipped with PV system and ESS, whereas passive consumers are equipped with ESS only. The domestic loads further can be categorized based on their power consumption, operation time, number of switching ON-OFF over 24 hours and consumer preferences. They are classified as: i) interruptible loads, ii) non-interruptible loads, and iii) interruptible loads with minimum delay.

Here power consumption of different domestic loads such as refrigerator, washing machine, induction oven, iron, fan, light, computer, and television has been discussed and analysed in detail for different operating modes which has been shown in Figure 3.

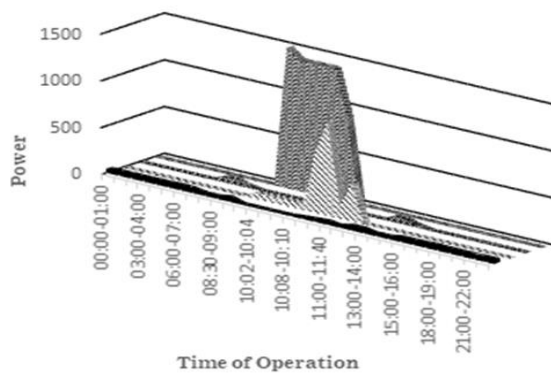


Figure 3. Power consumption of different home appliances

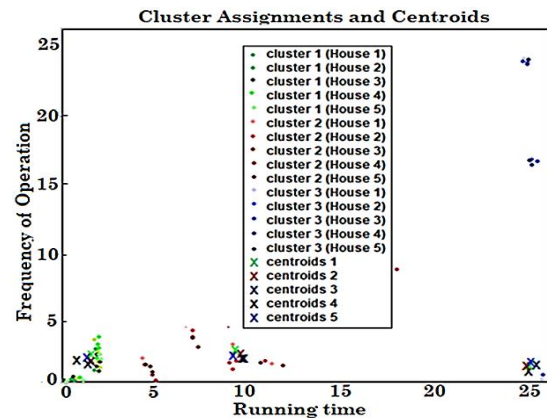


Figure 4. Categorization of domestic loads for 5 households using K-means clustering

Here, the K-means clustering technique has been used to prioritize the loads. Figure 4 is showing the clusters based on which the loads are marked with their priority ranking for five different domestic consumers respectively. The clustering result has been verified again using a mathematical model. Suppose, request time of the appliance a1 is τ_{ra1} and waiting time of the appliance a1 is τ_{wa1} .

$$\text{Therefore, } \tau_{wa1} = S_{a1} - \tau_{ra1} \quad (24)$$

$$\text{Total waiting time, } \tau_w = \sum_{i=1}^N \tau_{wai} \quad (25)$$

$$\text{Average waiting time, } \tau_w.\text{avg} = \tau_w / N \quad (26)$$

Here, we have considered α_{ai} as the rating of appliance ai where $i = \{1,2,3, \dots, N\}$, ρ_{a1}^t as the operating time of a1 over 24 hours and fa1 as the frequency of operation of a1 or No. of switch ON.

$$\rho_{a1}^* = \frac{\text{time of run}}{\text{No.of switch ON}}$$

$$\rho_{a1}^* = \rho_{a1}^t / f_{a1} \quad (27)$$

$$\rho_{ai}^* = \sum_{t=1}^{24} \sum_{a_1 \in A} \delta_{ai}^t / f_{ai} \quad \forall ai \in A \quad (28)$$

$$\text{Utilization factor, } U_{ai} = \frac{1}{24} \sum \rho_{ai}^t \quad (29)$$

$$\text{Priority Ranking, } \vartheta_{ai} = [U_{ai}] * [\rho_{ai}^*] \quad \forall ai \in A \quad (30)$$

Based on this ranking finally the load has been categorized as non-interruptible load, interruptible load with minimum delay time and interruptible load.

4.6. Proposed tariff structure

Several tariff models are available to define electricity prices for a day. Amongst these, time of use (ToU) tariff model is used to define the electricity price on the basis of time of use in a day, whereas critical peak pricing (CPP) and critical peak rebate (CPR) are variants of ToU. Another tariff structure, real time pricing (RTP) defines the utility cost of supplying electricity at a specific time. In this section, we have proposed a three-part dynamic tariff (C) structure, which is based on ToU, CPP, CPR and RTP.

$$C = \alpha + \beta x + \gamma(xt) \quad (31)$$

Here, α comprises of meter rent and monthly variable cost adjustment (MVCA). is a fixed charge independent of maximum demand and energy consumption. β depends on maximum demand (kVA) or sanctioned demand (kVA). γ depends on energy consumption (kWh).

$$\gamma = \gamma_{CES} + \gamma_{RES} \quad (32)$$

Here, γ_{CES} is the cost of energy from main grid and γ_{RES} is the cost of renewable energy which is fixed cost.

$$\gamma_{CES} = \begin{cases} \gamma_{1.CES} \text{ Moderate pricing hour (06:00am – 05:00pm)} \\ \gamma_{2.CES} \text{ Peak pricing hour (05:00pm – 11:00pm)} \\ \gamma_{3.CES} \text{ Low pricing hour (11:00pm – 06:00am)} \end{cases} \quad (33)$$

Pseudocode

```

Input: forecasted demand data, forecasted tariff (RTP).
For t = 1 to 24
  If 6 ≤ t ≤ 17
     $\gamma_{1.CES} = \text{RTP for moderate pricing hours}$ 
  Else If 17 ≤ t ≤ 23
     $\gamma_{2.CES} = \text{RTP for peak pricing hours}$ 
    Calculate  $x = \frac{\text{consumption during peak pricing hours}}{\text{consumption over 24 hours}} * 100\%$ 
    If  $x \geq 25\%$  of the total consumption over 24 hours
      Apply Penalty
       $\gamma_{2.CES.modified} = \text{tariff}_2 + (x \% \text{ of tariff}_2)$ 
    Else if  $x \leq 20\%$  of the total consumption over 24 hours
      Apply Rebate
       $\text{Rebate} = (20 + (20 - x))\% \text{ of (unit consumed during peak hours} * \gamma_{2.CES})$ 
    End If
  End Else If
  Else
     $\gamma_{3.CES} = \text{RTP for low pricing hours}$ 
  End If
End

```

4.7. Heuristic algorithm

The demand profiles of domestic consumers depend on geographical conditions and demography. Keeping in view this fact, due to highly volatile behaviour of consumers and intermittent characteristics of RESs, we have dealt with different heuristic algorithms. Here, a hybrid optimization technique based on GA and PSO has been developed which follows greedy selection technique and can be used for personal best and global best solution. It has been represented as hybrid greedy particle swarm optimization (HGPSO). We have used multiple knapsack problem (MKP) to balance the demand and supply and HGPSO to reach optimum point.

Pseudocode

```

Input: Fitness function (based on RES availability, Tariff and Consumers' comfort), lb, ub,
Population Size, NP (based on home appliances), T (terminating criteria).
Evaluate the objective function value (f) of P
Assign Pbest and fptest
Identify the solution as best fitness and assign that solution as gbest and fitness as
fgbest.
For t = 1 to T
For i = 1 to NP
Determine the velocity of ith particle
Determine the new position of ith particle
Bound position
Evaluate the objective function value
Update the population
Update Pbest, i and fptest
Update gbest and fgbest
End
Combine P and Pbest to perform ( $\mu + \lambda$ ) for selecting P in next iteration
End
Repeat T iterations
    
```

5. RESULTS AND DISCUSSION

Based on the data obtained from physical survey and online survey an efficient model has been designed in MATLAB/Simulink platform which has been analyzed on the basis of proposed optimization technique to figure out the improvements over the existing system. The efficiency of the model has also been analyzed in the following sections based on the consumers' and utility sector's perspective. This can further be categorized as monthly electricity bill, waiting time and PAR, peak demand respectively.

5.1. Consumers' preference

5.1.1. Monthly electricity bill

Total energy cost in our system has been reduced based on two parameters: i) flexible and efficient use of RES and ESS and ii) proposed dynamic tariff. Consumers need to either declare their load requirement with the ratings of the appliances a day ahead or they can follow the suggested demand profile by the utility company. They can choose and declare the best suited tariff plan a day ahead. Using this approach consumers will get maximum benefits as shown in Figures 5(a) and 5(b) and Table 2.

Table 2. The performance of AEMS on the basis of monthly electricity bill

Consumers	Monthly Electricity Expense		Savings in Monthly Electricity Expense (in %)
	Without AEMS	With HGPSO AEMS	
Household 1	3,597.80	2,440.55	32
Household 2	2,203.21	1,664.81	24
Household 3	2,332.15	1,499.10	36
Household 4	1,852.41	1,371.00	26
Household 5	3,953.67	2,810.47	29

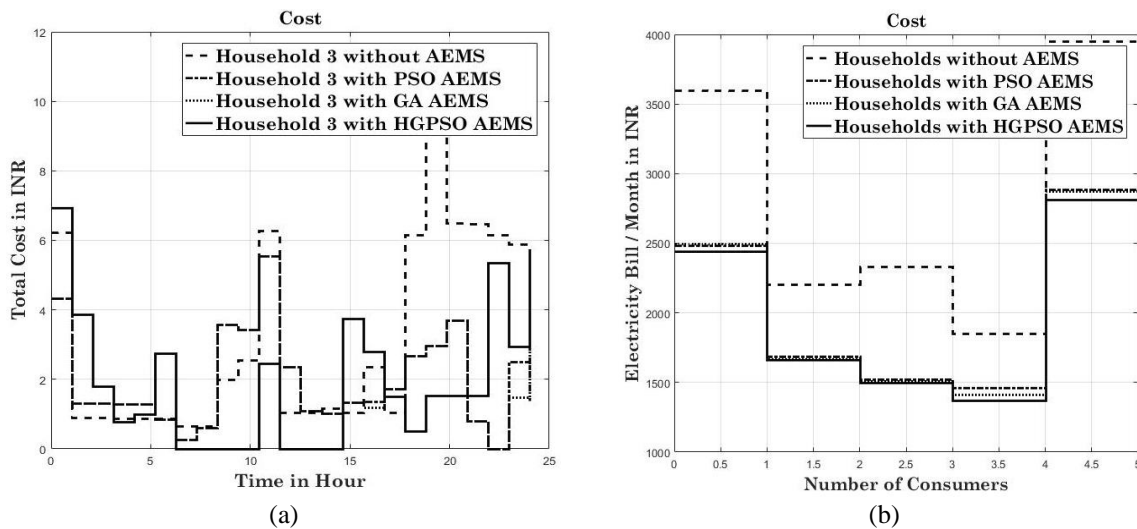


Figure 5. Cost curve for (a) single consumer (household 3) and (b) multiple consumers

In our system we have used ESS in a flexible way such that ESS is charged from main grid in low pricing time (12:00 am to 06:00 am) as shown in Figure 6 and from RES in moderate pricing time (10:00 am to 03:00 pm). This cheap energy has been used for home appliances at peak pricing time as shown in Figure 7. Therefore, the energy available from RES is not only used for home appliances but for charging ESS also as shown in Figure 8 where as Table 3 shows the parameters of our ESS.

In this paper we have simulated our system with ESS of improved capacity and charging/discharging rate. ESS with better charging/discharging rate helps to reduce the electricity cost. Hence the effect of ESS in reducing electricity cost has been shown in Figures 9 and 10.

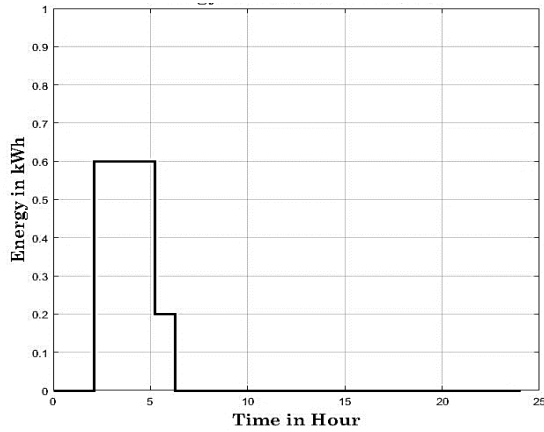


Figure 6. Energy stored in ESS from main grid

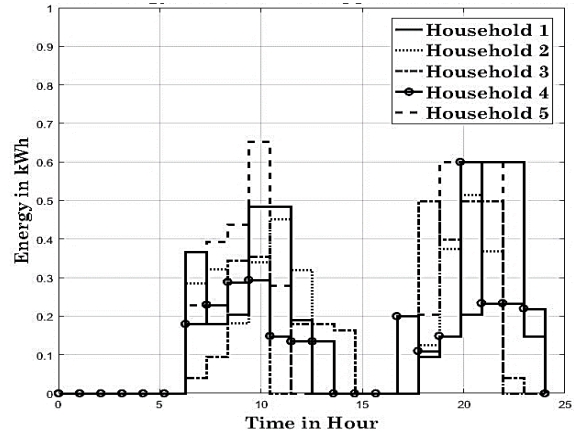


Figure 7. Energy used from ESS for home appliances

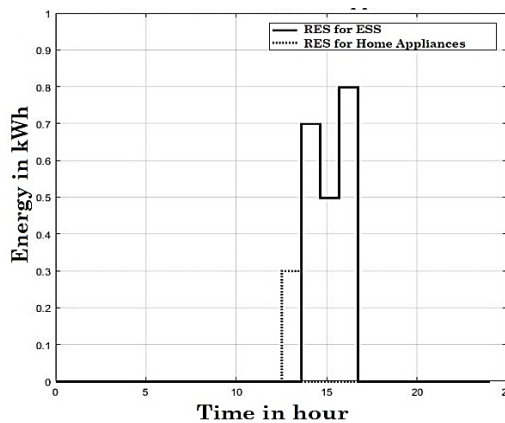


Figure 8. Use of RES

Table 3. ESS parameters

Capacity of ESS	Min. Energy Level	Max. Energy Level	Charging/Discharging Rate
2 kWh	0.5 kWh	0.5 kWh	0.3 kW

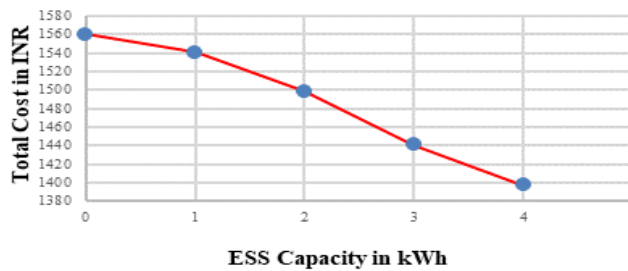


Figure 9. Effect of ESS capacity on cost reduction

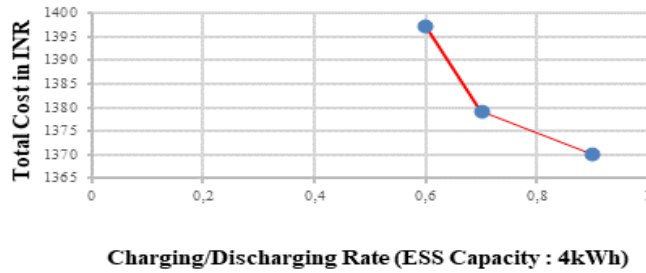


Figure 10. Effect of ESS charge/discharge rate on cost reduction

5.1.2. Waiting time

Here, in this article consumers’ preference has been considered as an important parameter to evaluate the efficiency of the proposed model. In Figure 11 it has been shown that with more flexible waiting time consumers will avail more benefit in terms of total cost. We have tried to achieve an AEMS using the proposed tariff and heuristic technique with minimum waiting time to maintain the comfort level of domestic consumers, which has been shown in Figure 12.

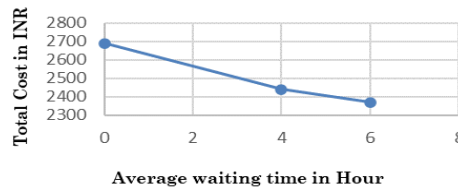


Figure 11. Trade off between cost and waiting time of appliances

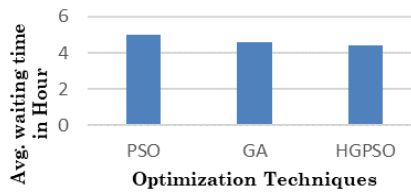


Figure 12. Reduction in waiting time using HGPSO AEMS

5.2. Utility sectors’ preference

5.2.1. PAR

PAR is the ratio of the maximum aggregated load consumption over a certain time period and the average of the aggregated load.

$$PAR = (\sum_{i=1}^N \sigma_{ai}^t)max / \frac{1}{T} (\sum_{i=1}^N \sigma_{ai}^t) \tag{34}$$

The high PAR affects the grid stability and increases the electricity cost. While reduction in PAR improves the stability and reliability of the grid and reduces the electricity cost for the consumers. Improvement of PAR using HGPSO AEMS is shown in Figure 13 and Table 4.

Table 4. The performance of EMS on the basis of PAR

Without AEMS	PAR		Reduction in PAR (in %)
	Without AEMS	With HGPSO AEMS	
2.86	1.64		43
3.64	2.16		41
3.11	2.07		33
3.69	2.46		33
3.63	2.37		35

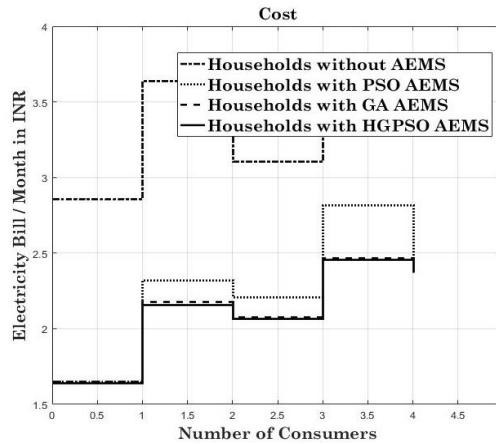


Figure 13. PAR reduction

5.2.2. Valley filling and peak reduction

Reducing the peak demand and reshaping the demand profile, robustness and reliability of the existing can be improved. The obtained result in terms of peak demand has been shown in Figure 14. The load demand from main grid has been shown in Figure 15 to point out the reduction in grid stress.

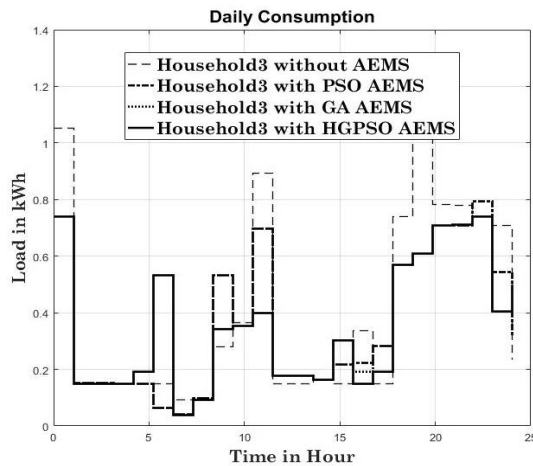


Figure 14. Peak reduction and valley filling with HGPSO for household 3

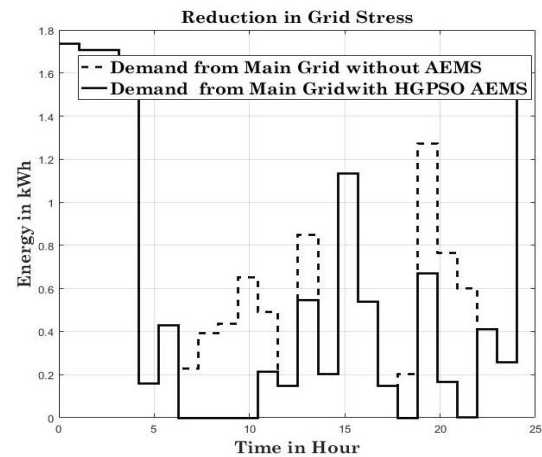


Figure 15. Load demand from main grid with and without HGPSO AEMS

Finally, the proposed HGPSO AEMS managed to achieve reduction in consumers’ electricity expense and at the same time it reduces system peak load. The discussed technique can also be applied to a larger distribution system. Users are allowed to pre-plan their next day’s consumption based on the desired demand profile and available tariff scheme using the illustrated application. Here a comparative study has been presented in Table 5.

Table 5. Comparative study of results obtained from existing techniques and proposed technique

Parameter	GA	PSO	DP	BPSO	ACO	FP	Hybrid Technique (GA & PSO)	EA	ILP	Hybrid Technique (LP & BPSO)	Proposed HGPSO
PAR Reduction	✓	✓	✓	✓	✓	✗	✓	✗	✗	✗	✓
Cost Reduction	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Consumers’ Preference	✗	✗	✗	✓	✓	✗	✗	-	✓	✓	✓
Less Complexity	✗	✗	✗	✗	-	-	-	✗	✗	✗	✓

6. CONCLUSION

This paper has tried to address issues related to load management by scheduling the load, shifting the peak over 24 hours, reducing the overall consumption, utilizing the RES and ESS efficiently and incorporating the advanced tariff scheme, which in turn will led to efficient power consumption and cost-effective power supply system. The objective of the case study is to generate an optimum load scheduling solution considering consumers' preference and convenience. A significant reduction in monthly electricity bill and peak load has been achieved which is an indication of improved grid stability. Therefore, it can be concluded that the utilities and federal agencies initiatives to save more energy and simultaneously to reduce peak load demand in all sectors can be supported by the proposed AEMS which is based on dynamic pricing-based tariff scheme and renewable energy integration.

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