

## RESEARCH ARTICLE

# Optimal Planning of Residential Microgrids Based on Multiple Demand Response Programs Using ABC Algorithm

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**ABSTRACT** The smart grid has revolutionized the conventional electricity grid with the proposition of demand-side management (DSM). A DSM program enables the user to schedule its energy consumption in compliance with any pricing signal. This scheduling helps the grid operator to reduce the peak load demand and jointly benefits the user to reduce its electricity costs. Despite that, while doing so, it jeopardizes the user's comfort. In the present paper, the authors have investigated the impact of communal DSM programs on the consumption patterns of users, including single as well as multiple households. The objective is to simultaneously minimize the electricity costs and user discomfort to make a win-win situation for both the grid operator and the user. Therefore, a multi-objective optimization problem (MOOP) has been formed to simultaneously minimize the daily electricity cost, peak to average ratio (PAR) of load demand, user discomfort, environmental emission, and total net present cost (TNPC). In order to evaluate the best scheduling method, sizing scenarios for a residential microgrid in a Southern Pakistani metropolis surrounded by rural areas are presented in this paper. The originality of this article comes from a comparison of the techno-economic and environmental performance of several sizing options for a residential load powered by renewable energy. The artificial bee colony (ABC) algorithm has been selected to solve the MOOP. The DSM programs are based upon different pricing signals, including real-time electricity pricing (RTEP), critical peak pricing (CPP), time of use (TOU), and day-ahead pricing (DAP) pricing. The results of the proposed ABC algorithm are compared with GA and standard algorithms, and they reveal the effectiveness of the proposed method. When demand response is used, the suggested optimization technique shows that the SH spring with PV/WG/grid-connected microgrid is the most investable-reliable sizing option with a minimal TNPC of \$1405.18 for DAP tariff with SH spring. Additionally, with a reduction in emissions of 6699 kg/yr, DAP tariff with SH spring shows that PV/WG/DG/grid-connected system has the greatest impact on the environment. For DAP tariff with SH spring, optimal sizes of PV, WG and converter are 26.7 kW, 30 kW and 6.67 kW, respectively.

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**INDEX TERMS** Demand side management, multi-objective optimization, peak to average ratio, electricity cost, user comfort, environmental emission, RTEP, CPP, TOU, DAP, residential microgrid, optimal operation, load shifting, genetic algorithm, ABC algorithm.

## NOMANCLATURE

ABC	Artificial bee colony
ACO	Ant colony optimization
AHP	Analytic hierarchy process
BPSO	Binary particle swarm optimization
C&CG	Column and constraint generation
CPP	Critical peak pricing
CS	Cuckoo search
DAP	Day-ahead pricing
DSM	Demand side management
DG	Distributed generation
DE	Differential algorithm
DR	Demand response
DP	Dynamic Programming
EDE	Enhance differential evolution
EED	Economic and environmental dispatch
EMC	Energy management controller
EA	Evolutionary algorithm
FF	Firefly
GA	Genetic algorithm
GWO	Grey wolf optimizer
HEMC	Home energy management controller
HEMS	Home energy management system
HSA	Harmony search algorithm
HGPO	Hybrid genetic particle swarm optimization
ILP	Integer linear programming
MINLP	Mixed-integer nonlinear programming
MOGA	Multiobjective Genetic Algorithm
MOPSO	Multi-objective particle swarm optimization
MPA	Marine predator algorithm
NSGA	Non-dominate sorting genetic algorithm
PAR	Peak to average ratio
PODR	Pareto optimal demand response
PSO	Particle swarm optimization
RTEP	Real-time electricity pricing
RES	Renewable energy sources
SH	Single household
TOU	Time-of-use
TLBO	Teaching-learning based optimization
TLGA	Teacher learning and genetic algorithm
VESS	virtual energy storage system
WDO	Wind driven optimization
WO	Whale optimization

## I. INTRODUCTION

Since its inception, the generation capacity of a power grid is always aimed to meet the peak load demand fully from the user side instead of the average demand. That demands which peak-load power plants such as diesel generators and gas turbines fulfill at the maximum cost of operation. Over time the existing power grid is dealing with abundant challenges comprising of increasing load demand, old infrastructure, and

absence of interaction and security issues. In this perspective, the smart grid has reshaped the operation of the conventional grid with the concept of demand-side management (DSM) [1], [2]. DSM has been presented to reshape the time pattern and extent of load demand by scheduling it. DSM further enhances the operational capabilities of a smart grid in several domains that include infrastructure construction, electricity market management and control of decentralized energy [3]. The main target of DSM is to schedule the load in strong correlation with low priced generation.

The published literature presents various methods which have been applied for DSM in smart grid paradigm. In general, DSM is about modifying the users' energy consumption so that to achieve a win-win situation for both user and utility grid [4]. Several DSM methods have been presented in the literature that includes peak cutting, shifting the load to the time when demand is low, the changeable shape of load, growth of load strategically, strategic conservation, and valley filling for this purpose [5]. Moreover, the communication infrastructure between the utility and user can also be managed by DSM. Also, it permits the incorporation of distributed energy resources (DERs) to enhance energy usage profile.

## II. RELATED WORK

In [6], distributed DSM algorithms are applied that are built upon the game theory setup and proximal decomposition for minimizing energy payment by using energy storage devices and appliance scheduling. In [7], the working of home energy management controller (HEMC) is developed for scheduling of energy consumption based on heuristic algorithms including genetic algorithm (GA), binary particle swarm optimization (BPSO) and ant colony optimization (ACO). The objectives were to reduce electricity bill and PAR with integration of renewable energy sources (RES). In [8], cost of electricity and PAR are lessened by employing intelligent programmable communication thermostat by the use of GA to manage electricity load during the limitation of comfort. In [9], a distributed generation (DG) planning model is presented which considers DSM and system reorganization at the same time to reduce the total cost over the planning horizon. For energy optimization, authors in [10], present HEMS design and classify the domestic appliances. The purpose of the aimed design is to lower the cost of electricity and to address the degree of uncertainty associated with various types of loads by using fractional programming approach. For the optimization of energy at domestic area, authors in [11], present HEMS model in which DSM methods are applied in cooperation with time-differentiated rates, load priority and DGs using GA.

In [12], renewable energy sources (RESs) are incorporated in day ahead scheduling of micro-sources for minimization of the generation and startup expenses of the RESs by

applying a combined differential evolution (DE) and Harmony search algorithm (HSA). In [13], a household load scheduling with incorporation of day ahead costing plan is demonstrated by using a hybrid teacher learning and genetic algorithm (TLGA). The authors in [14], propose a HEMS built using binary particle swarm optimization (BPSO) for reduction in the expenses of electricity with minimum consumer discomfort. The authors in [15], have used integration projection evolutionary algorithm (IPEA) to schedule the appliances at the time when electricity pricing is low. In [16], a non-cooperative game theory based DSM method is proposed to schedule the energy consumption while using storage appliances. In [17], a residential demand response with RES is proposed. In [18], a Ladson generalized bender algorithm (LGBA) is used to improve the energy usage profiles of multi-households with minimum discomfort level. The authors in [19], have used GA to execute demand response program using RES to minimize customer's electricity charges and peak load. In [20], authors have demonstrated energy management scheduling within a domestic area using two horizon algorithm (THA) to minimize electricity expense with reduction in computational time. In [21], a stochastic programming model is discussed to optimally schedule DERs. The objective of this work is to minimize energy expense and CO<sub>2</sub> emissions. In [22], a model is introduced to address the supply–demand balance constrained grid with a goal to get minimized generation expenses, CO<sub>2</sub> emissions and utility losses.

In [23], a multi-objective PSO algorithm is proposed to minimize dynamic economic and emission dispatch problem with consideration of DSM. In [24], a multi-objective PSO algorithm is proposed to minimize dynamic economic and emission dispatch problem with consideration of DSM. In [25], authors have introduced a design built on optimal financial options for the management of microgrid using GA. In [26], authors have proposed a multi-time scale optimization (MSO) for scheduling the energy utilization of various appliances. In [27], GA for DSM in domestic, commercial, industrial areas. In [28] and [29], both dynamic programming (DP) and integer linear programming (ILP) techniques are applied to reduce PAR and electricity expenses. However, these techniques are ineffective concerning the computational time. In [30], an energy management model with different types of appliances is presented for cost minimization and PAR. The authors in [31], have proposed a HEMS for load shifting to reduce in PAR and electricity expenses by using dynamic programming. In [32], economic analysis of DSM programs on unit commitment is discussed to schedule a load profile.

In [33], an improved PSO and shuffled frog-leaping algorithm (SFLA) based energy consumption and forecasting model is presented to implement the DSM plan. The authors in [34] have proposed the scheduling of generation units integrated with DSM programs to reduce electricity costs. Imperialist competitive algorithm (ICA) is employed for this problem. In [35], ABC algorithm is proposed to schedule

residential loads subjected to cost and time constraints, however PAR and user comfort is neglected. In [36], electricity price and demand forecasting schemes have been presented to reduce peak load. Authors have used a three-part forecast model which includes a new flexible packet wavelength transformation, a multi input multi output (MIMO) model and ABC algorithm for a stable prediction of price and load. In [37], a scheduling technique for the equipment used in rice industry is proposed by using three optimization algorithms including DE, PSO and ABC. The objectives were to minimize feeder load and cost of electricity. Results prove that ABC algorithm gives better results than other algorithms. In [38], an ABC algorithm based on improved-global-best-guided-approach (IGBGA) and adaptive-limit-strategy (ALS) is applied in to reduce total electricity cost and total energy consumption with integration of PV generation. Authors in [39], have minimized the total investment, operating, and outage costs considering DSM by using ABC algorithm. In [40], cost saving of commercial area by shifting loads is achieved by ABC algorithm while using time of use (TOU) tariff. In [41], combined ABC-GA algorithms are used to solve OPF and operation problems, respectively. In [42], different load profiles are used to minimize system operation cost and losses by using TOU as DR program with ABC algorithm.

The authors proposed DSM in [43] by including VESS which is a common heating/cooling system used as a microgrid in residential buildings with multi-objective optimization problem. In [44], DSM as PODR is proposed to solve multi-objective optimization problem. In [45], MINLP is used for two heating/cooling based grid-connected residential microgrid system with multi-objective optimization. NSGA-II is then used for searching Pareto front. The optimal scheduling is handled using AHP approach. In [46], day-ahead forecasting with DSM and EED is proposed with two versions of PSO to obtain DSM based load control plan and EED based power supply plan. In [47], MOGA is employed for solving multi-objective DSM problem. In [48], C&CG is used for minimization of multi-objective DSM problem. The optimal solution from non-dominated Pareto solutions is sorted by the fuzzy decision-making approach. The RERs uncertainty, the stochastic loads and energy prices are modelled using Monte Carlo method.

The majority of evolutionary algorithms are stochastic meta-heuristic procedures that draw their inspiration from nature [49]. Some of the often used and most appropriate algorithms in the context of smart grids include PSO [50], GA [51], ABC [52], GWO [53], TLBO [54], FF [55], CS [56], WO [57], and MPA [58]. PSO is inspired by bird-flock and is developed by Kennedy and Eberhart in 1995. GA is inspired by genetics and is developed by AS Fraser in 1957. ABC is inspired by honey-bee and is developed by Karaboga in 2005. GWO is inspired by grey-wolves and is developed by Seyedali Mirjalili et al. in 2013. TLBO is inspired by classroom and is developed by Rao et al. in 2011. FF is inspired by firefly and is developed by Yang et al. in 2008. CS is inspired

by cuckoo and is developed by Yang and Deb in 2009. WO is inspired by blue-whale and is developed by Seyedali Mirjalili et al. in 2016. MPA is inspired by ocean-predators and is developed by Afshin Faramarzi et al. in 2020.

**A. KEY CONTRIBUTIONS**

From the above literature survey, it can be seen that the majority of authors have applied various techniques in DSM to schedule the load for minimizing electricity cost. Some authors have included PAR as an objective function as well. A few authors have incorporated user comfort as an objective. A couple of authors have combined RES along with the grid while solving the DSM problem. As far as solution algorithms are concerned, GA, PSO, ACO, TLGA, IPEA, LGBA, THA, MSO, DP, ILP and ABC have been employed to solve the optimization problems.

It has been observed that the solution of the DSM problem with ABC algorithm is limited to certain objectives including minimization of electricity cost and load scheduling only. Table 1 shows synopsis of the application of ABC algorithm applied to DSM problems. A complete multi-objective DSM problem solved with the ABC algorithm has been seen to be missing in the literature. In the current paper, the authors have extended the scope of the DSM problem by reforming it as a multi-objective DSM and proposed the ABC algorithm for the solution of the optimization problem. ABC algorithm is selected due to its limit cycle ability which reduces the chance of local optimization, and therefore increases its diversity. Key contributions of this paper include:

- The DSM of a single household (SH) and multi household (MH) is proposed to simultaneously minimize the multiple objectives. Two test cases have been created and are being looked into.
- In the first case, five objectives, including electricity cost, PAR, user discomfort, TNPC and environmental emissions have been simultaneously minimized by using the ABC algorithm, and results are compared with standard algorithms. The consideration of user discomfort ensures that average waiting of appliances is reduced to increase the luxury of user.
- In second case, three objectives, including electricity cost, PAR, user discomfort have also been minimized using the ABC algorithm. In this case, the results are compared with GA because existing literature lacks such a test case.
- Four types of tariffs including real time electricity pricing (RTEP), critical peak pricing (CPP), time of use (TOU), and day-ahead pricing (DAP) have considered while solving the optimization problem. The existing literature lacks detailed analysis with four tariffs which are investigated in this paper.
- To examine the role of electrical power generation in sustainable development and analysis of the TNPC associated with the rise in emissions is carried out.

**TABLE 1. Synopsis of ABC algorithm applied to DSM problems.**

ABC Algorithm	Year	Objectives	Limitations
[35]	2016	To schedule residential loads subject to cost and time constraints.	PAR and user comfort are neglected. Detailed emission analysis is also not considered.
[36]	2016	To clip peak load to minimize electricity price and to forecast demand.	User comfort is missing. TNPC with detailed emission analysis is also not considered.
[38]	2018	To minimize the electricity cost by scheduling the load with integration of solar power.	Environmental emissions, PAR and user comfort are not considered.
[37]	2019	To minimize peak demand by scheduling the appliances.	TNPC with detailed emission analysis is not considered.
[39]	2019	To minimize the total investment, operating, and outage costs in a DSM program.	Environmental emissions, PAR and user comfort are not considered.
[40]	2020	To minimize the cost of electricity of a commercial customer by scheduling the load.	Environmental emissions, PAR and user comfort are not considered.
[41]	2022	Operational limits and restrictions for load shifting are among the constraints, which aim to reduce the total operating expenses with the cost of load shifting.	TNPC with detailed emission analysis is not considered, PAR and user comfort are not considered.
[42]	2022	To minimize operation cost and power losses.	Only TOU tariff is used as DR program. DR programs such as RTEP, CPP, DAP are not considered. TNPC with detailed emission analysis is also not considered.

- A multi-objective, renewable energy-based method to sizing DERs of proposed area in Pakistan’s south is proposed.
- Depending on the availability of power conversion sources, two operating sizing options (TNPC and emission) with thorough analyses are presented with different energy sources.
- The economic and environmental impacts are studied for producing power in remote or grid-connected microgrids in underdeveloped nations like Pakistan, as well as in cities surrounded by rural areas.
- How system sizing is affected by four DR programs (such RTEP, CPP, TOU, and DAP) is investigated. Additionally, the effects of DR programs on the share of

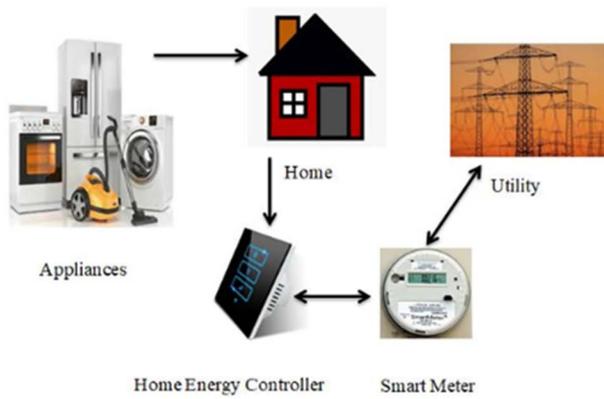


FIGURE 1. DSM.

renewable energy (RERs) and overall net present cost (TNPC) is analyzed.

- Comparing several time-based DR programs for the scheduling problem is studied. The findings of this study will be very helpful for designing tariffs since they need to make sure that the tariff they choose is as effective as feasible.
- Modifying the daily load curve using RTEP, CPP, TOU, and DAP.

Rest of the paper is as follows. Section 2 shows the proposed multi-objective DSM of a SH and MH. It comprises of formulation of the problem. In section 3, ABC algorithm is explained. Whereas, test cases and results are presented in section 4. The conclusions are drawn in section 5.

### III. DEMAND-SIDE MANAGEMENT

DSM is shown in Fig. 1, which envisions a single household (SH) comprising of different appliances as shown in Table 2. The ultimate objectives are to simultaneously minimize the electricity cost, PAR, user discomfort and environmental emissions by scheduling the load in the presence of a PV system. These objectives are subject to constraints of grid capacity limitations, time of operation limitations and user discomfort limitations. The optimal values of objectives are minimized by using the ABC algorithm based on two types of tariffs including RTEP and CPP in two test cases.

#### A. PROBLEM FORMULATION

##### 1) ELECTRICITY COST

The first objective is to minimize the electricity cost by scheduling the residential load during low-cost hours. For a single household,  $Y = \{y_1, y_2, y_3, \dots, y_N\}$  such that  $y_1, y_2, y_3, \dots, y_N$  denotes each appliance through the time range  $t \in T \triangleq \{1, 2, 3, \dots, N\}$ . Each time slot constitutes one hour and the total time range is 24h ( $T=24$ ), considering a single day. The total energy utilization of all appliances in a day can be mathematically represented as shown in Eq. (1) [59]:

$$E_{C,TL} = \sum_{t=1}^T \left( \sum_{q=1}^N E_{(y_q,t)} \right) \quad \forall t \in T, y \in Y \quad (1)$$

where,  $E_{C,TL}$  represents the total energy utilization of all appliances in a day which is the sum of energy utilization of all appliances over a time period of 24h, and its unit is in kWh. Similarly,  $E_{(y_q,t)}$  represents the power rating of each appliance in kW.

The appliances are categorized into three groups. Each appliance is classified based on user preference, energy utilization and time of operation. Assume that  $Y_n$  represents a set of appliances, and  $Y_n = \{E_a \cup R_a \cup S_a\}$ . Where,  $E_a$  represents elastic appliances,  $R_a$  represents frequently operated appliances and  $S_a$  represents shift able appliances.

##### a: ELASTIC APPLIANCES

The energy utilization profile and time period of these appliances can be flexibly adjusted by DSM that is why these are considered as flexible appliances. These include air conditioner (AC), water heater, refrigerator and water dispenser. The total energy consumed in 24h by  $E_a$  can be calculated as shown in Eq. (2) [59]:

$$c_{E_a,TL} = \sum_{t=1}^T \left( \sum_{E_a \in Y_n} u'_{E_a} \delta(t) \right) \quad (2)$$

where,  $c_{E_a,TL}$  is the total energy consumed in kWh in a day,  $u'_{E_a}$  is the power rating of elastic appliances in kW and  $\delta(t)$  is the ON-OFF state. The total cost of elastic appliances in a day can be calculated as shown in Eq. (3) [59]:

$$e_{E_a}^{TL} = \sum_{t=1}^T \left( \sum_{E_a \in Y_n} u'_{E_a} E(t) \delta(t) \right) \quad (3)$$

where,  $e_{E_a}^{TL}$  represents the total cost of elastic appliances in a day in cents/h,  $E(t)$  represents electricity pricing signal and  $\delta(t)$  is the ON-OFF state.

##### b: FREQUENTLY OPERATED APPLIANCES

The energy utilization profile of frequently operated appliances cannot be modified by DSM that is why these are called fixed appliances. These include oven, dishwasher, water pump and vacuum pump. The total energy consumed in 24h by  $R_a$  can be calculated as shown in Eq. (4) [59]:

$$c_{R_a,TL} = \sum_{t=1}^T \left( \sum_{R_a \in Y_n} L'_{R_a} \delta(t) \right) \quad (4)$$

where,  $c_{R_a,TL}$  is the total energy consumed in kWh in a day,  $L'_{R_a}$  is the power rating of frequently operated appliances in kW and  $\delta(t)$  is the ON-OFF state. The total cost of frequently operated appliances in a day can be calculated as shown in Eq. (5) [59]:

$$e_{R_a}^{TL} = \sum_{t=1}^T \left( \sum_{R_a \in Y_n} L'_{R_a} E(t) \delta(t) \right) \quad (5)$$

where,  $e_{R_a}^{TL}$  represents the total cost of frequently operated appliances in a day in cents/h,  $E(t)$  represents electricity pricing signal and  $\delta(t)$  is the ON-OFF state.

c: SHIFT ABLE APPLIANCES

Time of operation of shift able appliances is changeable by DSM with any time interval without affecting their performance. The limitation with these appliances is that when they are switched ON their duration of functioning has to be completed. These include cloth dryer and washing machine. The total energy consumed by in 24h by  $S_a$  is shown in Eq. (6) [59]:

$$c_{Sa,TL} = \sum_{t=1}^T \left( \sum_{Sa \in Y_n} v_{Sa}^t \delta(t) \right) \quad (6)$$

where,  $c_{Sa,TL}$  is the total energy consumed in kWh in a day,  $v_{Sa}^t$  is the power rating of shift able appliances in kW and  $\delta(t)$  is the ON-OFF state. The total cost of shift able appliances in a day can be calculated as shown in Eq. (7) [59]:

$$e_{Sa}^{TL} = \sum_{t=1}^T \left( \sum_{Sa \in Y_n} v_{Sa}^t E(t) \delta(t) \right) \quad (7)$$

where,  $e_{Sa}^{TL}$  represents the total cost of shift able appliances in a day in cents/h,  $E(t)$  represents electricity pricing signal and  $\delta(t)$  is the ON-OFF state. The total energy utilization of appliances during a period of 24 hours is given as shown in Eq. (8) [59]:

$$c_{TL} = c_{Ra,TL} + c_{Sa,TL} + c_{Ea,TL} \quad (8)$$

where,  $c_{TL}$  is the sum of energy consumed in kWh by all types of appliances. The total cost per day of  $R_a$ ,  $S_a$  and  $E_a$  appliances is calculated as shown in Eq. (9) [59]:

$$e_{TL} = e_{Ra}^{TL} + e_{Sa}^{TL} + e_{Ea}^{TL} \quad (9)$$

where,  $e_{TL}$  represents the total cost of all appliances in a day in cents/h. which is the sum of cost of elastic, frequently operated and shift-able appliances. The purchased cost of electricity from grid is [41]:

$$C_P(t) = T_{GP} \times P_{GP} \quad (10)$$

where,  $T_{GP}$  and  $P_{GP}$  represent the tariff and purchased power from grid, respectively. Selling electricity to grid is not considered in this paper. Hence, excess electricity may be available and can be analyzed in future reseach. The total electricity cost per day is calculated as shown [59]:

$$Cost_T = \sum_{t=1}^T \sum_{yi} E(t) g_{yi}(t) \delta(t) \quad (11)$$

where,  $Cost_T$  is the total electricity cost per day,  $E(t)$  is the electricity pricing signal,  $g_{yi}$  denotes the energy utilization of the appliances in kWh. The first objective can be mathematically represented as shown [59]:

$$\min Cost_T = \sum_{t=1}^T \sum_{yi} E(t) g_{yi}(t) \delta(t) \quad (12)$$

2) PAR

The second objective is to minimize PAR by scheduling the residential load during low-cost hours. PAR is the ratio of the maximum combined load used during a specific time interval to the average of the combined load. Grid stability is damaged when PAR is high. It also increases the electricity cost of the user. Simultaneously when PAR is low, the stability of the grid is improved and electricity cost is minimized as well. The second objective can me mathematically represented as shown [59]:

$$L_{peak} = \max_{t \in T} c_T(t) \quad (13)$$

$$L_{avg} = \sum_{t=1}^T c_T(t) \quad (14)$$

$$\min PAR = \frac{L_{peak}}{L_{avg}} \quad (15)$$

where,  $L_{peak}$  and  $L_{avg}$  indicate the maximum combined load and average load in kW in 24h, respectively, and  $c_T(t)$  denotes the total hourly energy utilization of appliances.

3) USER DISCOMFORT

The third objective is to minimize user discomfort. During load scheduling the energy utilization patterns of  $R_a$  could not be shifted. On the other hand, energy utilization patterns of  $S_a$  and  $E_a$  are changeable to run during off-peak hours. However, it causes inconvenience for the user, and therefore average waiting time of appliances is reduced to minimize user discomfort. To estimate the waiting time of appliances, start-up time instant  $a_\alpha$  and closing time instant  $b_\beta$ , is assumed such that ( $a_\alpha < b_\beta$ ). The waiting time of the appliances is calculated as shown [59]:

$$W = |(\alpha_a - T_r)| \quad (16)$$

where,  $W$  represents the waiting time in h and  $T_r$  is the time of request of an appliance. The average waiting time of the appliances is calculated as shown [59]:

$$W_{avg} = \frac{\sum_{y=1}^{Y_n} a_\alpha - T_r}{Y_N} \quad (17)$$

where,  $W_{avg}$  is the average waiting time of all appliances and  $Y_N$  is the set of appliances. The third objective can be mathematically represented as shown [59]:

$$\min W_{avg} = \frac{\sum_{y=1}^{Y_n} a_\alpha - T_r}{Y_N} \quad (18)$$

4) ENVIRONMENTAL EMISSIONS

The fourth objective is to minimize the environmental emissions including  $CO_2$ ,  $NO_x$  and  $SO_2$ . The emissions are taken into account to cater concerns of environmental protection

TABLE 2. Emission coefficients.

Coefficient	Value
$a_i$	$4.091 \times 10^{-2}$
$b_i$	$-5.554 \times 10^{-4}$
$c_i$	$6.490 \times 10^{-6}$
$d_i$	$2.00 \times 10^{-4}$
$e_i$	$2.857 \times 10^{-2}$

and climate change. These emissions are measured in kg/h and are calculated as shown [60]:

$$F_E = \sum_{i=1}^{ng} (a_i + b_i P_{gi} + c_i P_{gi}^2 + d_i^{(e_i P_{gi})}) \quad (19)$$

where,  $F_E$  is the amount of environmental emissions in kg/h,  $P_{gi}$  is grid’s power in kW.  $a_i$ ,  $b_i$ ,  $c_i$ ,  $d_i$  and  $e_i$  are emission coefficients. Table 2 shows the values of these coefficients. The fourth objective can be mathematically represented as shown [60]:

$$\min F_E = \sum_{i=1}^{ng} (a_i + b_i P_{gi} + c_i P_{gi}^2 + d_i^{(e_i P_{gi})}) \quad (20)$$

The above-mentioned objectives are subject to certain constraints as stated below. The first constraint is about the limitations of grid capacity. The total energy utilization of the appliances during time interval  $t \in T$  should be less than equal to  $C_g$ . Therefore, the total energy utilization is limited as shown:

$$0 \leq c_{TL} \leq C_g \quad (21)$$

where,  $c_{TL}$  is the sum of energy consumed in kWh by all types of appliances and  $C_g$  is the grid’s maximum capacity to supply power. The second constraint is about the limitations of energy consumption of  $E_a$  and  $S_a$ . The third constraint is about limitations of user discomfort. The  $W_{avg}$  of  $E_a$  and  $S_a$  is restricted to be less than 5h [59].

#### IV. PROPOSED ABC ALGORITHM

ABC algorithm was at first introduced in 2003 by Karobaga [52]. It is an algorithm which was founded on the foraging behaviors of honey bees. At the moment it has been applied to different research problems by several researchers [61], [62], [63]. The employee, spectator, and scout bees are the three sorts of bees that the ABC algorithm is based on. The method is divided into three phases: the worker bee phase, the observer bee phase, and the scout bee phase.

- In employee bees’ phase, the employee bees search for the food sources and store this food source information in memory. Each food source denotes a solution of the optimization problem. The employee bees pass on this food source information to the onlooker bees.
- In onlooker bees’ phase, the onlooker bees stay at the hive and evaluate the food source information brought by the employee bees. They check the nectar amount of the food sources and decide to whether accept or reject

them. This is normally done by monitoring the waggle dance of the employee bees. The onlooker bees also store the food source information and respective decisions in memory. Based on decision, they direct the employee bees for next iteration of search.

- A worker bee is labelled a scout bee if she provides the same food source information for a predetermined number of cycles (known as limit cycles) without producing improved results. The scout bee is told to look for fresh food sources in new, arbitrary locations. The likelihood of local optimization is decreased by this search procedure, and algorithm variety is increased.

In the current paper, a food source represents a solution in the form of a scheduled load. Similarly, the nectar amount represents electricity cost, PAR, user discomfort and environmental emissions. The flow chart of ABC algorithm is shown in Fig. 2 and the step by step procedure is as follows:

- In first step, parameters of the ABC algorithm are initialized. These parameters include the number of employee bees, number of onlooker bees, number of limit cycles, initial food sources (population) and max number of iterations (MI).
- The worker bees look for food sources in this step. Each worker bee finds a food source, measures the nectar content, remembers its location, and transmits the information to a watcher bee.
- In this step, the observer bees assess the data on the food sources (including the amount of nectar brought by the worker bees). The spectator bees memorise all the data acquired from the nearby worker bees and choose the finest food source from it. The observer bees then lead the worker bees to look for more food sources. The worker bees keep looking for new food sources and gathering information about them. Once more, spectator bees assess the data and repeat the process of deciding on the greatest food source. The iterative process begins in this manner and is continued till the MI. If any observer bee notices repeated repeating of food source information by any employee bee for a predetermined number of cycles, that employee bee is classified as a scout bee during the evaluation process. This scout bee is instructed to search for food sources in different, illogical locations. Each observer bee compares the information about the food source with the knowledge about the nearby food source and changes this information in memory by [42]:

$$R_{new} = R_{oldm} + u(R_{oldm} - R_{oldn})|_{m \neq n} \quad (22)$$

where,  $R_{new}$  shows updated solution,  $R_{oldm}$  shows an outdated fix at an arbitrary food source location  $m$  and  $R_{oldn}$  shows the dated remedy at the location of the food supply  $n$ .  $u$  is the random number between  $[-2, 2]$ . The probability  $R_R$  of the fitness of the food sources is

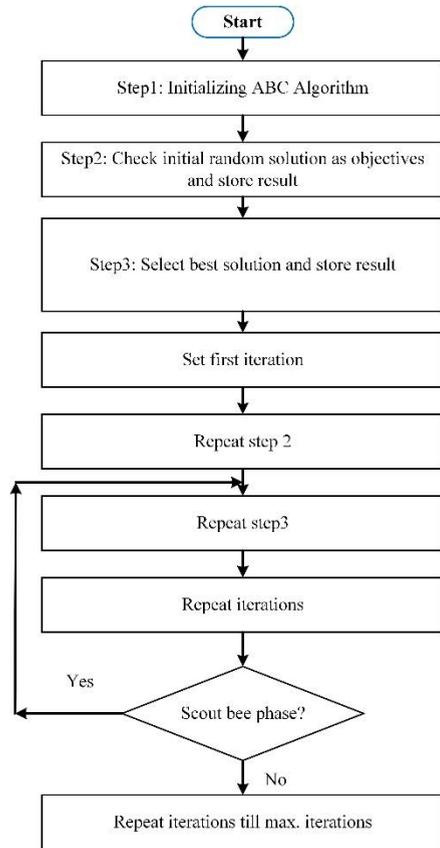


FIGURE 2. Flowchart of proposed ABC algorithm.

calculated by [64]:

$$R_R = \frac{fitness_R}{\sum_{R=1}^{N_e} fitness_R} \quad (23)$$

V. RESULTS AND DISCUSSION

In this section, the simulation of proposed DSM of a SH and MH has been done with the ABC algorithm. The complete system has been modeled and is implemented in MATLAB. Two test cases have been investigated while considering RTEP, CPP, TOU and DAP tariffs. All of these four tariffs are shown in Fig. 3 in a 24h horizon.

Table 3 [59] shows complete description of these appliances.

A. WINTER SH

1) LOAD SCHEDULING

Fig. 4 shows the hourly load scheduling of winter SH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy is 128.96 kWh/day for both unscheduled and ABC scheduled load. The unscheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour) and 13.35 kW (at 03:00 hour), respectively. The average value for both unscheduled and ABC scheduled load is 5.37 kW. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.48,

TABLE 3. Description of appliances.

Appliance Category	Appliance	Power Rating (kW)	Operating Time (h)
Elastic appliances	Refrigerator	1	15
	AC	1.5	14
	Water heater	4.45	4
	Water dispenser	1.5	9
Frequently operated appliances	Vacuum pump	0.6	6
	Water pump	1.18	8
	Dish washer	0.78	10
	Oven	1.44	18
Shift able appliances	Washing machine	3.6	3
	Cloth dryer	4.4	2

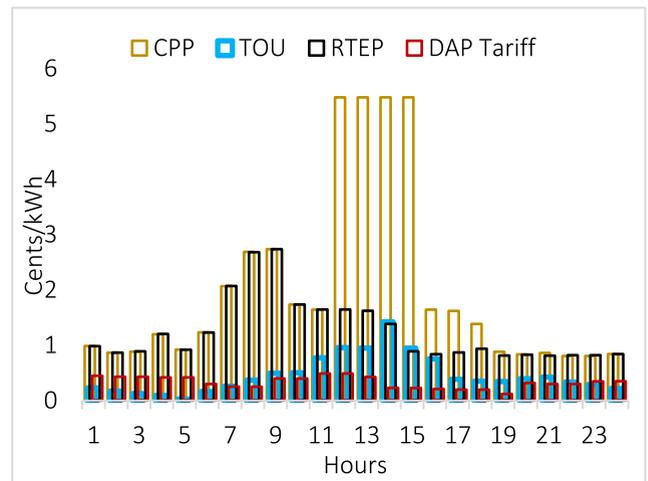


FIGURE 3. Four tariffs used in this study.

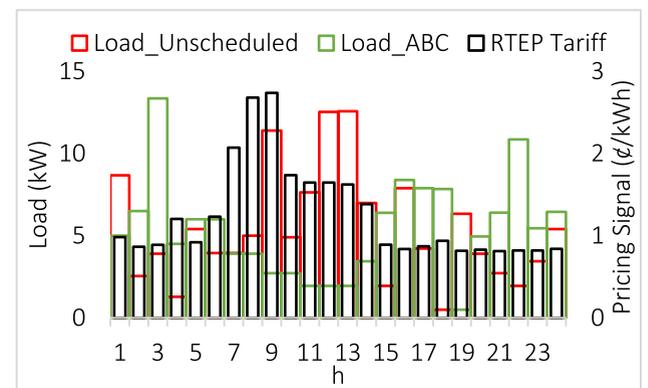


FIGURE 4. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (winter SH).

respectively. For SH winter load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 5 shows the hourly load scheduling of winter SH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy is 128.96 kWh/day for both unscheduled and ABC scheduled load. The unscheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour) and 10.85 kW (at 21:00 hour), respectively. The average value for both

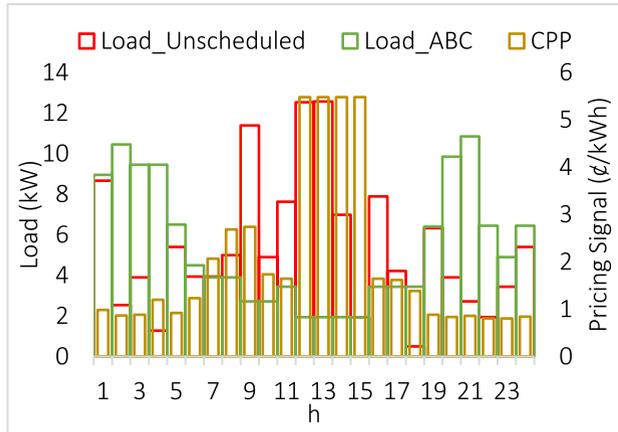


FIGURE 5. Hourly load scheduling with CPP tariff using proposed ABC algorithm (winter SH).

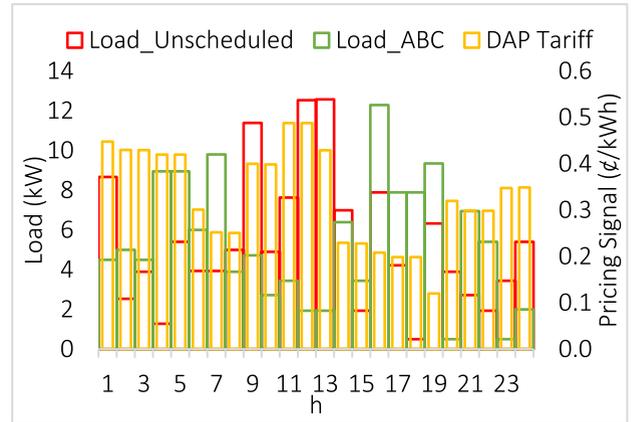


FIGURE 7. Hourly load scheduling with DAP tariff using proposed ABC algorithm (winter SH).

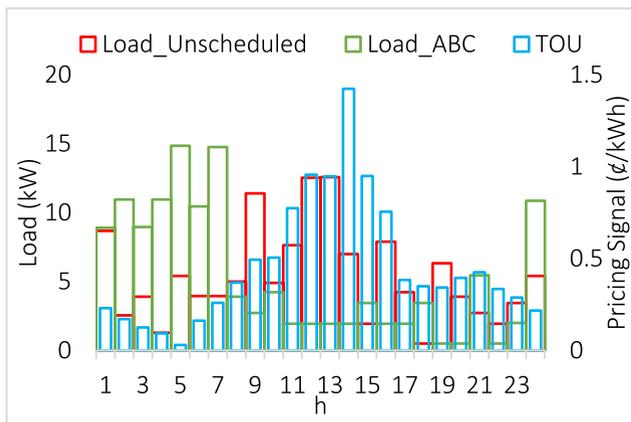


FIGURE 6. Hourly load scheduling with TOU tariff using proposed ABC algorithm (winter SH).

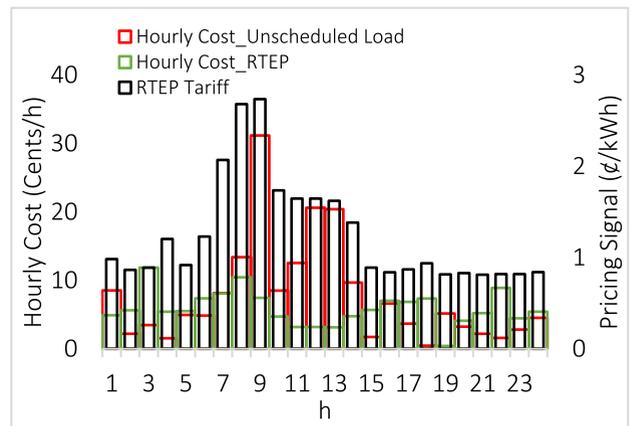


FIGURE 8. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (winter SH).

unscheduled and ABC scheduled load is 5.37 kW. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.02, respectively. For SH winter load with CPP tariff, PAR is minimized by 13.7% with the proposed ABC scheduling.

Fig. 6 shows the hourly load scheduling of winter SH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy is 128.96 kWh/day for both unscheduled and ABC scheduled load. The unscheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour) and 14.85 kW (at 05:00 hour), respectively. The average value for both unscheduled and ABC scheduled load is 5.37 kW. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.76, respectively. For SH winter load with TOU tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 7 shows the hourly load scheduling of winter SH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy is 128.96 kWh/day for both unscheduled and ABC scheduled load. The unscheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour) and 12.29 kW (at 16:00 hour), respectively. The average value for both unscheduled and ABC scheduled load is 5.37 kW. The PAR

for unscheduled and ABC scheduled load are 2.34 and 2.29, respectively. For SH winter load with DAP tariff, PAR is minimized by 2.1% with the proposed ABC scheduling.

## 2) ELECTRICITY COST

Fig. 8 shows the hourly electricity cost of winter SH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 31.17 cents/h (at 09:00 hour) and 11.87 cents/h (at 03:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 7.58 cents/h and 5.88 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 182.03 cents/h and 141.12 cents/h, respectively. For SH winter load with RTEP tariff, average daily cost is minimized by 22.5% with the proposed ABC scheduling.

Fig. 9 shows the hourly electricity cost of winter SH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 68.88 cents/h (at 13:00 hour) and 11.33 cents/h (at 04:00 hour), respectively. The average value of energy cost

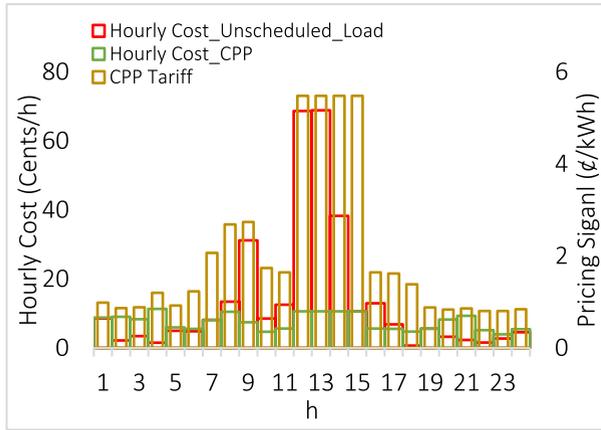


FIGURE 9. Hourly electricity cost with CPP tariff using proposed ABC algorithm (winter SH).

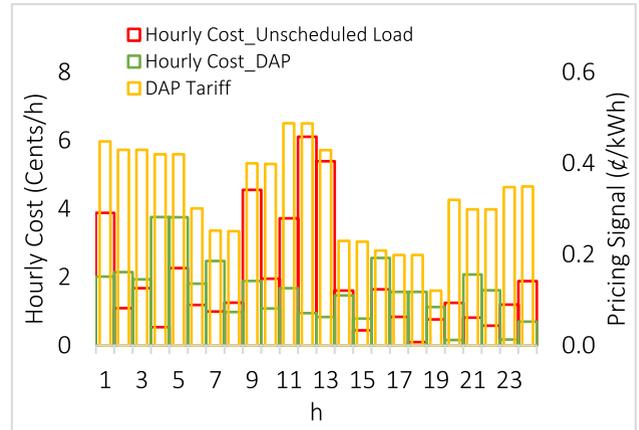


FIGURE 11. Hourly electricity cost with DAP tariff using proposed ABC algorithm (winter SH).

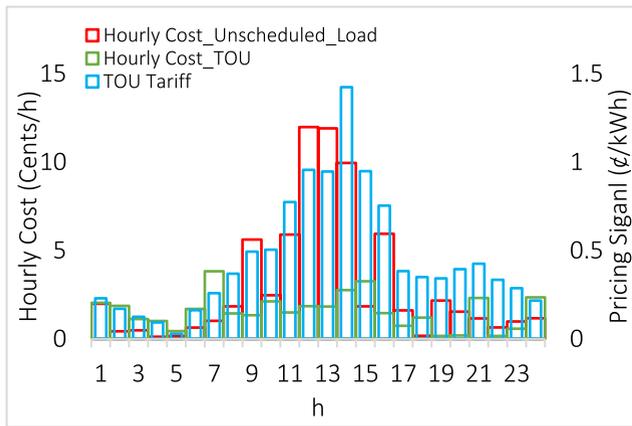


FIGURE 10. Hourly electricity cost with TOU tariff using proposed ABC algorithm (winter SH).

for unscheduled and ABC scheduled load are 13.60 cents/h and 7.57 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 326.45 cents/h and 181.80 cents/h, respectively. For SH winter load with CPP tariff, average daily cost is minimized by 44.3% with the proposed ABC scheduling.

Fig. 10 shows the hourly electricity cost of winter SH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 11.98 cents/h (at 12:00 hour) and 3.83 cents/h (at 07:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 2.99 cents/h and 1.56 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 71.80 cents/h and 37.34 cents/h, respectively. For SH winter load with TOU tariff, average daily cost is minimized by 47.9% with the proposed ABC scheduling.

Fig. 11 shows the hourly electricity cost of winter SH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 6.11 cents/h (at 12:00 hour) and 3.76 cents/h

(at 04:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 1.91 cents/h and 1.63 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 45.73 cents/h and 39.09 cents/h, respectively. For SH winter load with DAP tariff, average daily cost is minimized by 14.5% with the proposed ABC scheduling.

### B. SPRING SH

#### 1) LOAD SCHEDULING

Fig. 12 shows the hourly load scheduling of spring SH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 105.80 kWh/day and 79.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 7.80 kW (at 01:00 hour) and 6.00 kW (at 06:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 4.41 kW and 3.31 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.76 and 1.81, respectively. For SH spring load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite multiple simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 13 shows the hourly load scheduling of spring SH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 105.80 kWh/day and 79.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 7.80 kW (at 01:00 hour) and 6.80 kW (at 03:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 4.41 kW and 3.31 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 2.05, respectively. For SH spring load with CPP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite multiple simulations. The average value for unscheduled and ABC scheduled load are also not same.

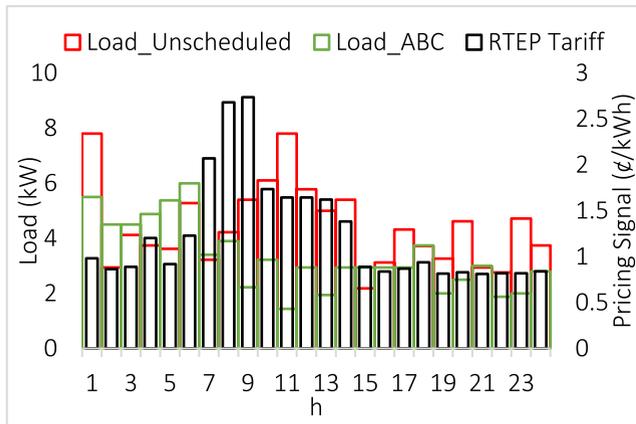


FIGURE 12. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (spring SH).

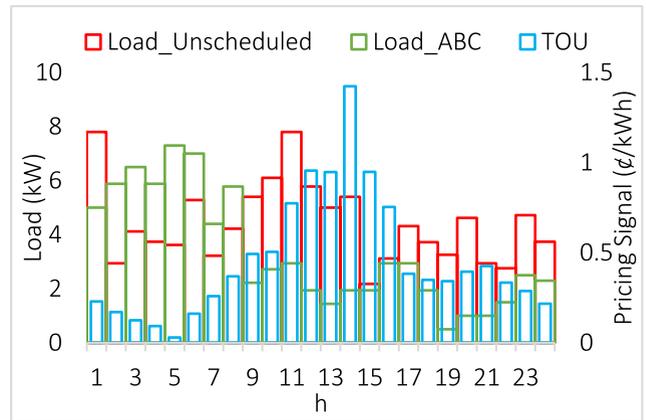


FIGURE 14. Hourly load scheduling with TOU tariff using proposed ABC algorithm (spring SH).

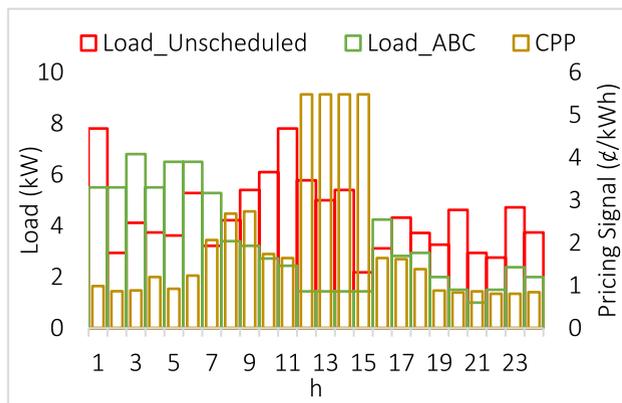


FIGURE 13. Hourly load scheduling with CPP tariff using proposed ABC algorithm (spring SH).

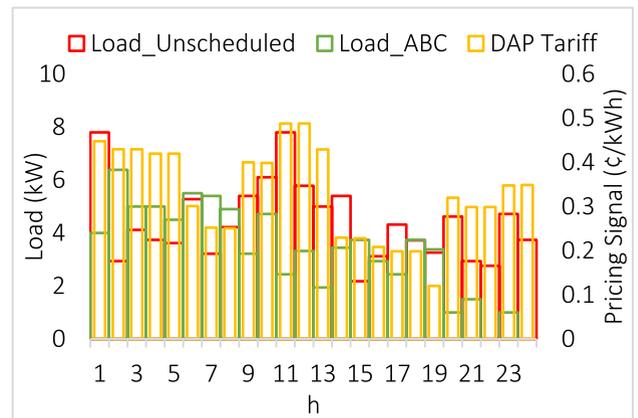


FIGURE 15. Hourly load scheduling with DAP tariff using proposed ABC algorithm (spring SH).

Fig. 14 shows the hourly load scheduling of spring SH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 105.80 kWh/day and 79.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 7.80 kW (at 01:00 hour) and 7.30 kW (at 05:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 4.41 kW and 3.31 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 2.20, respectively. For SH spring load with TOU tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite multiple simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 15 shows the hourly load scheduling of spring SH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 105.80 kWh/day and 79.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 7.80 kW (at 01:00 hour) and 6.38 kW (at 02:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 4.41 kW and 3.31 kW, respectively. The PAR for unscheduled

and ABC scheduled load are 1.77 and 1.93, respectively. For SH spring load with DAP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite multiple simulations. The average value for unscheduled and ABC scheduled load are also not same.

## 2) ELECTRICITY COST

Fig. 16 shows the hourly electricity cost of spring SH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 9.75 cents/h (at 11:00 hour) and 10.45 cents/h (at 08:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 3.97 cents/h and 4.08 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 95.24 cents/h and 97.89 cents/h, respectively. For SH spring load with RTEP tariff, average daily cost is increased by 2.8% with the proposed ABC scheduling.

Fig. 17 shows the hourly electricity cost of spring SH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled

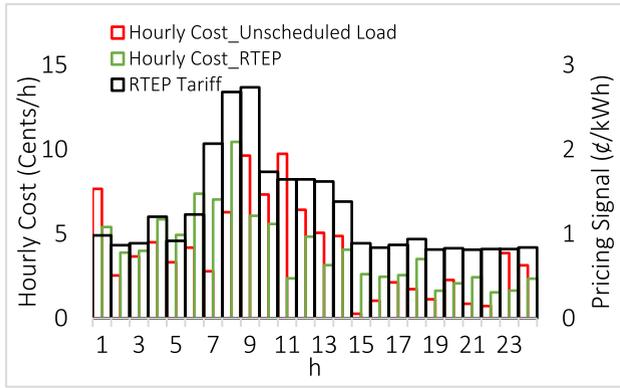


FIGURE 16. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (spring SH).

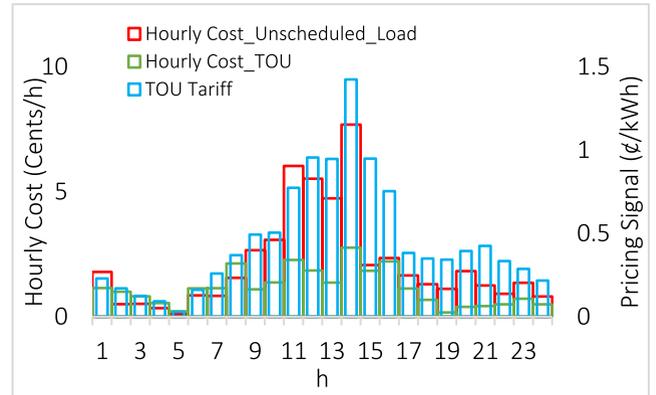


FIGURE 18. Hourly electricity cost with TOU tariff using proposed ABC algorithm (spring SH).

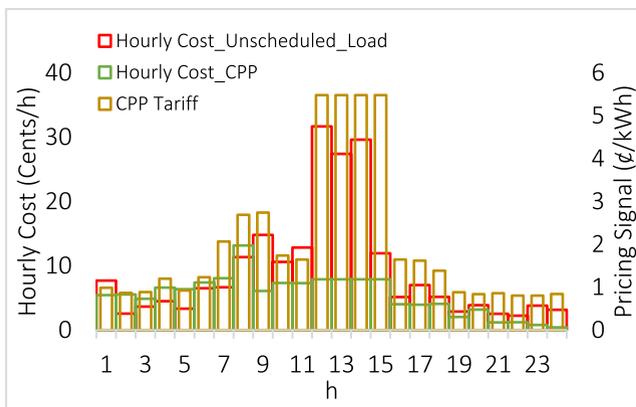


FIGURE 17. Hourly electricity cost with CPP tariff using proposed ABC algorithm (spring SH).

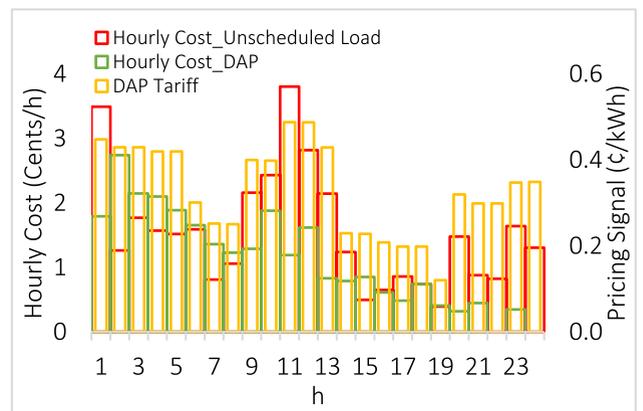


FIGURE 19. Hourly electricity cost with DAP tariff using proposed ABC algorithm (spring SH).

load are 31.67 cents/h (at 12:00 hour) and 13.16 cents/h (at 08:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 9.20 cents/h and 5.44 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 220.76 cents/h and 130.52 cents/h, respectively. For SH spring load with CPP tariff, average daily cost is reduced by 40.9% with the proposed ABC scheduling.

Fig. 18 shows the hourly electricity cost of spring SH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 7.69 cents/h (at 14:00 hour) and 2.76 cents/h (at 14:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 2.12 cents/h and 1.14 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 50.91 cents/h and 27.44 cents/h, respectively. For SH spring load with TOU tariff, average daily cost is reduced by 46.1% with the proposed ABC scheduling.

Fig. 19 shows the hourly electricity cost of spring SH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 3.80 cents/h (at 11:00 hour) and 2.74 cents/h

(at 02:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 1.54 cents/h and 1.11 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 36.93 cents/h and 26.73 cents/h, respectively. For SH spring load with DAP tariff, average daily cost is reduced by 27.6% with the proposed ABC scheduling.

### C. SUMMER SH

#### 1) LOAD SCHEDULING

Fig. 20 shows the hourly load scheduling of summer SH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 129.36 kWh/day. The unscheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour) and 10.10 kW (at 05:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 5.39 kW. The PAR for unscheduled and ABC scheduled load are 1.87 and 1.87, respectively. For SH summer load with RTEP tariff, PAR is same for both unscheduled and proposed ABC scheduling.

Fig. 21 shows the hourly load scheduling of summer SH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled

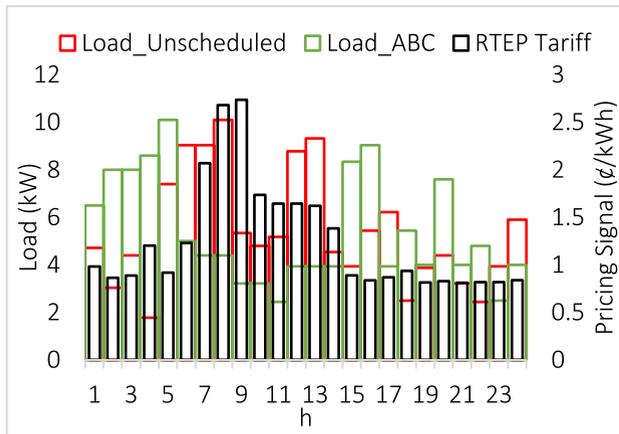


FIGURE 20. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (summer SH).

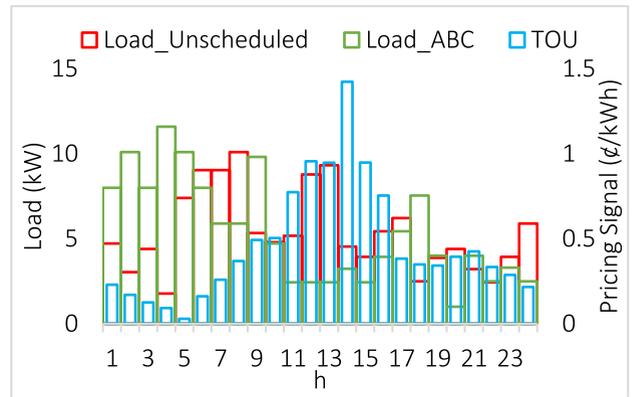


FIGURE 22. Hourly load scheduling with TOU tariff using proposed ABC algorithm (Summer SH).

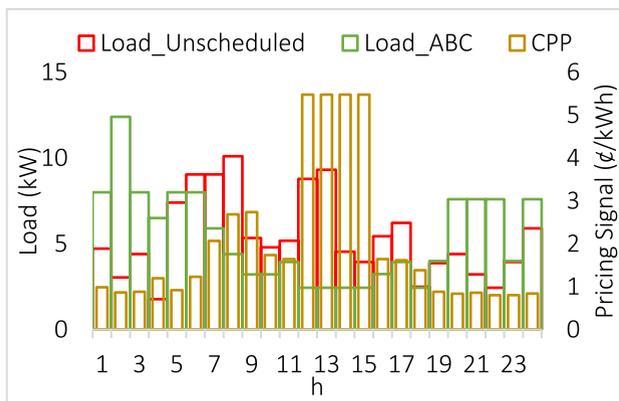


FIGURE 21. Hourly load scheduling with CPP tariff using proposed ABC algorithm (summer SH).

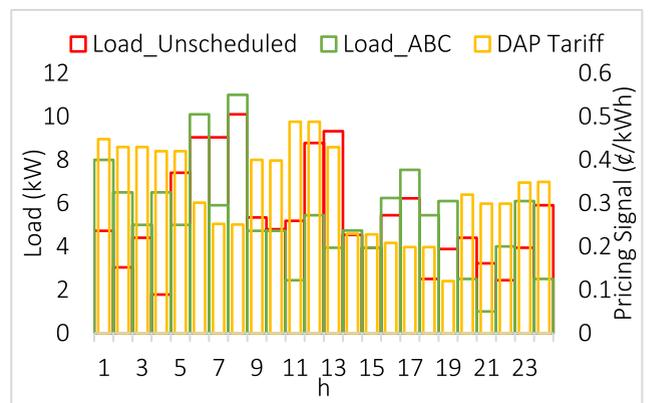


FIGURE 23. Hourly load scheduling with DAP tariff using proposed ABC algorithm (summer SH).

load is 129.36 kWh/day. The unscheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour) and 12.40 kW (at 02:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 5.39 kW. The PAR for unscheduled and ABC scheduled load are 1.87 and 2.30, respectively. For SH summer load with CPP tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 22 shows the hourly load scheduling of summer SH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 129.36 kWh/day. The unscheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour) and 11.60 kW (at 04:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 5.39 kW. The PAR for unscheduled and ABC scheduled load are 1.87 and 2.15, respectively. For SH summer load with TOU tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 23 shows the hourly load scheduling of summer SH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 129.36 kWh/day. The unscheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour) and 11.00 kW

(at 08:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 5.39 kW. The PAR for unscheduled and ABC scheduled load are 1.87 and 2.04, respectively. For SH summer load with DAP tariff, PAR is not minimized with the proposed ABC scheduling.

## 2) ELECTRICITY COST

Fig. 24 shows the hourly electricity cost of summer SH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 27.07 cents/h (at 08:00 hour) and 11.79 cents/h (at 08:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 7.49 cents/h and 6.23 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 179.78 cents/h and 149.53 cents/h, respectively. For SH summer load with RTEP tariff, average daily cost is reduced by 16.8% with the proposed ABC scheduling.

Fig. 25 shows the hourly electricity cost of summer SH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 51.07 cents/h (at 13:00 hour) and 13.37 cents/h (at 12:00-15:00 hour), respectively. The average value of

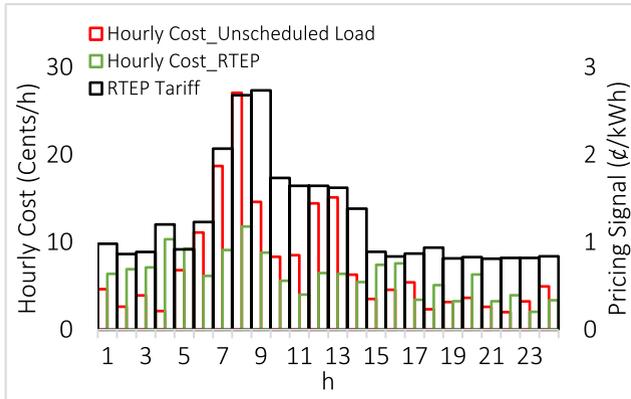


FIGURE 24. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (summer SH).

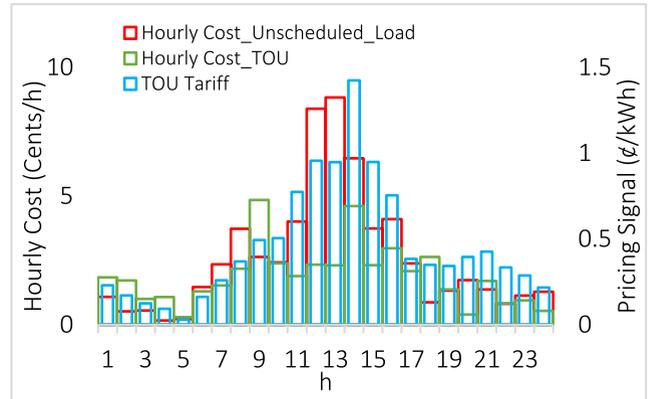


FIGURE 26. Hourly electricity cost with TOU tariff using proposed ABC algorithm (summer SH).

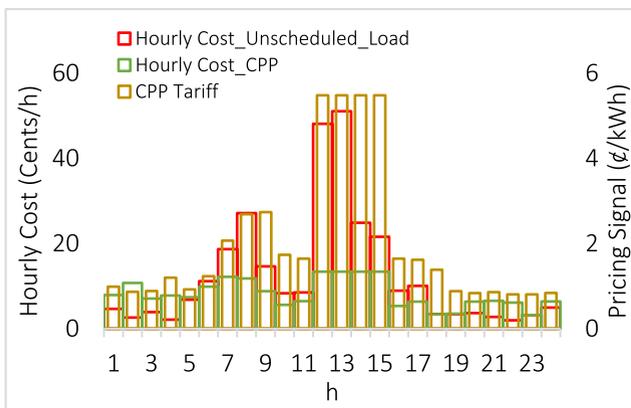


FIGURE 25. Hourly electricity cost with CPP tariff using proposed ABC algorithm (summer SH).

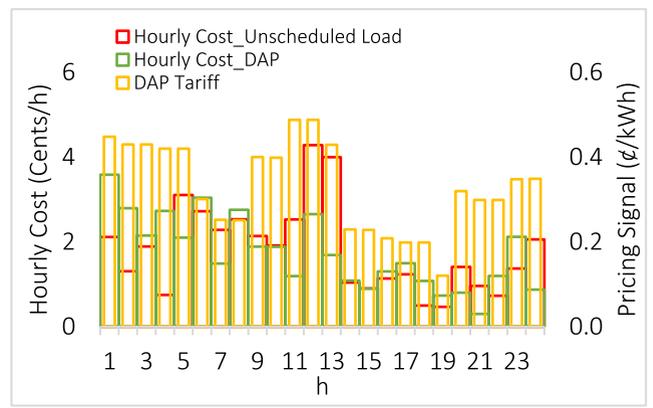


FIGURE 27. Hourly electricity cost with DAP tariff using proposed ABC algorithm (summer SH).

energy cost for unscheduled and ABC scheduled load are 12.36 cents/h and 8.18 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 296.70 cents/h and 196.39 cents/h, respectively. For SH summer load with CPP tariff, average daily cost is reduced by 33.8% with the proposed ABC scheduling.

Fig. 26 shows the hourly electricity cost of summer SH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 8.83 cents/h (at 13:00 hour) and 4.84 cents/h (at 09:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 2.57 cents/h and 1.88 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 61.60 cents/h and 45.13 cents/h, respectively. For SH summer load with TOU tariff, average daily cost is reduced by 26.7% with the proposed ABC scheduling.

Fig. 27 shows the hourly electricity cost of summer SH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 4.28 cents/h (at 12:00 hour) and 3.58 cents/h (at 01:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 1.81 cents/h and

1.74 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 43.35 cents/h and 41.82 cents/h, respectively. For SH summer load with DAP tariff, average daily cost is reduced by 3.5% with the proposed ABC scheduling.

#### D. FALL SH

##### 1) LOAD SCHEDULING

Fig. 28 shows the hourly load scheduling of fall SH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 170.51 kWh/day. The unscheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour) and 20.45 kW (at 01:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 7.10 kW. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.88, respectively. For SH fall load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 29 shows the hourly load scheduling of fall SH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 170.51 kWh/day. The unscheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour) and 16.05 kW

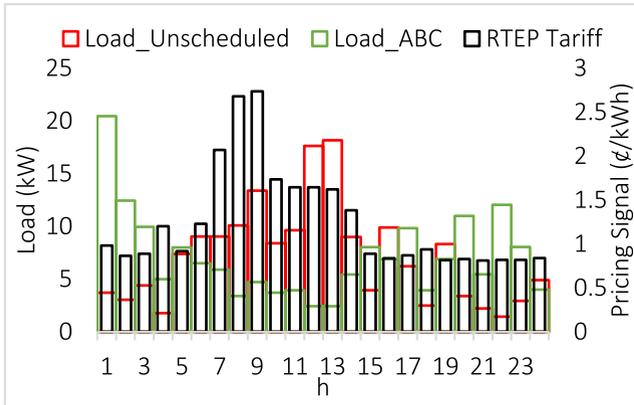


FIGURE 28. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (fall SH).

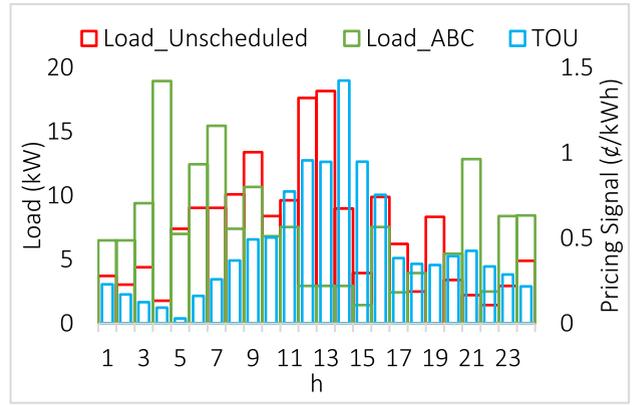


FIGURE 30. Hourly load scheduling with TOU tariff using proposed ABC algorithm (fall SH).

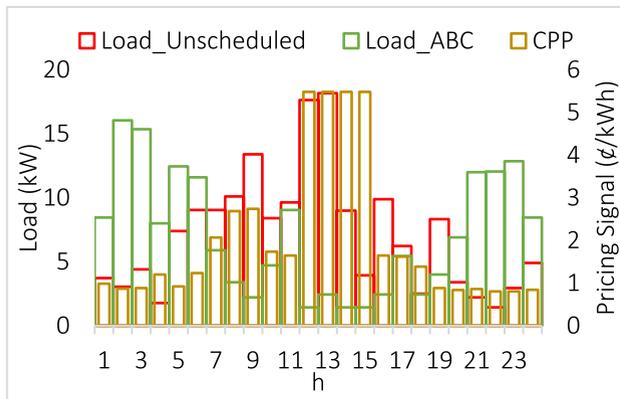


FIGURE 29. Hourly load scheduling with CPP tariff using proposed ABC algorithm (fall SH).

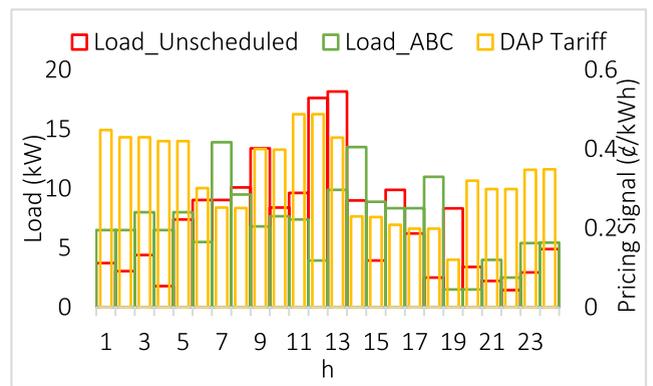


FIGURE 31. Hourly load scheduling with DAP tariff using proposed ABC algorithm (fall SH).

(at 02:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 7.10 kW. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.26, respectively. For SH fall load with CPP tariff, PAR is minimized with the proposed ABC scheduling.

Fig. 30 shows the hourly load scheduling of fall SH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 170.51 kWh/day. The unscheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour) and 18.95 kW (at 04:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 7.10 kW. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.67, respectively. For SH fall load with TOU tariff, PAR is not minimized with the proposed ABC scheduling.

Fig. 31 shows the hourly load scheduling of fall SH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load is 170.51 kWh/day. The unscheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour) and 13.90 kW (at 07:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 7.10 kW. The PAR for unscheduled and ABC scheduled load are 2.56 and 1.96, respectively.

For SH fall load with TOU tariff, PAR is minimized with the proposed ABC scheduling.

## 2) ELECTRICITY COST

Fig. 32 shows the hourly electricity cost of fall SH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 36.64 cents/h (at 09:00 hour) and 20.10 cents/h (at 01:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 10.53 cents/h and 7.83 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 252.71 cents/h and 187.96 cents/h, respectively. For SH fall load with RTEP tariff, average daily cost is reduced by 25.6% with the proposed ABC scheduling.

Fig. 33 shows the hourly electricity cost of fall SH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 99.57 cents/h (at 13:00 hour) and 14.87 cents/h (at 11:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 19.16 cents/h and 9.24 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 459.81 cents/h and

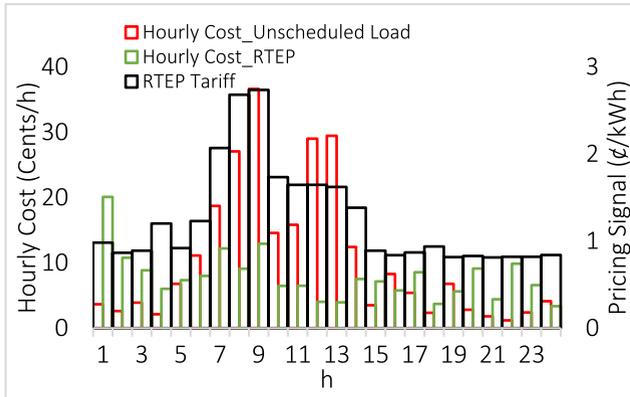


FIGURE 32. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (fall SH).

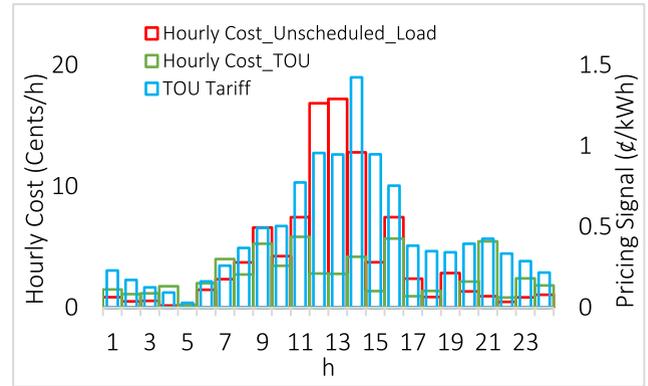


FIGURE 34. Hourly electricity cost with TOU tariff using proposed ABC algorithm (fall SH).

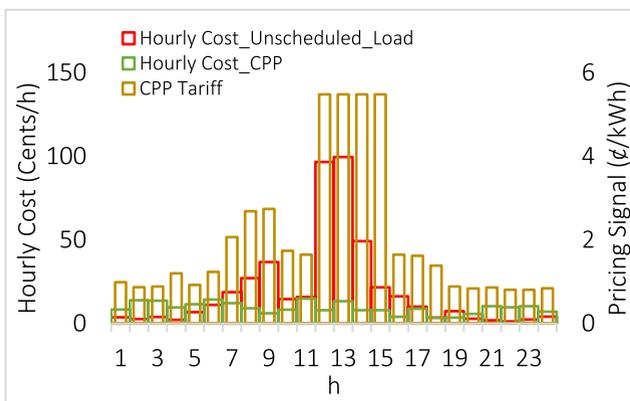


FIGURE 33. Hourly electricity cost with CPP tariff using proposed ABC algorithm (fall SH).

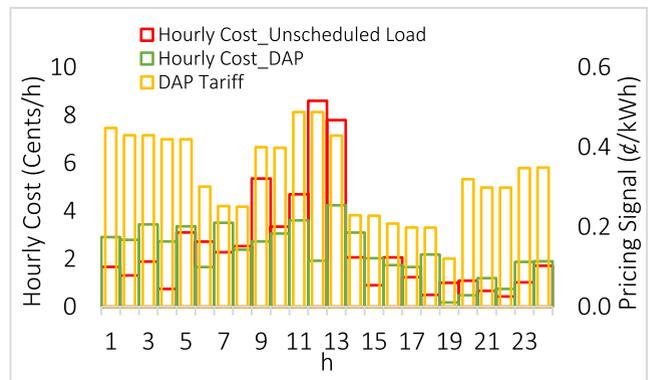


FIGURE 35. Hourly electricity cost with DAP tariff using proposed ABC algorithm (fall SH).

221.71 cents/h, respectively. For SH fall load with CPP tariff, average daily cost is reduced by 51.8% with the proposed ABC scheduling.

Fig. 34 shows the hourly electricity cost of fall SH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 17.21 cents/h (at 13:00 hour) and 5.83 cents/h (at 11:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 4.04 cents/h and 2.54 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 97.00 cents/h and 60.91 cents/h, respectively. For SH fall load with TOU tariff, average daily cost is reduced by 37.2% with the proposed ABC scheduling.

Fig. 35 shows the hourly electricity cost of fall SH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 8.60 cents/h (at 12:00 hour) and 4.24 cents/h (at 13:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 2.45 cents/h and 2.31 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 58.71 cents/h and 55.40 cents/h, respectively. For SH fall load with DAP tariff, average daily cost is reduced by 5.6% with the proposed ABC scheduling.

### E. WINTER MH

#### 1) LOAD SCHEDULING

Fig. 36 shows the hourly load scheduling of winter MH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6448.00 kWh/day and 5135.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour) and 567.50 kW (at 19:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 268.67 kW and 213.98 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.65, respectively. For MH winter load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 37 shows the hourly load scheduling of winter MH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6448.00 kWh/day and 5360.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour) and 639.50 kW (at 17:00 hour), respectively. The average value for unscheduled and ABC

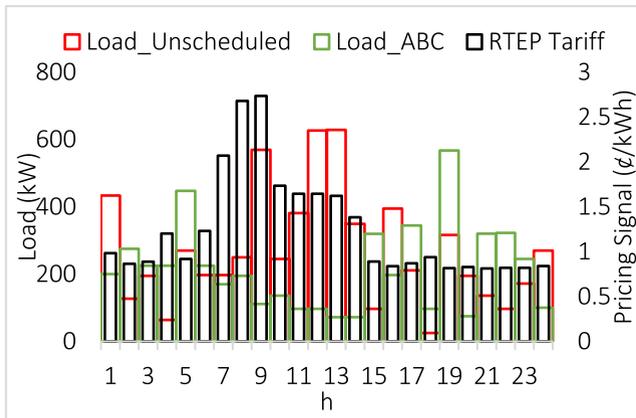


FIGURE 36. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (winter MH).

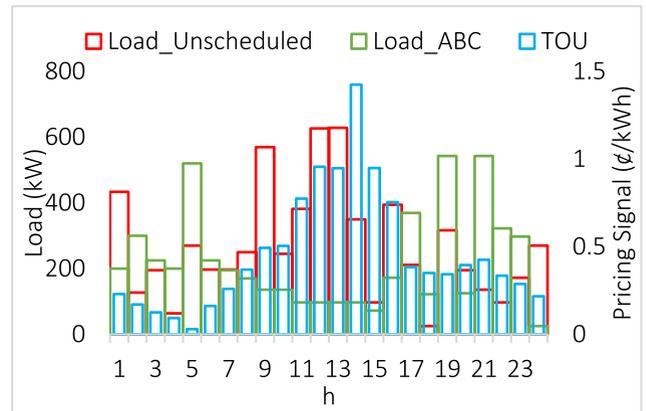


FIGURE 38. Hourly load scheduling with TOU tariff using proposed ABC algorithm (winter MH).

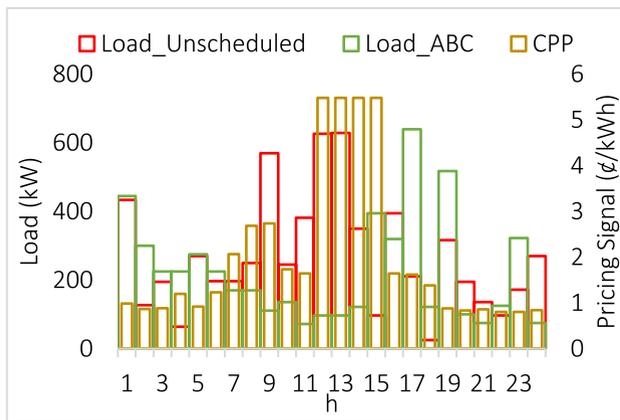


FIGURE 37. Hourly load scheduling with CPP tariff using proposed ABC algorithm (winter MH).

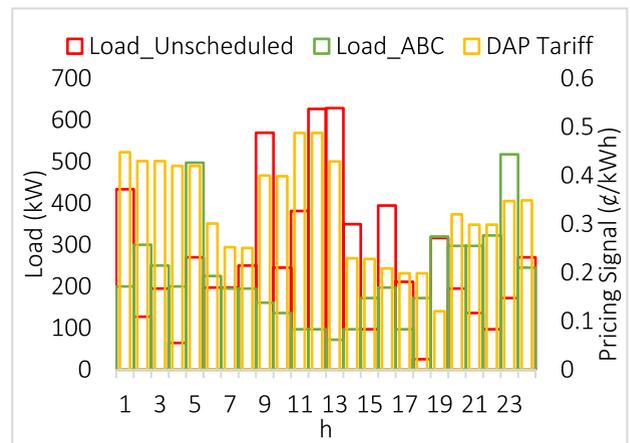


FIGURE 39. Hourly load scheduling with DAP tariff using proposed ABC algorithm (winter MH).

scheduled load are 268.67 kW and 223.35 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.86, respectively. For MH winter load with CPP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 38 shows the hourly load scheduling of winter MH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6448.00 kWh/day and 5285.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour) and 542.50 kW (at 19:00 and 21:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 268.67 kW and 220.23 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.46, respectively. For MH winter load with TOU tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 39 shows the hourly load scheduling of winter MH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6448.00 kWh/day and 5360.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour) and 517.50 kW (at 23:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 268.67 kW and 223.35 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.34 and 2.32, respectively. For MH winter load with DAP tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

## 2) ELECTRICITY COST

Fig. 40 shows the hourly electricity cost of winter MH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 1558.30 cents/h (at 09:00 hour) and 522.72 cents/h (at 08:00 hour), respectively. The average value of energy cost

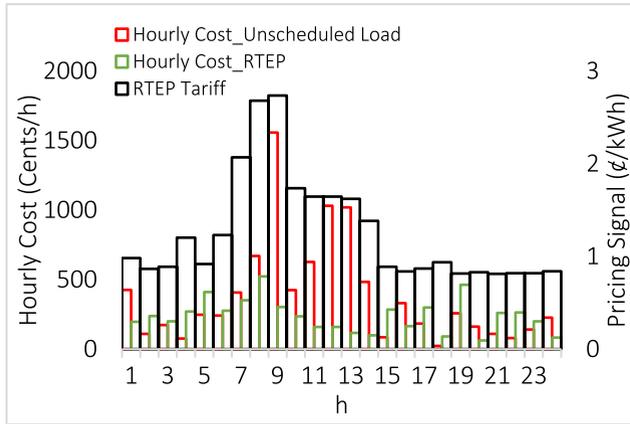


FIGURE 40. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (winter MH).

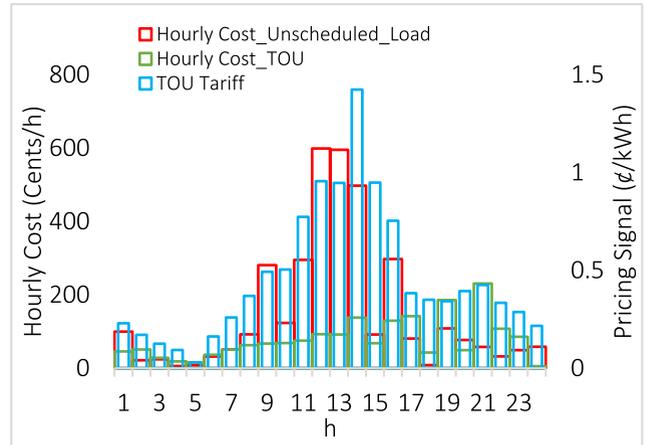


FIGURE 42. Hourly electricity cost with TOU tariff using proposed ABC algorithm (winter MH).

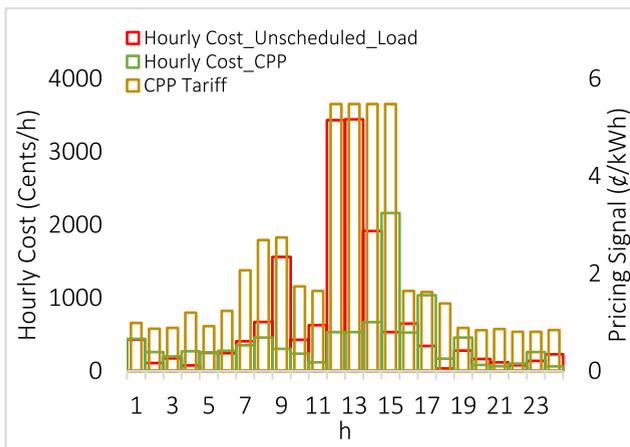


FIGURE 41. Hourly electricity cost with CPP tariff using proposed ABC algorithm (winter MH).

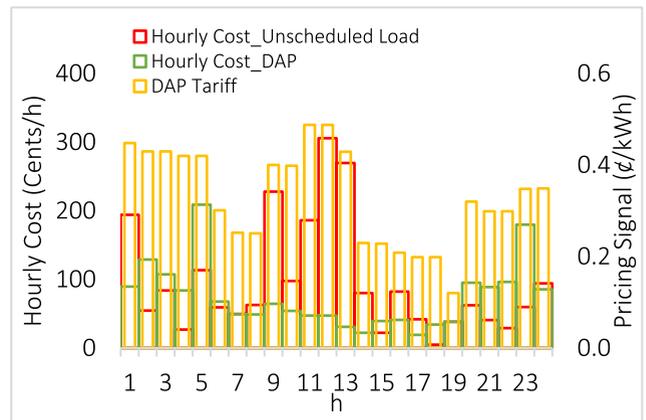


FIGURE 43. Hourly electricity cost with DAP tariff using proposed ABC algorithm (winter MH).

for unscheduled and ABC scheduled load are 379.23 cents/h and 238.23 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 9101.58 cents/h and 5717.52 cents/h, respectively. For MH winter load with RTEP tariff, average daily cost is reduced by 37.2% with the proposed ABC scheduling.

Fig. 41 shows the hourly electricity cost of winter MH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 3444.20 cents/h (at 13:00 hour) and 2161.90 cents/h (at 15:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 680.11 cents/h and 409.05 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 16322.77 cents/h and 9817.23 cents/h, respectively. For MH winter load with CPP tariff, average daily cost is reduced by 39.8% with the proposed ABC scheduling.

Fig. 42 shows the hourly electricity cost of winter MH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 598.83 cents/h (at 12:00 hour) and 230.97 cents/h (at 21:00 hour), respectively. The average value of energy cost

for unscheduled and ABC scheduled load are 149.58 cents/h and 78.75 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 3589.89 cents/h and 1890.05 cents/h, respectively. For MH winter load with TOU tariff, average daily cost is reduced by 47.3% with the proposed ABC scheduling.

Fig. 43 shows the hourly electricity cost of winter MH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 305.54 cents/h (at 12:00 hour) and 208.80 cents/h (at 05:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 95.27 cents/h and 73.70 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 2286.47 cents/h and 1768.70 cents/h, respectively. For MH winter load with DAP tariff, average daily cost is reduced by 22.7% with the proposed ABC scheduling.

### F. SPRING MH

#### 1) LOAD SCHEDULING

Fig. 44 shows the hourly load scheduling of spring MH with RTEP tariff by using proposed ABC algorithm. Scaled

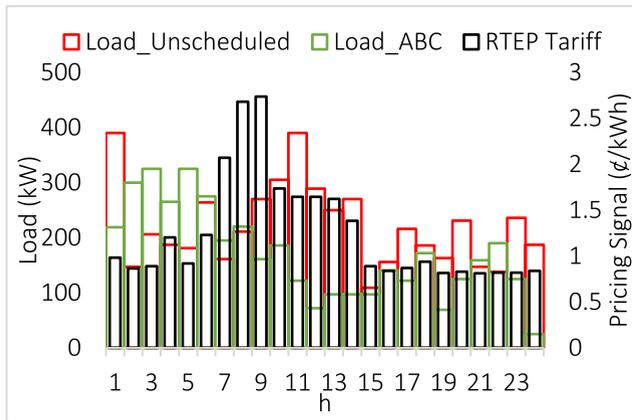


FIGURE 44. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (spring MH).

annual average energy for unscheduled and ABC scheduled load are 5290.00 kWh/day and 4084.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour) and 325.00 kW (at 03:00, 05:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 220.42 kW and 170.17 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 1.91, respectively. For MH spring load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 45 shows the hourly load scheduling of spring MH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 5290.00 kWh/day and 4084.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour) and 350.00 kW (at 03:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 220.42 kW and 170.17 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 2.06, respectively. For MH spring load with CPP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 46 shows the hourly load scheduling of spring MH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 5290.00 kWh/day and 4084.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour) and 315.00 kW (at 01:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 220.42 kW and 170.17 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 1.85, respectively. For MH spring load

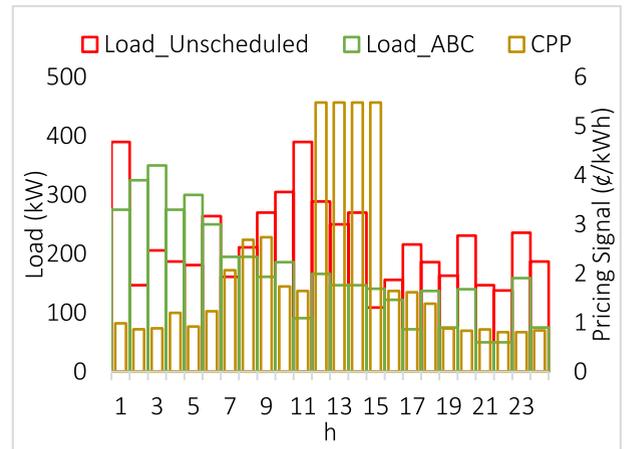


FIGURE 45. Hourly load scheduling with CPP tariff using proposed ABC algorithm (spring MH).

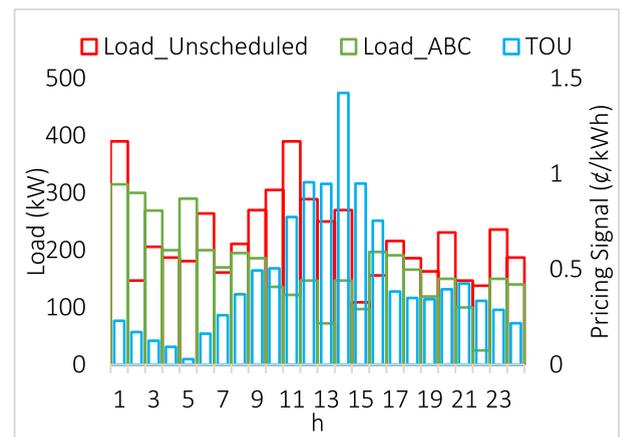


FIGURE 46. Hourly load scheduling with TOU tariff using proposed ABC algorithm (spring MH).

with TOU tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 47 shows the hourly load scheduling of spring MH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 5290.00 kWh/day and 4034.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour) and 300.00 kW (at 02:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 220.42 kW and 168.08 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.77 and 1.78, respectively. For MH spring load with DAP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

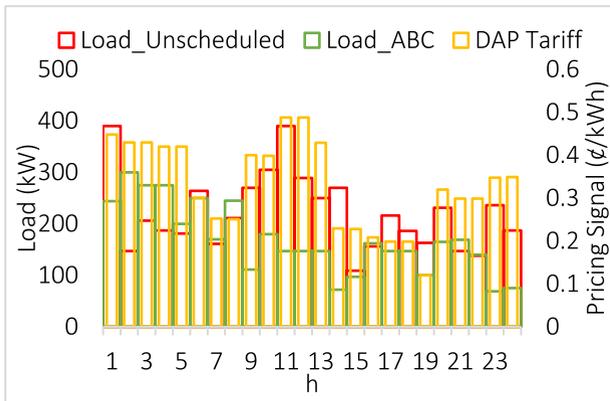


FIGURE 47. Hourly load scheduling with DAP tariff using proposed ABC algorithm (spring MH).

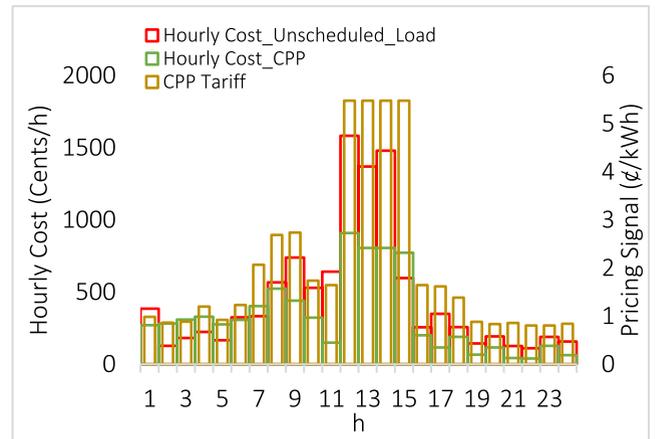


FIGURE 49. Hourly electricity cost with CPP tariff using proposed ABC algorithm (spring MH).

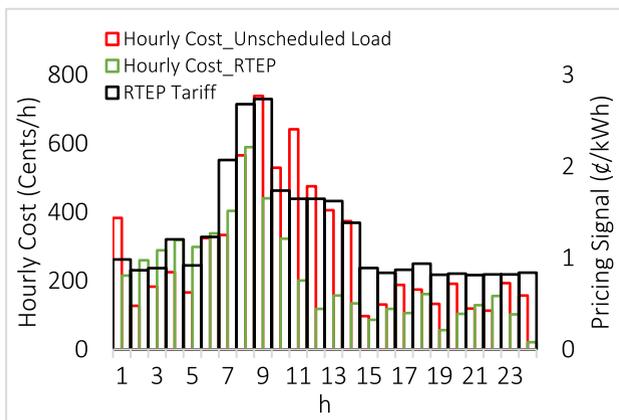


FIGURE 48. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (spring MH).

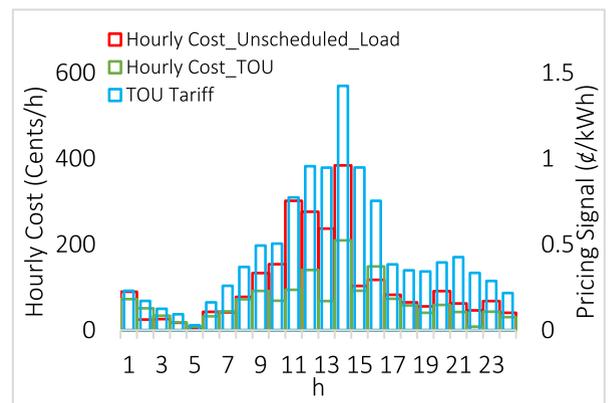


FIGURE 50. Hourly electricity cost with TOU tariff using proposed ABC algorithm (spring MH).

## 2) ELECTRICITY COST

Fig. 48 shows the hourly electricity cost of spring MH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 738.77 cents/h (at 09:00 hour) and 589.73 cents/h (at 08:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 290.45 cents/h and 213.64 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 6970.81 cents/h and 5127.31 cents/h, respectively. For MH spring load with RTEP tariff, average daily cost is reduced by 26.4% with the proposed ABC scheduling.

Fig. 49 shows the hourly electricity cost of spring MH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 1583.70 cents/h (at 12:00 hour) and 909.68 cents/h (at 12:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 459.91 cents/h and 328.16 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 11037.87 cents/h and 7875.76 cents/h, respectively. For MH spring load with

CPP tariff, average daily cost is reduced by 28.6% with the proposed ABC scheduling.

Fig. 50 shows the hourly electricity cost of spring MH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 384.44 cents/h (at 14:00 hour) and 209.31 cents/h (at 14:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 106.06 cents/h and 66.76 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 2545.43 cents/h and 1602.25 cents/h, respectively. For MH spring load with TOU tariff, average daily cost is reduced by 37.1% with the proposed ABC scheduling.

Fig. 51 shows the hourly electricity cost of spring MH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 190.24 cents/h (at 11:00 hour) and 128.91 cents/h (at 02:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 76.95 cents/h and 58.16 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 1846.80 cents/h and 1395.93 cents/h, respectively. For MH spring load with

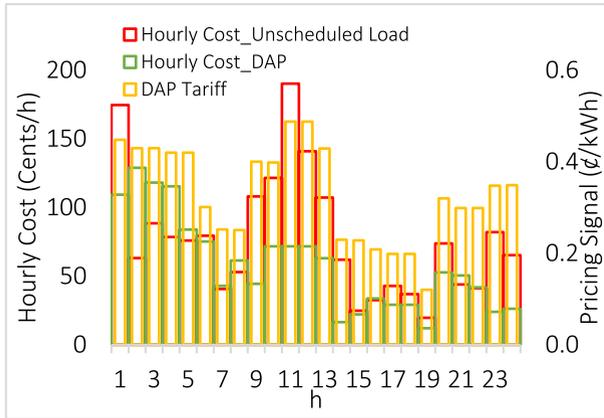


FIGURE 51. Hourly electricity cost with DAP tariff using proposed ABC algorithm (spring MH).

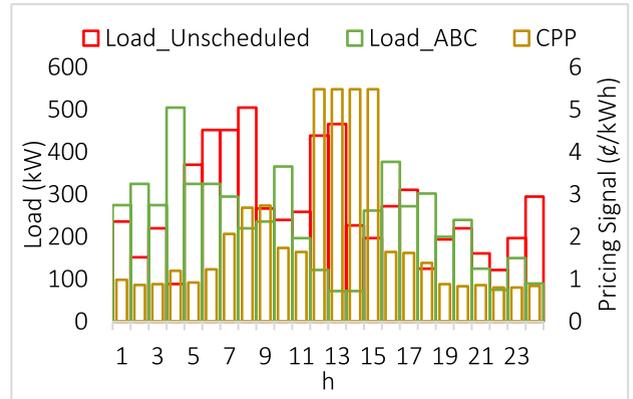


FIGURE 53. Hourly load scheduling with CPP tariff using proposed ABC algorithm (summer MH).

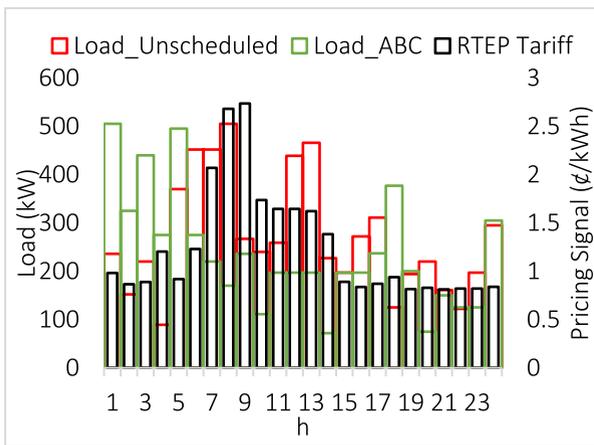


FIGURE 52. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (summer MH).

DAP tariff, average daily cost is reduced by 24.4% with the proposed ABC scheduling.

G. SUMMER MH

1) LOAD SCHEDULING

Fig. 52 shows the hourly load scheduling of summer MH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6468.00 kWh/day and 5703.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour) and 505.00 kW (at 01:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 269.50 kW and 237.62 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.87 and 2.12, respectively. For MH summer load with RTEP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 53 shows the hourly load scheduling of summer MH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6468.00 kWh/day and 5703.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour) and 505.00 kW (at 04:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 269.50 kW and 237.62 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.87 and 2.12, respectively. For MH summer load with CPP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 54 shows the hourly load scheduling of summer MH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6468.00 kWh/day and 5553.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour) and 400.00 kW (at 05:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 269.50 kW and 231.37 kW, respectively. The PAR for unscheduled and ABC scheduled load are 1.87 and 1.73, respectively. For MH summer load with TOU tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 55 shows the hourly load scheduling of summer MH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 6468.00 kWh/day and 5553.00 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour) and 545.00 kW (at 01:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 269.50 kW and 231.37 kW, respectively. The PAR for unscheduled and ABC scheduled load are

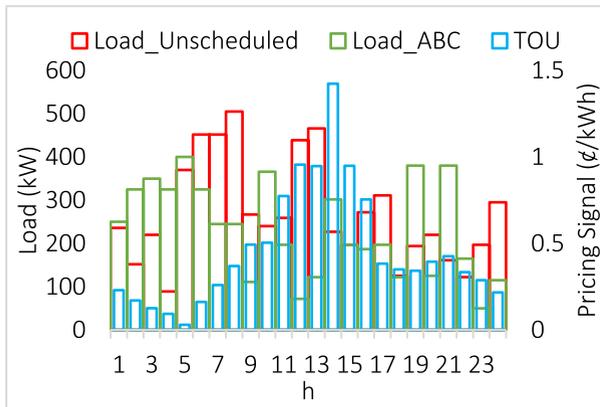


FIGURE 54. Hourly load scheduling with TOU tariff using proposed ABC algorithm (summer MH).

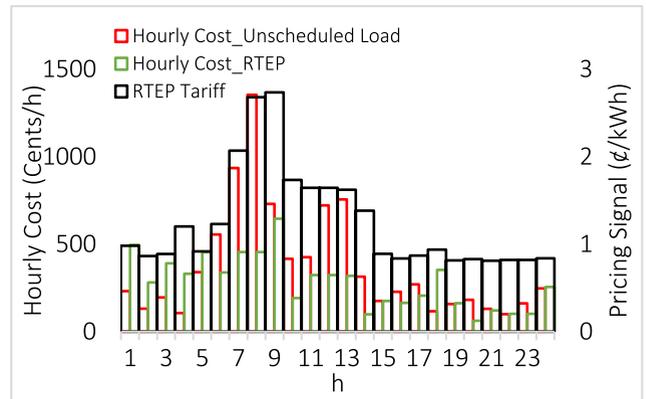


FIGURE 56. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (summer MH).

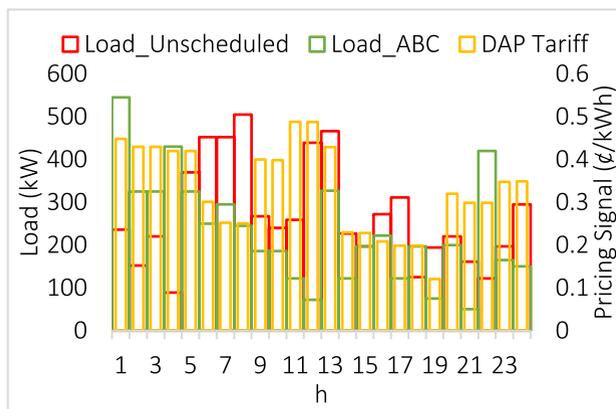


FIGURE 55. Hourly load scheduling with DAP tariff using proposed ABC algorithm (summer MH).

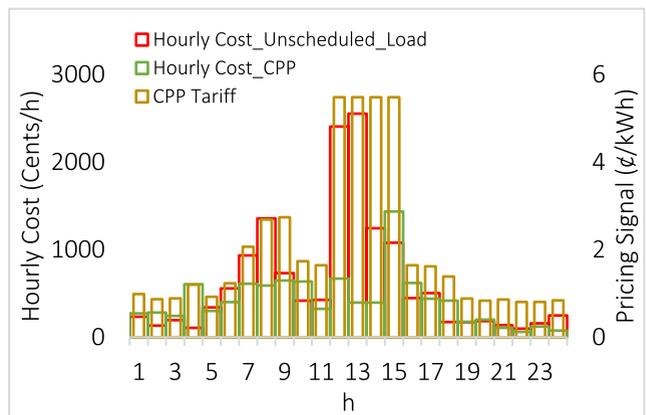


FIGURE 57. Hourly electricity cost with CPP Tariff using proposed ABC algorithm (summer MH).

1.87 and 2.35, respectively. For MH summer load with DAP tariff, PAR is not minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

## 2) ELECTRICITY COST

Fig. 56 shows the hourly electricity cost of summer MH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 1353.70 cents/h (at 08:00 hour) and 645.74 cents/h (at 10:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 374.54 cents/h and 284.09 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 8988.95 cents/h and 6818.10 cents/h, respectively. For MH summer load with RTEP tariff, average daily cost is reduced by 24.1% with the proposed ABC scheduling.

Fig. 57 shows the hourly electricity cost of summer MH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled

load are 2553.70 cents/h (at 13:00 hour) and 1435.80 cents/h (at 15:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 618.12 cents/h and 417.61 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 14834.98 cents/h and 10022.56 cents/h, respectively. For MH summer load with CPP tariff, average daily cost is reduced by 32.4% with the proposed ABC scheduling.

Fig. 58 shows the hourly electricity cost of summer MH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 441.47 cents/h (at 13:00 hour) and 430.01 cents/h (at 14:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 128.33 cents/h and 95.58 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 3080.02 cents/h and 2293.92 cents/h, respectively. For MH summer load with TOU tariff, average daily cost is reduced by 25.5% with the proposed ABC scheduling.

Fig. 59 shows the hourly electricity cost of summer MH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled

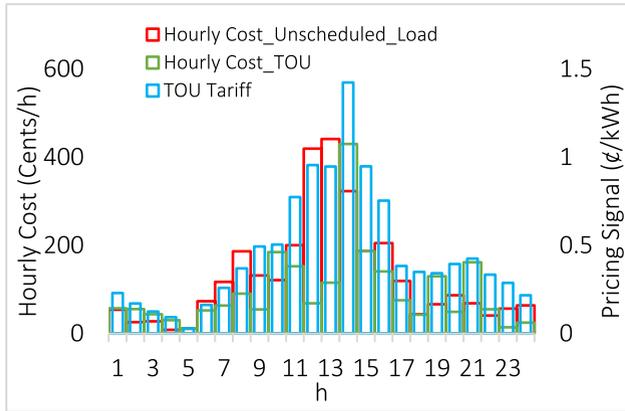


FIGURE 58. Hourly electricity cost with TOU tariff using proposed ABC algorithm (summer MH).

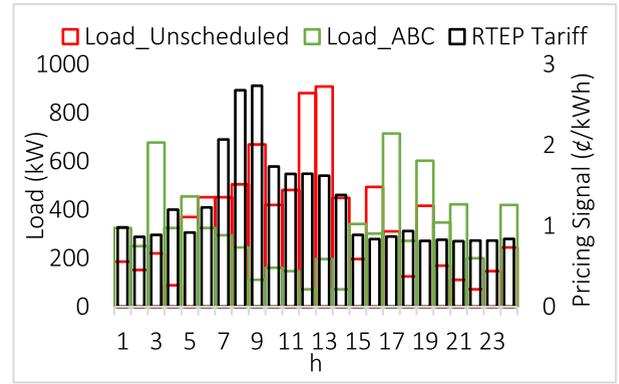


FIGURE 60. Hourly load scheduling with RTEP tariff using proposed ABC algorithm (fall MH).

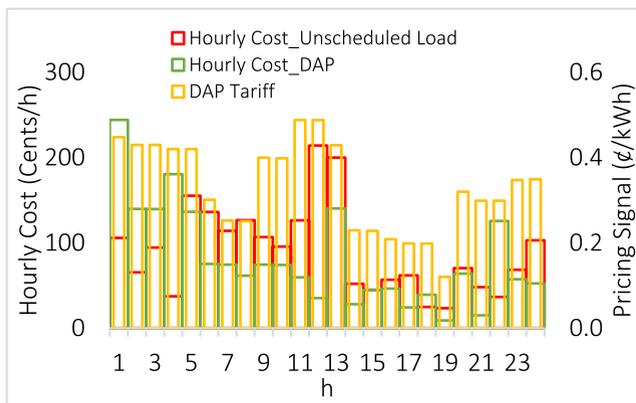


FIGURE 59. Hourly electricity cost with DAP tariff using proposed ABC algorithm (summer MH).

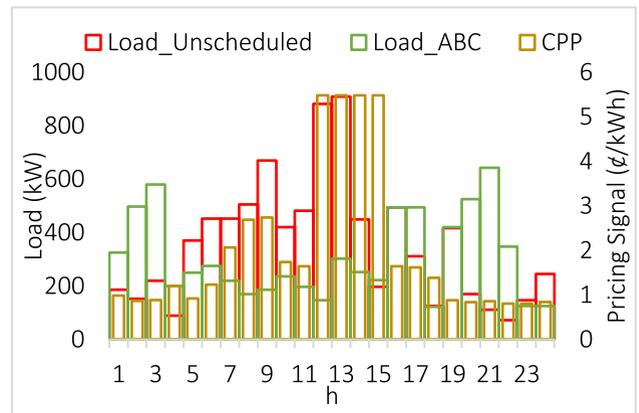


FIGURE 61. Hourly load scheduling with CPP tariff using proposed ABC algorithm (fall MH).

load are 214.10 cents/h (at 12:00 hour) and 244.11 cents/h (at 01:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 90.31 cents/h and 80.85 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 2167.55 cents/h and 1940.41 cents/h, respectively. For MH summer load with DAP tariff, average daily cost is reduced by 10.5% with the proposed ABC scheduling.

### H. FALL MH

#### 1) LOAD SCHEDULING

Fig. 60 shows the hourly load scheduling of fall MH with RTEP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 8525.50 kWh/day and 7280.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour) and 714.50 kW (at 17:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 355.23 kW and 303.35 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.35, respectively. For MH fall load with RTEP tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled

annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 61 shows the hourly load scheduling of fall MH with CPP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 8525.50 kWh/day and 7355.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour) and 642.50 kW (at 21:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 355.23 kW and 306.48 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.10, respectively. For MH fall load with CPP tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 62 shows the hourly load scheduling of fall MH with TOU tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 8525.50 kWh/day and 7355.50 kWh/day, respectively. The

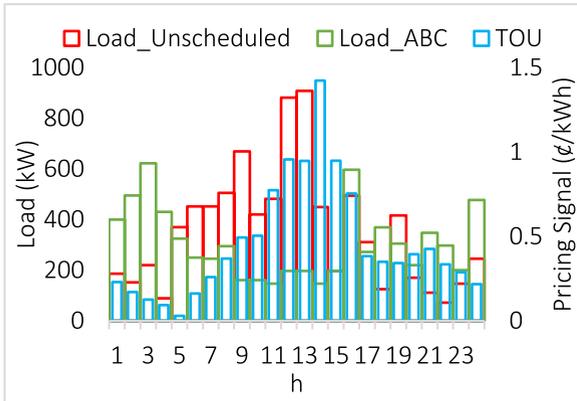


FIGURE 62. Hourly load scheduling with TOU tariff using proposed ABC algorithm (fall MH).

unscheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour) and 622.50 kW (at 03:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 355.23 kW and 306.48 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.03, respectively. For MH fall load with TOU tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

Fig. 63 shows the hourly load scheduling of fall MH with DAP tariff by using proposed ABC algorithm. Scaled annual average energy for unscheduled and ABC scheduled load are 8525.50 kWh/day and 7355.50 kWh/day, respectively. The unscheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour) and 672.00 kW (at 16:00 hour), respectively. The average value for unscheduled and ABC scheduled load are 355.23 kW and 306.48 kW, respectively. The PAR for unscheduled and ABC scheduled load are 2.56 and 2.19, respectively. For MH fall load with DAP tariff, PAR is minimized with the proposed ABC scheduling. Moreover, scaled annual average energy for unscheduled and ABC scheduled load are not same despite repeated simulations. The average value for unscheduled and ABC scheduled load are also not same.

2) ELECTRICITY COST

Fig. 64 shows the hourly electricity cost of fall MH with RTEP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 1831.90 cents/h (at 09:00 hour) and 656.75 cents/h (at 08:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 526.48 cents/h and 335.44 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 12635.50 cents/h and 8050.63 cents/h, respectively. For MH fall load with RTEP tariff, average daily cost is reduced by 36.3% with the proposed ABC scheduling.

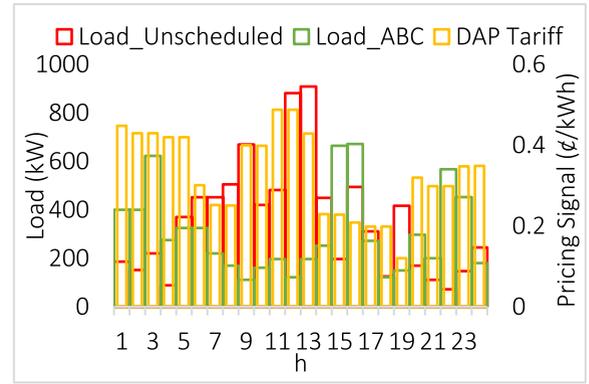


FIGURE 63. Hourly load scheduling with DAP tariff using proposed ABC algorithm (fall MH).

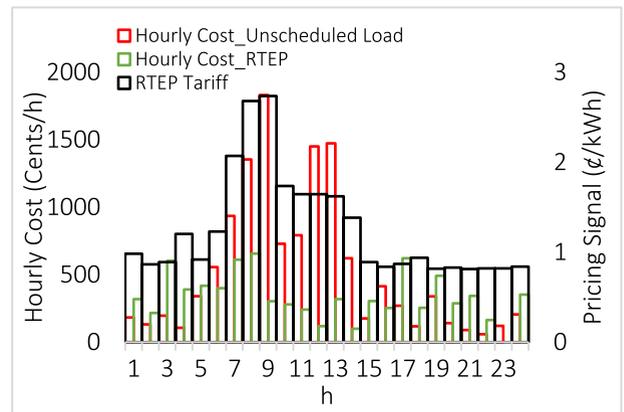


FIGURE 64. Hourly electricity cost with RTEP tariff using proposed ABC algorithm (fall MH).

Fig. 65 shows the hourly electricity cost of fall MH with CPP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 4978.60 cents/h (at 13:00 hour) and 1655.50 cents/h (at 14:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 957.93 cents/h and 538.26 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 22990.43 cents/h and 12918.30 cents/h, respectively. For MH fall load with CPP tariff, average daily cost is reduced by 43.8% with the proposed ABC scheduling.

Fig. 66 shows the hourly electricity cost of fall MH with TOU tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 860.68 cents/h (at 13:00 hour) and 450.28 cents/h (at 16:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 202.09 cents/h and 118.60 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 4850.23 cents/h and 2846.39 cents/h, respectively. For MH fall load with TOU tariff, average daily cost is reduced by 41.3% with the proposed ABC scheduling.

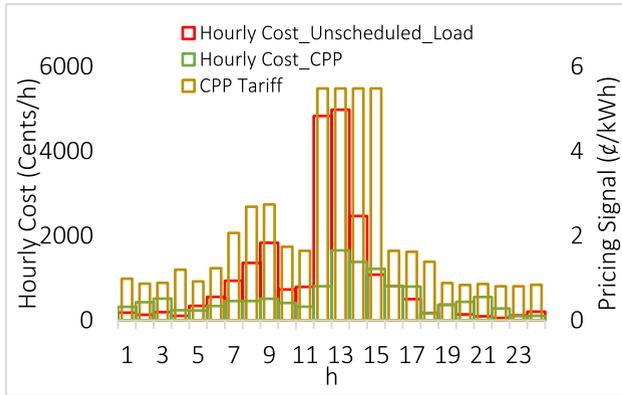


FIGURE 65. Hourly electricity cost with CPP tariff using proposed ABC algorithm (fall MH).

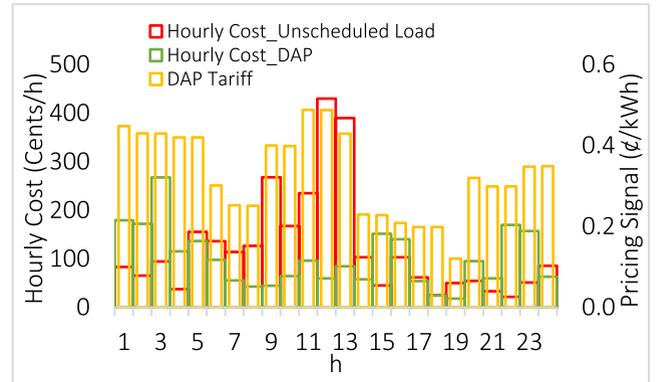


FIGURE 67. Hourly electricity cost with DAP tariff using proposed ABC algorithm (fall MH).

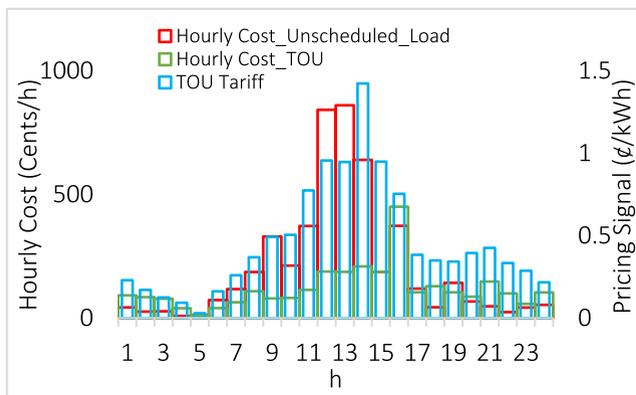


FIGURE 66. Hourly electricity cost with TOU tariff using proposed ABC algorithm (fall MH).

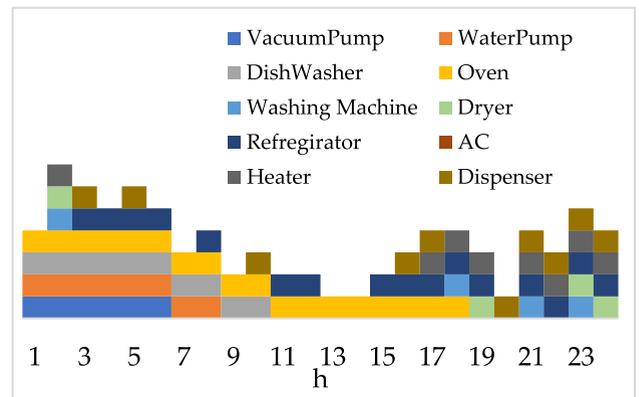


FIGURE 68. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (winter SH).

Fig. 67 shows the hourly electricity cost of fall MH with DAP tariff by using proposed ABC algorithm. The maximum energy cost for the unscheduled and ABC scheduled load are 429.91 cents/h (at 12:00 hour) and 267.43 cents/h (at 03:00 hour), respectively. The average value of energy cost for unscheduled and ABC scheduled load are 122.31 cents/h and 100.21 cents/h, respectively. Average daily cost for unscheduled and ABC scheduled load are 2935.56 cents/h and 2405.10 cents/h, respectively. For MH fall load with DAP tariff, average daily cost is reduced by 18.1% with the proposed ABC scheduling.

### I. APPLIANCES SCHEDULING

#### 1) WINTER SH

Fig. 68 shows the hourly appliances scheduling of winter SH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 18:00 and 21:00. Dryer is ON at 02:00, 19:00, 23:00 and 24:00. Refrigerator is ON at 03:00-06:00, 08:00, 11:00-12:00, 15:00-19:00 and 21:00-24:00. AC is OFF throughout the winter season. Heater is ON at 02:00, 17:00-19:00 and 21:00-24:00.

Dispenser is ON at 03:00, 05:00, 10:00, 16:00-17:00 and 20:00-24:00.

Fig. 69 shows the hourly appliances scheduling of winter SH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 03:00-05:00 and 20:00. Dryer is ON at 19:00-21:00 and 23:00. Refrigerator is ON at 01:00-04:00, 06:00, 10:00, 12:00-18:00, 20:00 and 22:00-23:00. AC is OFF throughout the winter season. Heater is ON at 01:00-04:00, 20:00-22:00 and 24:00. Dispenser is ON at 02:00, 05:00, 11:00, 16:00-19:00, 21:00-22:00 and 24:00.

Fig. 70 shows the hourly appliances scheduling of winter SH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 04:00, 07:00 and 21:00. Dryer is ON at 01:00, 05:00, 07:00 and 24:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is OFF throughout the winter season. Heater is ON at 02:00-07:00, 21:00 and 24:00. Dispenser is ON at 02:00, 04:00-07:00, 10:00, 15:00, 18:00 and 23:00-24:00.

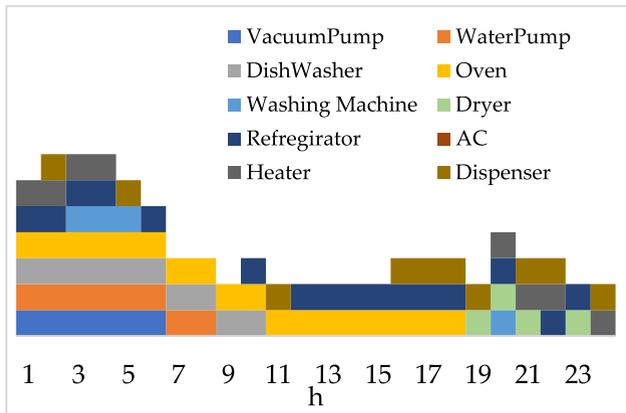


FIGURE 69. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (winter SH).

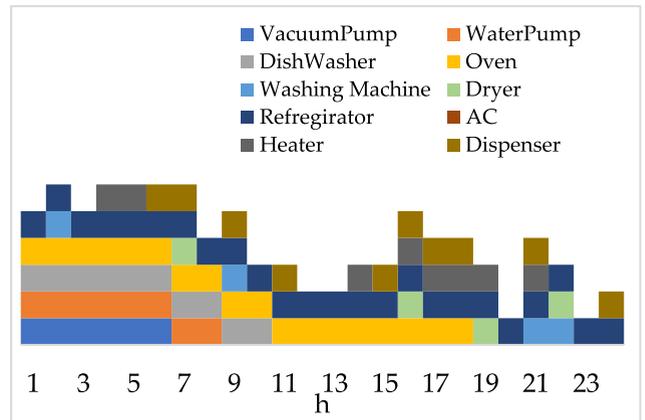


FIGURE 71. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (winter SH).

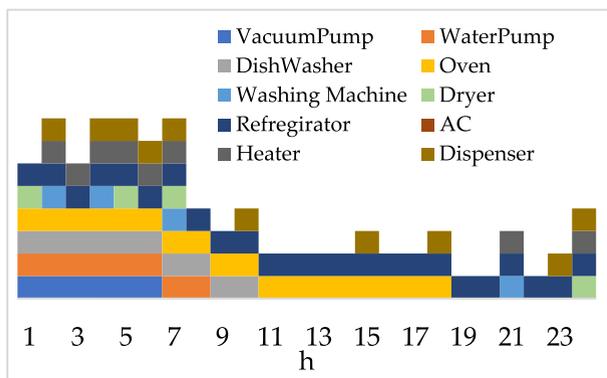


FIGURE 70. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (winter SH).

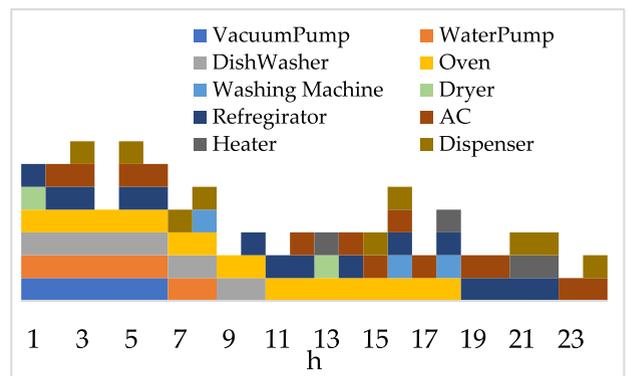


FIGURE 72. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (spring SH).

Fig. 71 shows the hourly appliances scheduling of winter SH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 09:00 and 21:00-22:00. Dryer is ON at 07:00, 16:00, 19:00 and 22:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is OFF throughout the winter season. Heater is ON at 04:00-05:00, 14:00, 16:00-19:00 and 21:00. Dispenser is ON at 06:00-07:00, 09:00, 11:00, 15:00-18:00, 21:00 and 24:00.

2) SPRING SH

Fig. 72 shows the hourly appliances scheduling of spring SH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 08:00, 16:00 and 18:00. Dryer is ON at 01:00 and 13:00. Refrigerator is ON at 01:00-03:00, 05:00-06:00, 10:00-12:00, 14:00, 16:00 and 18:00-22:00. AC is ON at 02:00-03:00, 05:00-06:00, 12:00, 14:00-17:00, 19:00-20:00 and 23:00-24:00. Heater is ON at 13:00, 18:00 and 21:00-22:00. Dispenser is ON at 03:00, 05:00, 07:00-08:00, 15:00-16:00, 21:00-22:00 and 24:00.

Fig. 73 shows the hourly appliances scheduling of spring SH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 17:00, 19:00 and 21:00. Dryer is ON at 01:00 and 06:00. Refrigerator is ON at 01:00-04:00, 06:00-07:00, 09:00, 16:00-22:00 and 24:00. AC is ON at 01:00-02:00, 04:00, 06:00-07:00, 10:00, 16:00 and 18:00-23:00. Heater is ON at 03:00 and 11:00. Dispenser is ON at 01:00, 03:00, 07:00, 11:00-12:00, 16:00, 19:00, 21:00 and 23:00.

Fig. 74 shows the hourly appliances scheduling of spring SH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 04:00, 08:00, 17:00, 19:00, 21:00 and 24:00. Dryer is ON at 05:00 and 24:00. Refrigerator is ON at 04:00, 06:00-08:00, 10:00-12:00, 15:00, 17:00-19:00 and 21:00-24:00. AC is ON at 01:00-02:00, 04:00-05:00, 08:00, 11:00, 16:00-17:00, 20:00 and 22:00-24:00. Heater is ON at 03:00 and 06:00. Dispenser is ON at 02:00-03:00, 05:00-08:00, 14:00, 16:00 and 21:00.

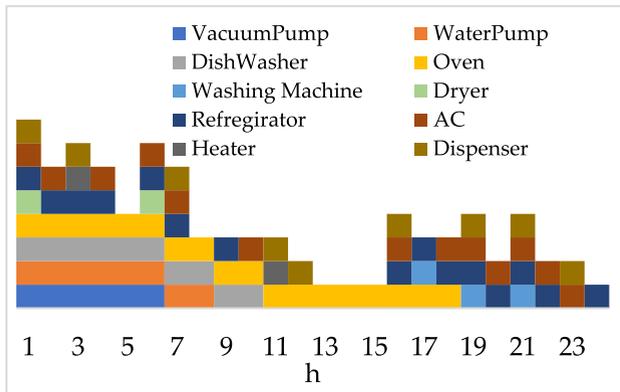


FIGURE 73. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (spring SH).

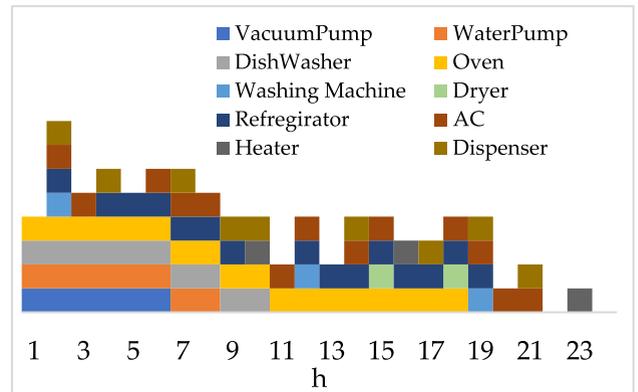


FIGURE 75. Hourly appliances scheduling with DAP Tariff using proposed ABC algorithm (spring SH).

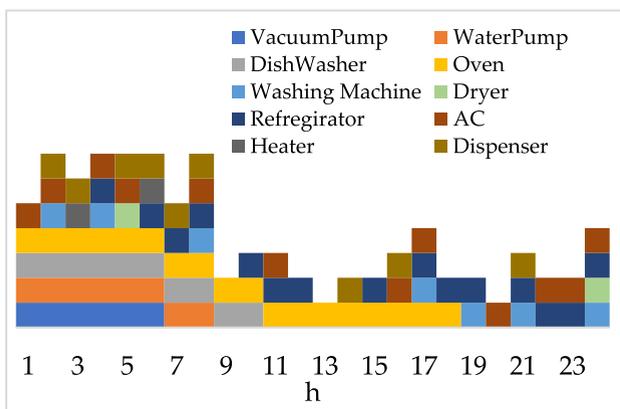


FIGURE 74. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (spring SH).

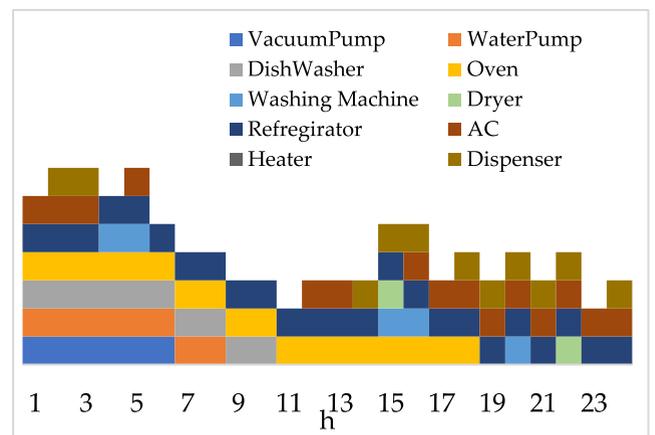


FIGURE 76. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (summer SH).

Fig. 75 shows the hourly appliances scheduling of spring SH with DAP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 12:00 and 19:00. Dryer is ON at 15:00 and 18:00. Refrigerator is ON at 02:00, 04:00-09:00 and 12:00-19:00. AC is ON at 02:00-03:00, 06:00-08:00, 11:00-12:00, 14:00-15:00 and 18:00-21:00. Heater is ON at 10:00, 16:00 and 23:00. Dispenser is ON at 02:00, 04:00, 07:00, 09:00-10:00, 14:00, 17:00, 19:00 and 21:00.

### 3) SUMMER SH

Fig. 76 shows the hourly appliances scheduling of summer SH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 04:00-05:00, 09:00 and 18:00. Dryer is ON at 14:00 and 23:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 01:00-03:00, 05:00, 12:00-13:00 and 16:00-24:00. Heater is OFF throughout summer season. Dispenser is ON at 02:00-03:00, 14:00-16:00, 18:00-22:00 and 24:00.

Fig. 77 shows the hourly appliances scheduling of summer SH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 20:00-22:00 and 24:00. Dryer is ON at 02:00 and 16:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 01:00-07:00, 11:00, 17:00 and 19:00-24:00. Heater is OFF throughout summer season. Dispenser is ON at 01:00-03:00, 05:00-06:00 and 19:00-24:00.

Fig. 78 shows the hourly appliances scheduling of summer SH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 04:00-05:00, 09:00 and 18:00. Dryer is ON at 14:00 and 23:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 01:00-09:00, 17:00-19:00 and 21:00-23:00. Heater is OFF throughout summer season. Dispenser is ON at 01:00, 03:00-04:00, 06:00, 09:00-10:00, 15:00-16:00, 19:00, 21:00 and 24:00.

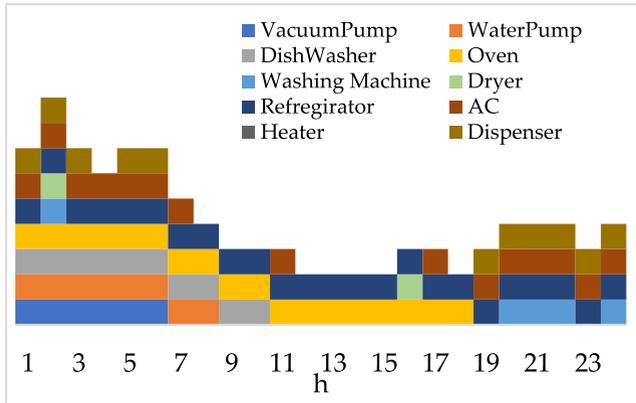


FIGURE 77. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (summer SH).

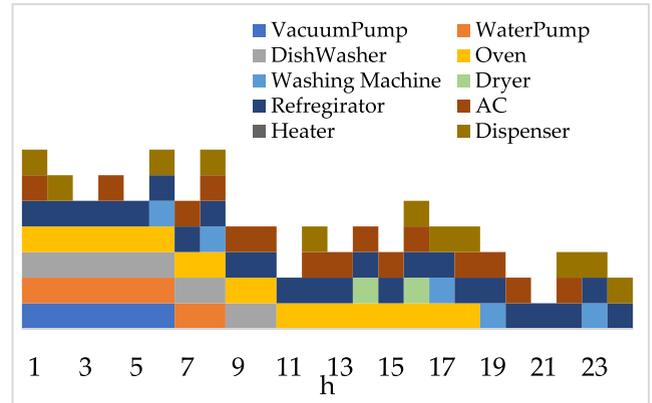


FIGURE 79. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (summer SH).

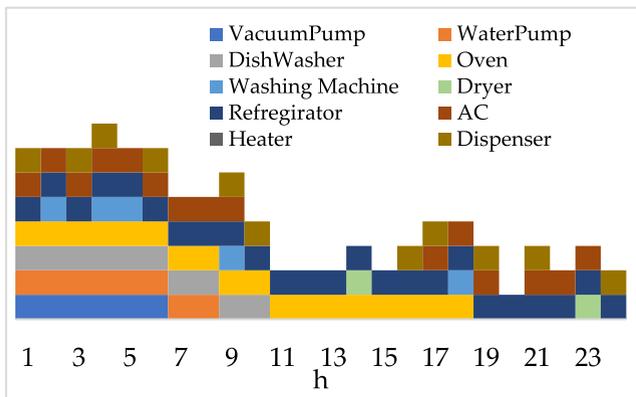


FIGURE 78. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (summer SH).

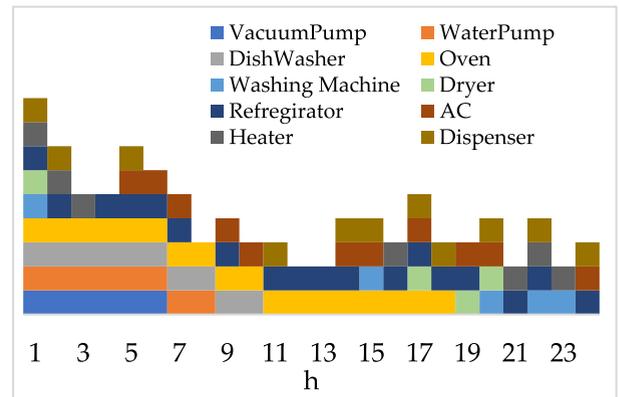


FIGURE 80. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (fall SH).

Fig. 79 shows the hourly appliances scheduling of summer SH with DAP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 06:00, 08:00, 17:00, 19:00 and 23:00. Dryer is ON at 14:00 and 16:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 01:00, 04:00, 07:00-10:00, 12:00-16:00, 18:00-20:00 and 22:00. Heater is OFF throughout summer season. Dispenser is ON at 01:00-02:00, 06:00, 08:00, 12:00, 16:00-18:00 and 22:00-24:00.

#### 4) FALL SH

Fig. 80 shows the hourly appliances scheduling of fall SH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 06:00, 08:00, 17:00, 19:00 and 23:00. Dryer is ON at 01:00, 15:00, 20:00 and 22:00-23:00. Refrigerator is ON at 01:00-02:00, 04:00-07:00, 09:00, 11:00-14:00, 16:00-19:00, 21:00-22:00 and 24:00. AC is ON at 05:00-07:00, 09:00-10:00, 14:00-15:00, 17:00, 19:00-20:00 and 24:00. Heater is ON at 01:00-03:00, 16:00

and 21:00-23:00. Dispenser is ON at 01:00-02:00, 05:00, 11:00, 14:00-15:00, 17:00-18:00, 20:00, 22:00 and 24:00.

Fig. 81 shows the hourly appliances scheduling of fall SH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 02:00, 06:00, 11:00, and 21:00-22:00. Dryer is ON at 03:00, 20:00-21:00 and 23:00. Refrigerator is ON at 02:00-07:00, 10:00-11:00, 13:00 and 16:00-24:00. AC is ON at 02:00-07:00, 10:00-11:00, 17:00 and 19:00-23:00. Heater is ON at 01:00 and 24:00. Dispenser is ON at 02:00, 04:00-06:00, 11:00, 17:00, 19:00 and 21:00-24:00.

Fig. 82 shows the hourly appliances scheduling of fall SH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 04:00, 07:00, 10:00-11:00 and 16:00. Dryer is ON at 03:00-04:00, 21:00 and 23:00. Refrigerator is ON at 01:00-04:00, 06:00-11:00, 16:00-18:00 and 20:00-24:00. AC is ON at 02:00, 05:00-08:00, 12:00-14:00, 16:00 and 22:00-24:00. Heater is ON

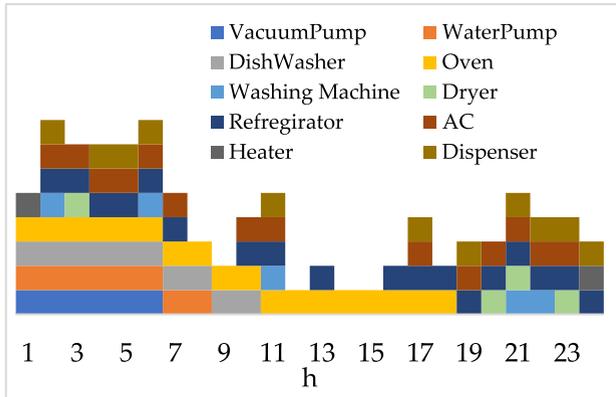


FIGURE 81. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (fall SH).

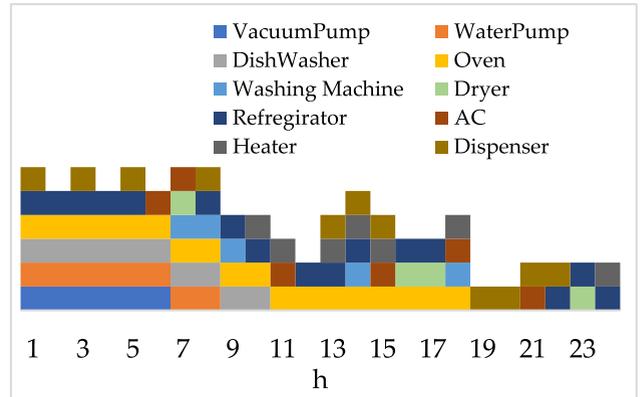


FIGURE 83. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (fall SH).

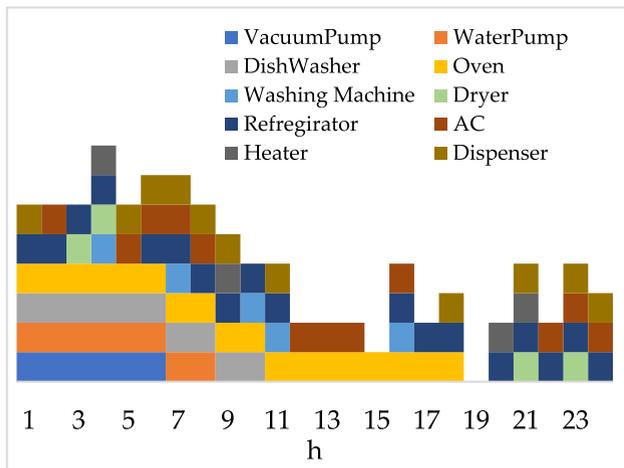


FIGURE 82. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (fall SH).

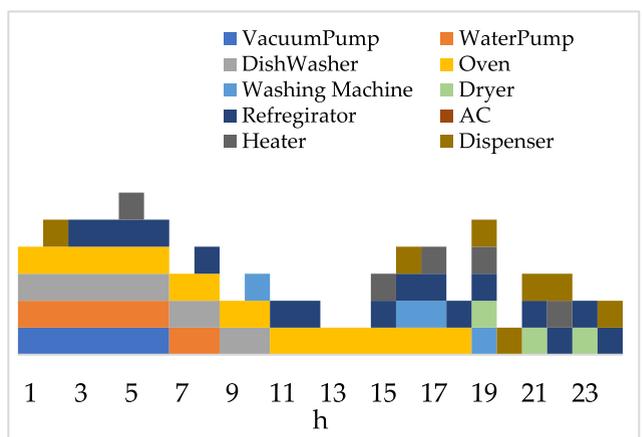


FIGURE 84. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (winter MH).

at 04:00, 09:00 and 20:00-21:00. Dispenser is ON at 01:00, 05:00-09:00, 11:00, 18:00, 21:00 and 23:00-24:00.

Fig. 83 shows the hourly appliances scheduling of fall SH with DAP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 07:00-09:00, 14:00 and 18:00. Dryer is ON at 07:00, 16:00-17:00 and 23:00. Refrigerator is ON at 01:00-05:00, 08:00-10:00, 12:00-14:00, 16:00-17:00 and 22:00-24:00. AC is ON at 06:00-07:00, 11:00, 15:00, 18:00 and 21:00. Heater is ON at 10:00, 11:00, 13:00-15:00, 18:00 and 24:00. Dispenser is ON at 01:00, 03:00, 05:00, 08:00, 13:00-15:00 and 19:00-22:00.

### 5) WINTER MH

Fig. 84 shows the hourly appliances scheduling of winter MH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 10:00, 16:00-17:00 and 19:00. Dryer is ON at 19:00, 21:00 and 23:00. Refrigerator

is ON at 03:00-06:00, 08:00, 11:00-12:00, 15:00-19:00 and 21:00-24:00. AC is OFF throughout the winter season. Heater is ON at 05:00, 15:00, 17:00, 19:00 and 22:00. Dispenser is ON at 02:00, 16:00, 19:00-22:00 and 24:00.

Fig. 85 shows the hourly appliances scheduling of winter MH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 14:00, 17:00-18:00 and 22:00. Dryer is ON at 01:00, 17:00 and 19:00. Refrigerator is ON at 01:00-04:00, 06:00, 10:00, 12:00-18:00, 20:00 and 22:00-23:00. AC is OFF throughout the winter season. Heater is ON at 15:00-17:00, 19:00 and 23:00. Dispenser is ON at 02:00, 05:00, 15:00, 17:00 and 19:00-24:00.

Fig. 86 shows the hourly appliances scheduling of winter MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 12:00-13:00, 18:00 and 20:00. Dryer is ON at 05:00, 19:00 and 21:00. Refrigerator is ON at 02:00-03:00, 05:00-07:00, 09:00-11:00, 14:00, 16:00, 18:00-22:00 and 24:00. AC is OFF throughout the

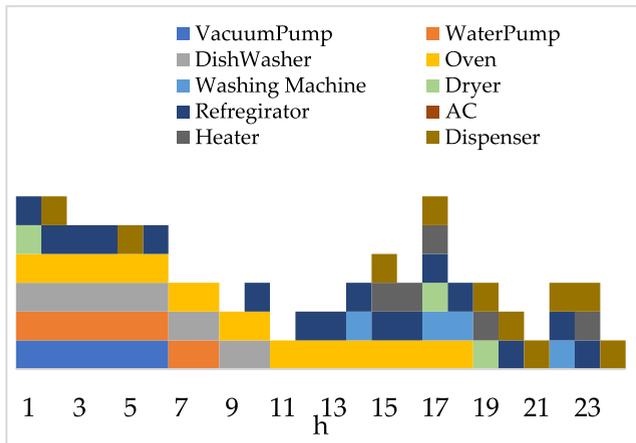


FIGURE 85. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (winter MH).

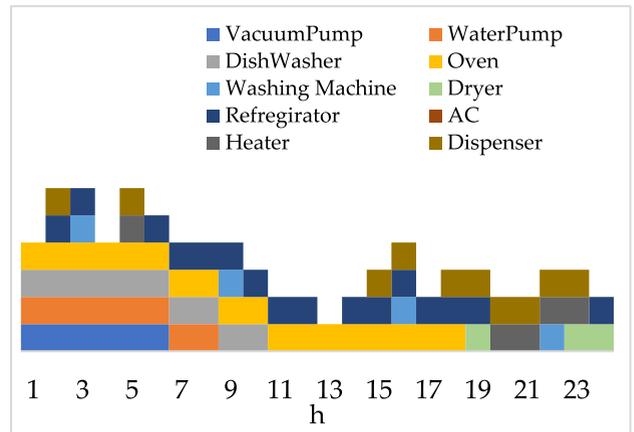


FIGURE 87. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (winter MH).

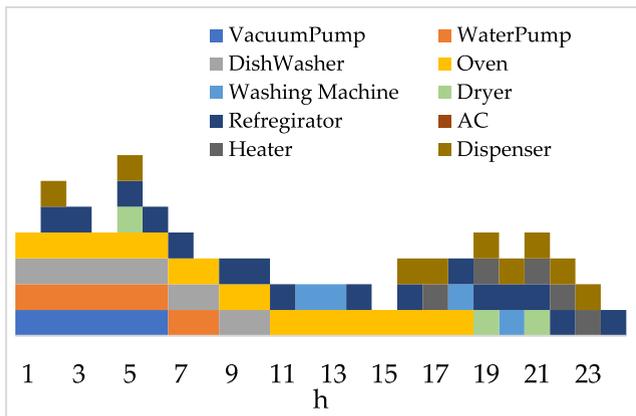


FIGURE 86. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (winter MH).

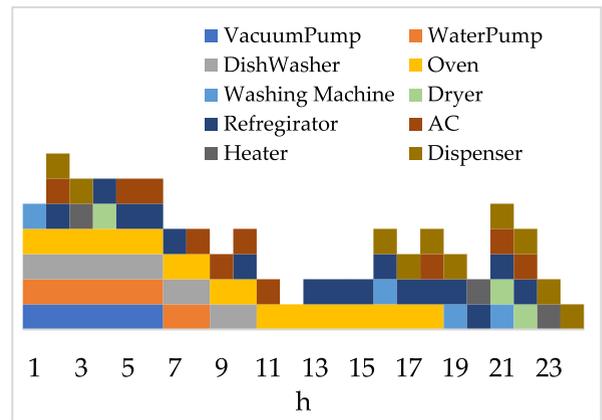


FIGURE 88. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (spring MH).

winter season. Heater is ON at 17:00, 19:00 and 21:00-23:00. Dispenser is ON at 02:00, 05:00, 16:00-17:00 and 19:00-23:00.

Fig. 87 shows the hourly appliances scheduling of winter MH with DAP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 03:00, 09:00, 16:00 and 22:00. Dryer is ON at 19:00 and 23:00-24:00. Refrigerator is ON at 02:00-03:00, 06:00-12:00, 14:00-19:00 and 24:00. AC is OFF throughout the winter season. Heater is ON at 05:00 and 20:00-23:00. Dispenser is ON at 02:00, 05:00, 15:00-16:00 and 18:00-23:00.

### 6) SPRING MH

Fig. 88 shows the hourly appliances scheduling of spring MH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 01:00, 16:00, 19:00 and 21:00. Dryer is ON at 04:00 and 21:00-22:00. Refrigerator is

ON at 02:00, 04:00-07:00, 10:00 and 13:00-22:00. AC is ON at 02:00, 05:00-06:00, 08:00-11:00, 18:00 and 21:00-22:00. Heater is ON at 03:00, 20:00 and 23:00. Dispenser is ON at 02:00-03:00, 16:00-19:00 and 21:00-24:00.

Fig. 89 shows the hourly appliances scheduling of spring MH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 11:00-12:00, 15:00 and 23:00. Dryer is ON at 18:00, 20:00 and 23:00. Refrigerator is ON at 01:00-05:00, 07:00-08:00, 10:00, 12:00-14:00, 16:00 and 20:00-23:00. AC is ON at 02:00-06:00, 09:00-10:00, 12:00-15:00, 20:00 and 24:00. Heater is ON at 01:00, 19:00 and 23:00. Dispenser is ON at 03:00, 05:00, 16:00 and 18:00-24:00.

Fig. 90 shows the hourly appliances scheduling of spring MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 03:00 and 17:00-19:00. Dryer is ON at 01:00, 05:00 and 24:00. Refrigerator is

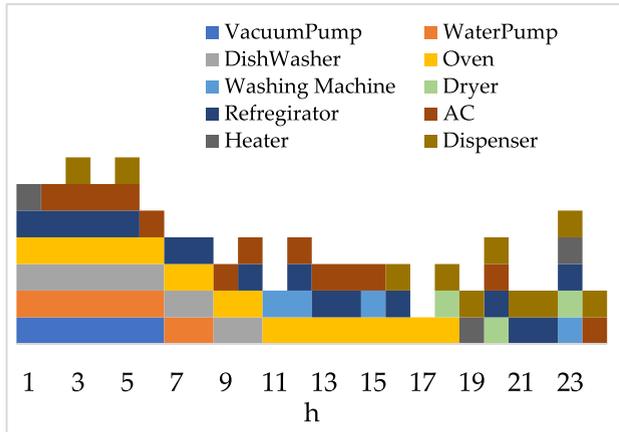


FIGURE 89. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (spring MH).

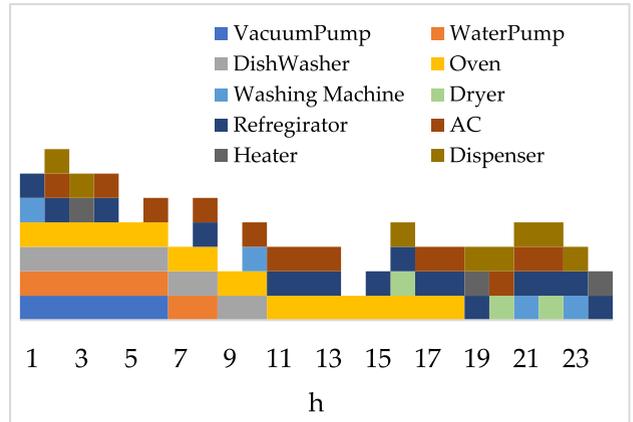


FIGURE 91. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (spring MH).

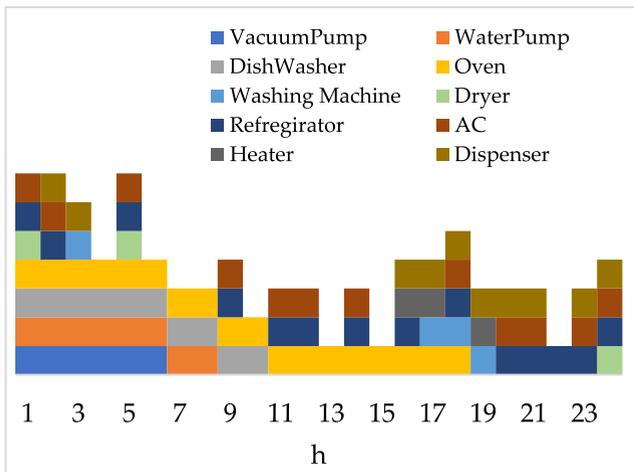


FIGURE 90. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (spring MH).

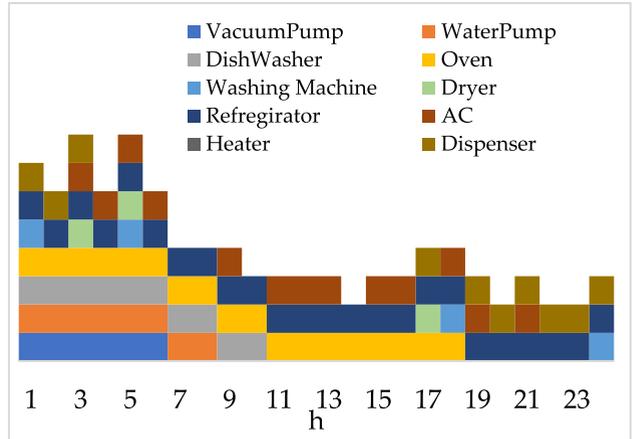


FIGURE 92. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (summer MH).

ON at 01:00-02:00, 05:00, 09:00, 11:00-12:00, 14:00, 16:00, 18:00 and 20:00-24:00. AC is ON at 01:00-02:00, 05:00, 09:00, 11:00-12:00, 14:00, 18:00, 20:00-21:00 and 23:00-24:00. Heater is ON at 16:00-17:00 and 19:00. Dispenser is ON at 02:00-03:00, 16:00-21:00, and 23:00-24:00.

Fig. 91 shows the hourly appliances scheduling of spring MH with DAP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 01:00, 10:00, 21:00 and 23:00. Dryer is ON at 16:00, 20:00 and 22:00. Refrigerator is ON at 01:00-02:00, 04:00, 08:00, 11:00-13:00, 15:00-19:00 and 21:00-24:00. AC is ON at 02:00, 04:00, 06:00, 08:00, 10:00-13:00, 17:00-18:00 and 20:00-22:00. Heater is ON at 03:00, 19:00 and 24:00. Dispenser is ON at 02:00-03:00, 16:00, and 19:00-23:00.

7) SUMMER MH

Fig. 92 shows the hourly appliances scheduling of summer MH with RTEP tariff by using proposed ABC algorithm.

Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 01:00, 05:00, 18:00 and 24:00. Dryer is ON at 03:00, 05:00 and 17:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 03:00-06:00, 09:00, 11:00-13:00, 15:00-16:00, 18:00-19:00 and 21:00. Heater is OFF throughout the summer season. Dispenser is ON at 01:00-03:00, 17:00 and 19:00-24:00.

Fig. 93 shows the hourly appliances scheduling of summer MH with CPP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 05:00, 10:00, 13:00 and 21:00. Dryer is ON at 16:00-17:00 and 22:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 08:00-10:00, 13:00-19:00 and 21:00-23:00. Heater is OFF throughout the summer season. Dispenser is ON at 01:00-03:00, 16:00, 18:00-20:00 and 22:00-24:00.

Fig. 94 shows the hourly appliances scheduling of summer MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON

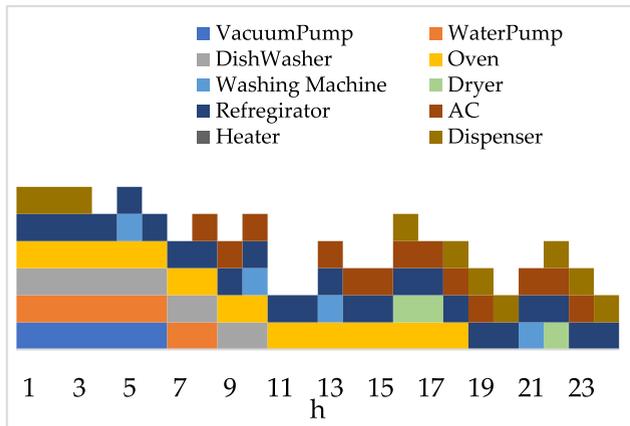


FIGURE 93. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (summer MH).

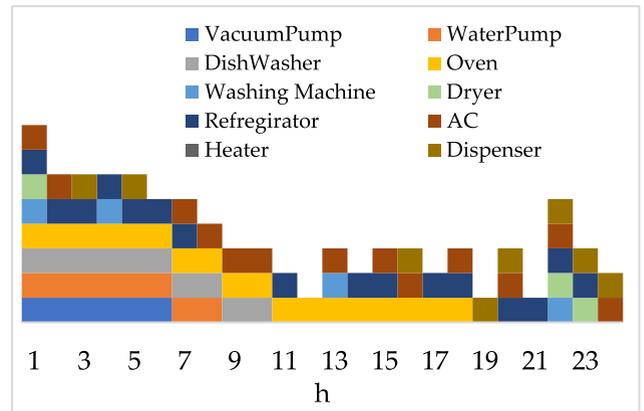


FIGURE 95. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (summer MH).

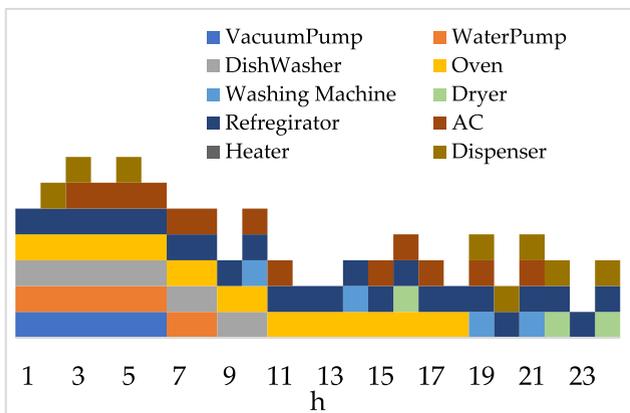


FIGURE 94. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (summer MH).

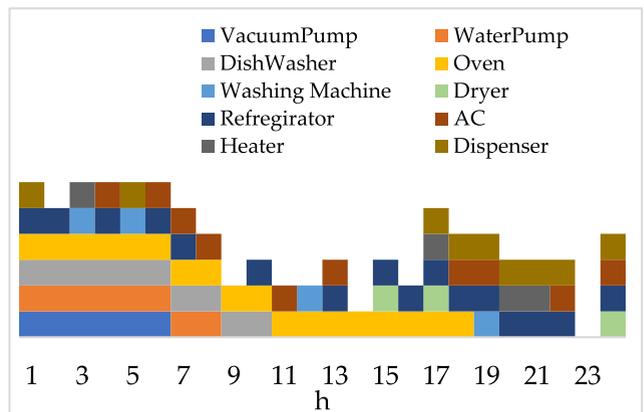


FIGURE 96. Hourly appliances scheduling with RTEP tariff using proposed ABC algorithm (fall MH).

at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 10:00, 14:00, 19:00 and 21:00. Dryer is ON at 16:00, 22:00 and 24:00. Refrigerator is ON throughout the day at 01:00-24:00. AC is ON at 03:00-08:00, 10:00-11:00, 15:00-17:00, 19:00 and 21:00. Heater is OFF throughout the summer season. Dispenser is ON at 02:00-03:00, 05:00, 19:00-22:00 and 24:00.

Fig. 95 shows the hourly appliances scheduling of summer MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 01:00, 04:00, 13:00 and 22:00. Dryer is ON at 01:00 and 22:00-23:00. Refrigerator is ON at 01:00-07:00, 11:00, 14:00-15:00, 17:00-18:00 and 20:00-23:00. AC is ON at 01:00-02:00, 07:00-10:00, 13:00, 15:00-16:00, 18:00, 20:00, 22:00 and 24:00. Heater is OFF throughout the summer season. Dispenser is ON at 03:00, 05:00, 16:00, 19:00-20:00 and 22:00-24:00.

### 8) FALL MH

Fig. 96 shows the hourly appliances scheduling of fall MH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00,

respectively. Washing machine is ON at 05:00, 12:00 and 19:00. Dryer is ON at 15:00, 17:00 and 24:00. Refrigerator is ON at 01:00-02:00, 04:00, 06:00-07:00, 10:00, 13:00, 15:00-22:00 and 24:00. AC is ON at 04:00, 06:00-08:00, 11:00, 13:00, 18:00-19:00, 22:00 and 24:00. Heater is ON at 03:00, 17:00 and 20:00-21:00. Dispenser is ON at 01:00, 05:00, 17:00-22:00 and 24:00.

Fig. 97 shows the hourly appliances scheduling of fall MH with RTEP tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 03:00, 13:00-14:00 and 20:00. Dryer is ON at 19:00-21:00. Refrigerator is ON at 01:00, 03:00, 05:00, 07:00, 10:00-11:00, 13:00 and 16:00-24:00. AC is ON at 03:00, 06:00, 09:00-12:00, 15:00-16:00, and 19:00-21:00. Heater is ON at 02:00, 17:00 and 22:00. Dispenser is ON at 01:00-03:00, 15:00-17:00, 19:00, 21:00 and 23:00-24:00.

Fig. 98 shows the hourly appliances scheduling of fall MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00,

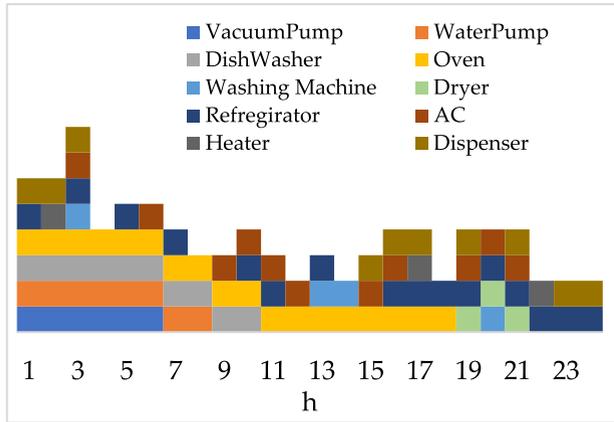


FIGURE 97. Hourly appliances scheduling with CPP tariff using proposed ABC algorithm (fall MH).

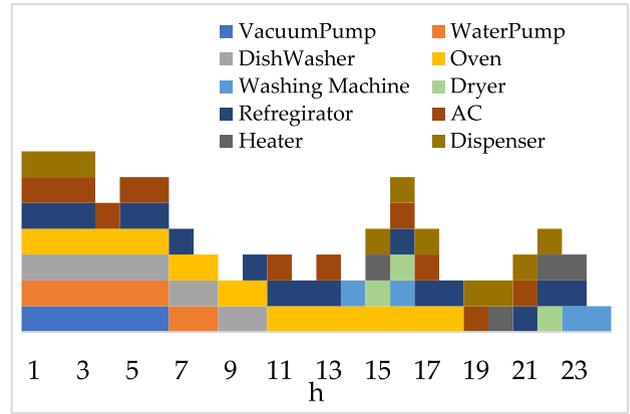


FIGURE 99. Hourly appliances scheduling with DAP tariff using proposed ABC algorithm (fall MH).

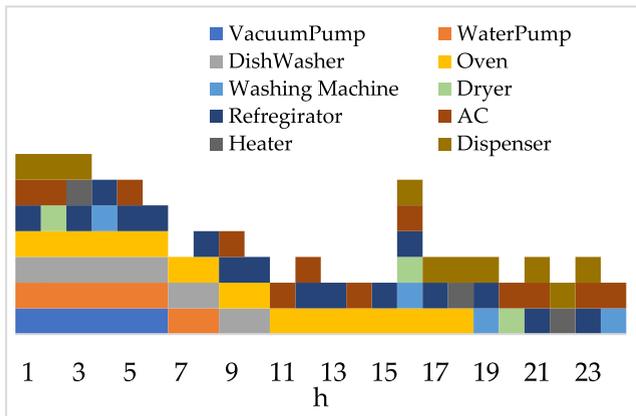


FIGURE 98. Hourly appliances scheduling with TOU tariff using proposed ABC algorithm (fall MH).

respectively. Washing machine is ON at 04:00, 16:00, 19:00 and 24:00. Dryer is ON at 02:00, 16:00 and 20:00. Refrigerator is ON at 01:00, 03:00-06:00, 08:00-10:00, 12:00-13:00, 15:00-17:00, 19:00, 21:00 and 23:00. AC is ON at 01:00-02:00, 05:00, 09:00, 11:00-12:00, 14:00, 16:00, 20:00-21:00 and 23:00-24:00. Heater is ON at 03:00, 18:00 and 22:00. Dispenser is ON at 01:00-03:00, 16:00-19:00 and 21:00-23:00.

Fig. 99 shows the hourly appliances scheduling of fall MH with TOU tariff by using proposed ABC algorithm. Vacuum pump, water pump, dishwasher and oven are ON at 01:00-06:00, 01:00-08:00, 01:00-10:00 and 01:00-18:00, respectively. Washing machine is ON at 14:00, 16:00 and 23:00-24:00. Dryer is ON at 15:00-16:00 and 22:00. Refrigerator is ON at 01:00-03:00, 05:00-07:00, 10:00-13:00, 16:00-18:00 and 21:00-23:00. AC is ON at 01:00-06:00, 11:00, 13:00, 16:00-17:00, 19:00 and 21:00. Heater is ON at 15:00, 20:00 and 22:00-23:00. Dispenser is ON at 01:00-03:00, 15:00-17:00 and 19:00-22:00.

Table 4 shows the comparison of computational burden of proposed ABC algorithm with different heuristic algorithms. It is observed that ABC algorithm is most optimal with

TABLE 4. Computational time for heuristic methods.

Strategy	Method	Computational time (s)
SH	WDO [59]	2.61
	HSA [59]	2.01
	GHSA [59]	1.5
	GA [59]	1.43
	ABC	0.96
MH	WDO [59]	100.21
	HSA [59]	96.1
	GHSA [59]	70.46
	GA [59]	60.33
	ABC	39.95

reduced computational time as compared to the other heuristic methods. Table 5 shows the hourly load scheduling of proposed ABC algorithm with different heuristic techniques for RTEP tariff. Table 6 shows the hourly load scheduling of proposed ABC algorithm with different heuristic techniques for CPP tariff.

Fig. 100 shows the hourly load scheduling of winter SH with four tariffs by using GA and proposed ABC algorithm. For SH winter load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 12.57 kW (at 13:00), 15.35 kW (at 06:00) and 13.35 kW (at 03:00), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.85 and 2.48, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. For SH winter load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour), 10.90 kW (at 05:00 hour) and 10.85 kW (at 21:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.03 and 2.02, respectively. PAR is minimized by 13.7% with the proposed ABC scheduling. While PAR is higher with GA as compared to ABC. For SH winter load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 12.57 kW (at 13:00 hour), 14.87 kW

**TABLE 5.** Load comparison by different techniques using RTEP tariff.

Time (Hours)	Unscheduled	WDO [59]	HSA [59]	GHSA [59]	GA [59]	Proposed ABC
1	6.23	8.37	7.11	6.20	5.81	9.36
2	2.89	6.94	5.78	6.01	5.81	7.86
3	4.21	6.43	5.78	5.81	3.58	8.95
4	2.15	6.20	5.78	5.71	4.32	5.75
5	5.96	7.14	5.78	6.14	4.32	7.37
6	6.83	6.98	5.78	5.81	4.32	5.88
7	6.31	7.85	5.78	4.19	4.32	4.40
8	7.36	8.14	5.78	4.39	3.45	3.90
9	8.88	7.88	5.78	5.23	4.13	3.22
10	6.05	4.49	5.78	5.881	3.74	3.22
11	7.56	2.97	2.19	5.881	4.13	2.44
12	11.18	4.49	2.19	2.19	3.74	2.82
13	11.27	2.97	2.19	2.06	3.42	2.57
14	6.48	3.03	3.03	2.06	3.35	3.94
15	3.00	6.39	5.81	6.39	2.22	6.43
16	6.59	3.74	5.81	6.39	3.45	6.82
17	5.25	4.49	5.81	6.39	6.36	6.15
18	2.31	6.62	6.26	6.39	6.36	5.24
19	5.45	6.62	7.85	8.11	6.36	3.35
20	4.08	6.62	8.66	8.11	9.60	6.51
21	2.78	8.11	8.66	8.11	9.60	4.71
22	2.15	8.11	9.43	9.63	11.80	7.40
23	3.76	8.11	11.002	10.83	11.80	4.50
24	4.99	9.24	11.7	10.99	12.44	4.31

**TABLE 6.** Load comparison by different techniques using CPP tariff.

Time (Hours)	Unscheduled	WDO [65]	HSA [65]	GHSA [65]	GA [65]	Proposed ABC
1	6.56	6.55	5.86	5.84	6.46	7.73
2	3.04	4.34	5.73	5.84	5.03	11.10
3	4.43	6.30	5.73	5.84	5.03	9.90
4	2.26	6.49	5.73	5.73	5.03	7.36
5	6.27	6.52	5.73	6.27	7.09	8.36
6	7.18	6.62	5.98	5.79	5.07	7.65
7	6.64	8.58	7.41	5.00	7.85	5.25
8	7.74	8.01	7.41	5.00	7.85	3.78
9	9.35	8.90	7.41	5.00	8.77	2.85
10	6.37	3.99	5.95	5.95	9.34	3.35
11	7.96	2.21	5.95	5.95	3.39	4.72
12	11.77	3.70	2.221	2.19	2.94	1.82
13	11.86	6.71	2.221	2.19	2.94	2.07
14	6.82	4.153	2.221	3.64	4.15	1.82
15	3.16	6.24	2.221	3.64	3.67	1.82
16	6.93	4.153	5.95	6.21	2.94	3.34
17	5.52	4.53	6.27	8.14	2.94	3.91
18	2.43	2.98	6.27	6.43	7.445	2.82
19	5.74	6.43	6.46	6.43	7.445	4.10
20	4.29	9.40	6.46	8.87	7.445	6.46
21	2.92	8.11	9.37	6.46	8.14	7.86
22	2.26	8.46	9.37	10.86	8.14	6.90
23	3.96	10.13	10.86	10.86	8.90	6.03
24	5.25	10.89	10.86	10.86	8.90	6.13

(at 01:00 hour) and 14.85 kW (at 05:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.76 and 2.76, respectively. PAR is not

minimized with the proposed ABC scheduling. While PAR is same with GA as compared to ABC. For SH winter load with DAP tariff, the unscheduled, GA scheduled and ABC

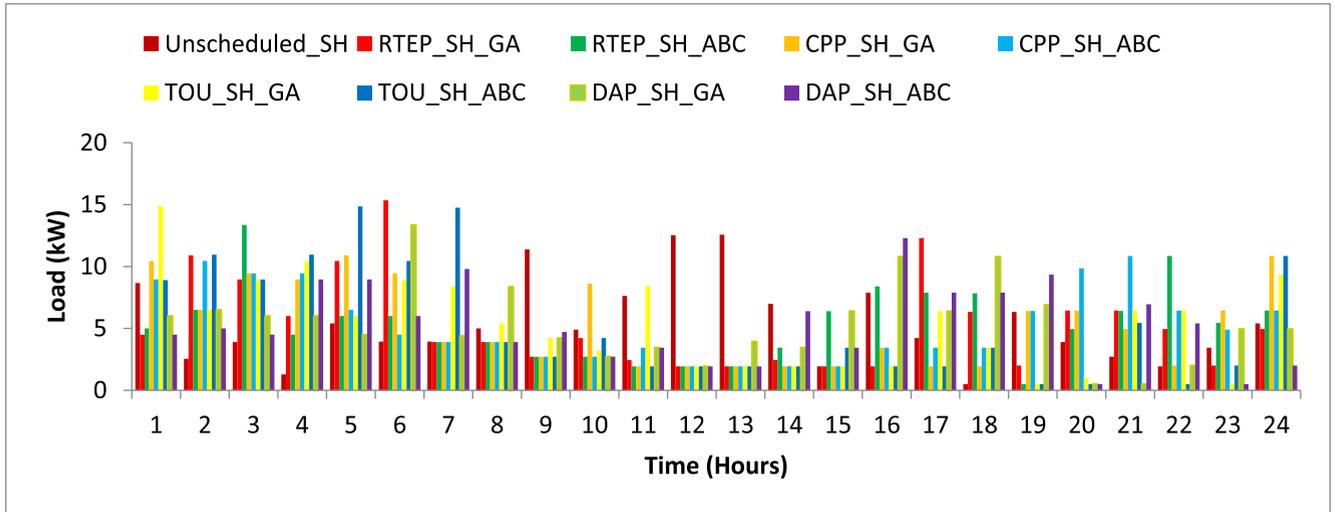


FIGURE 100. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (winter SH).

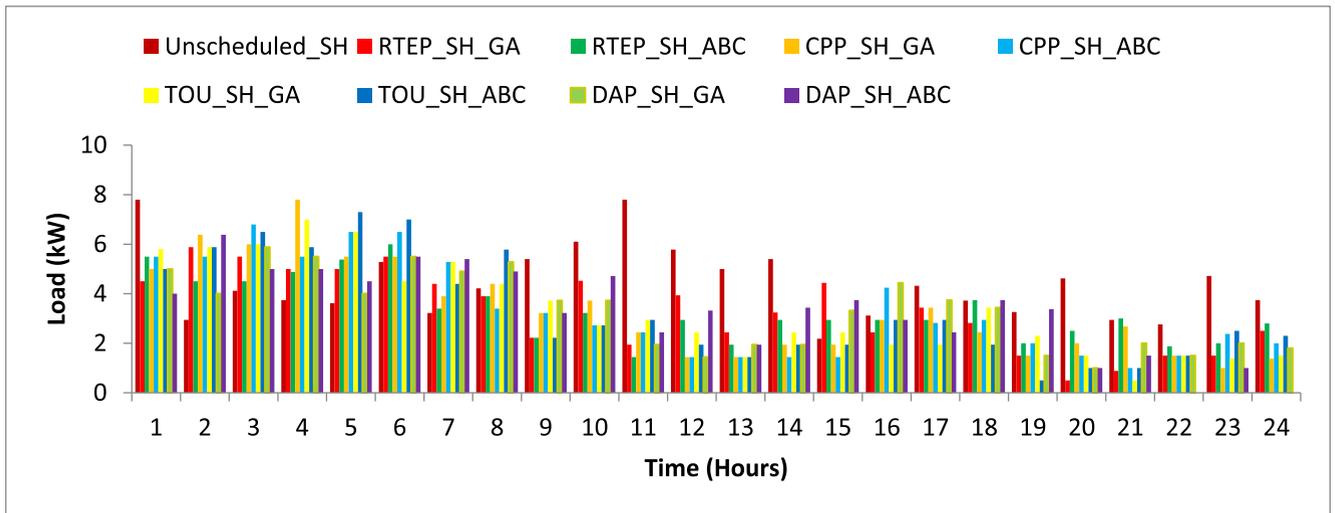


FIGURE 101. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (spring SH).

scheduled peak loads are 12.57 kW (at 13:00 hour), 13.35 kW (at 06:00 hour) and 12.29 kW (at 16:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.48 and 2.29, respectively. PAR is minimized by 2.1% with the proposed ABC scheduling. While PAR is higher with GA as compared to ABC scheduled and unscheduled load.

Fig. 101 shows the hourly load scheduling of spring SH with four tariffs by using GA and proposed ABC algorithm. For SH spring load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 7.80 kW (at 01:00), 5.88 kW (at 02:00) and 6.00 kW (at 06:00), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.76, 1.77 and 1.81, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. For SH spring load with CPP

tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 7.80 kW (at 01:00), 7.80 kW (at 04:00) and 6.80 kW (at 03:00), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 2.35 and 2.05, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. For SH spring load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 7.80 kW (at 01:00), 7.00 kW (at 04:00) and 7.30 kW (at 05:00), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 2.11 and 2.20, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. For SH spring load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 7.80 kW (at 01:00), 5.88 kW (at 03:00) and 6.38 kW (at 02:00), respectively. The PAR for unscheduled,

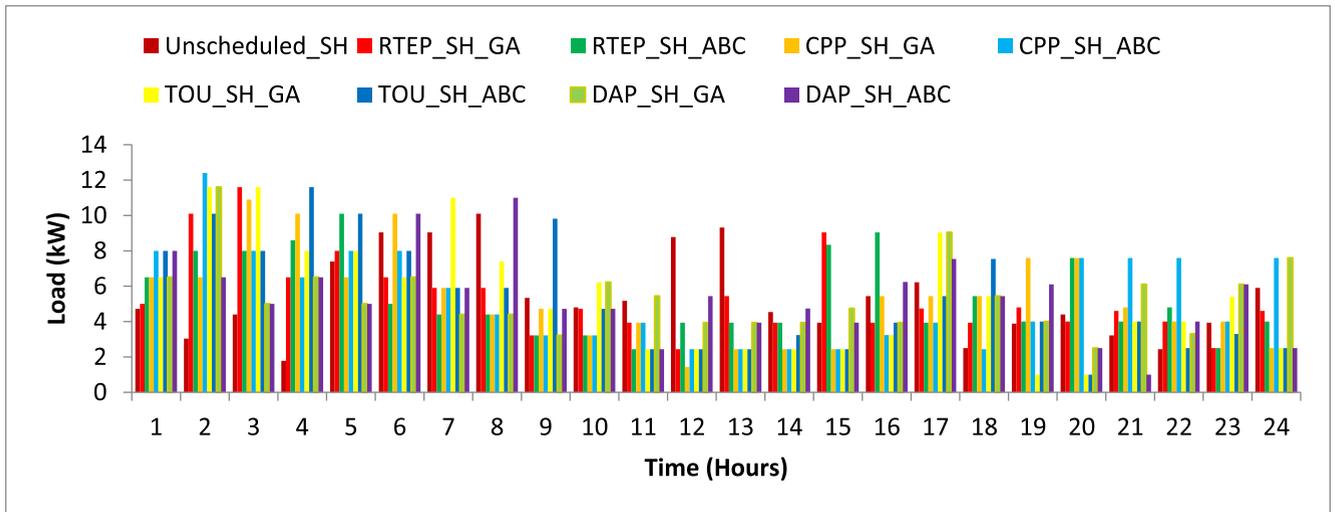


FIGURE 102. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (summer SH).

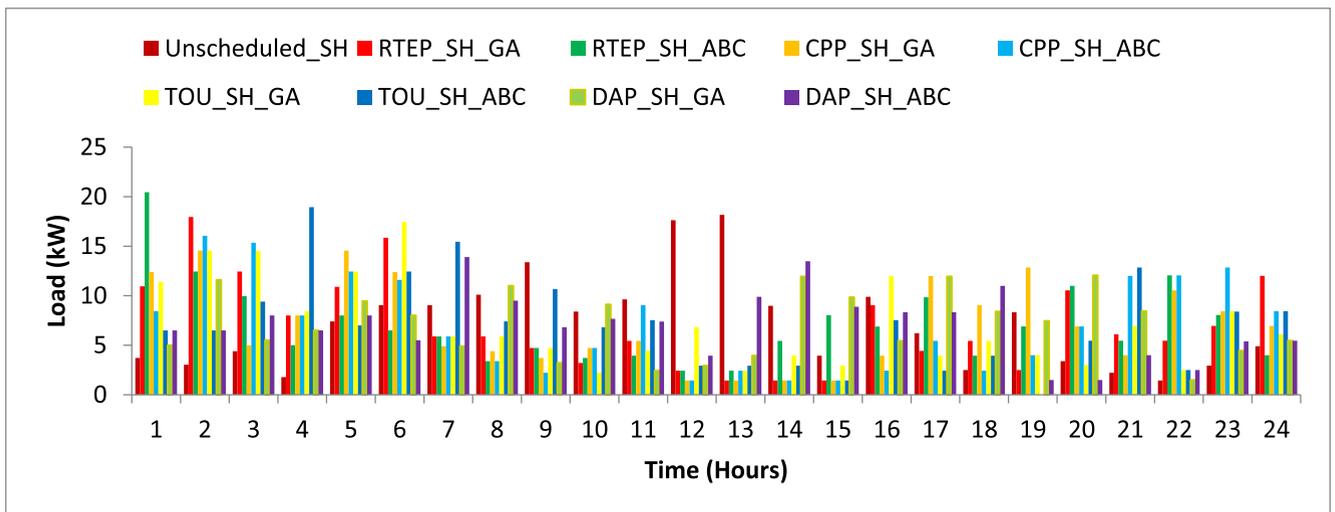


FIGURE 103. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (fall SH).

GA scheduled and ABC scheduled load are 1.77, 1.78 and 1.93, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC.

Fig. 102 shows the hourly load scheduling of summer SH with four tariffs by using GA and proposed ABC algorithm. For SH summer load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour), 11.60 kW (at 03:00) and 10.10 kW (at 05:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.15 and 1.87, respectively. The unscheduled load and ABC shows minimum PAR. While PAR is higher with GA as compared to ABC and unscheduled load. For SH summer load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour), 10.90 kW (at 03:00) and 12.40 kW (at 02:00 hour), respectively.

The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.04 and 2.30, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. For SH summer load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour), 11.60 kW (at 03:00, 04:00) and 11.60 kW (at 04:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.15 and 2.15, respectively. The unscheduled load shows minimum PAR. While PAR is same with GA as compared to ABC. For SH summer load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 10.10 kW (at 08:00 hour), 11.60 kW (at 02:00) and 11.00 kW (at 08:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.15 and 2.04, respectively. The unscheduled

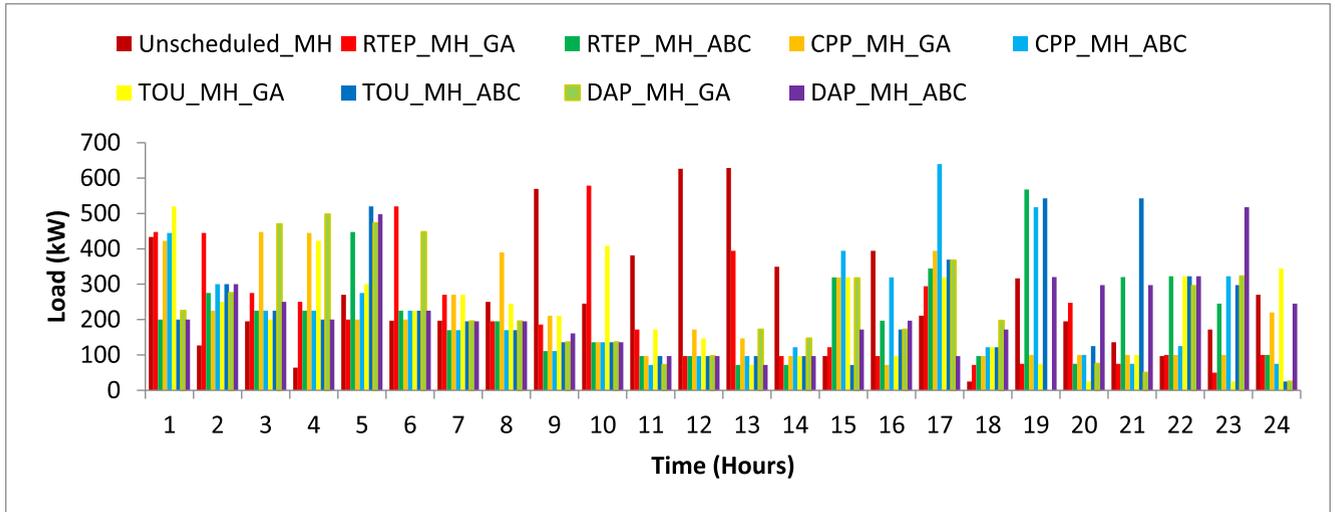


FIGURE 104. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (winter MH).

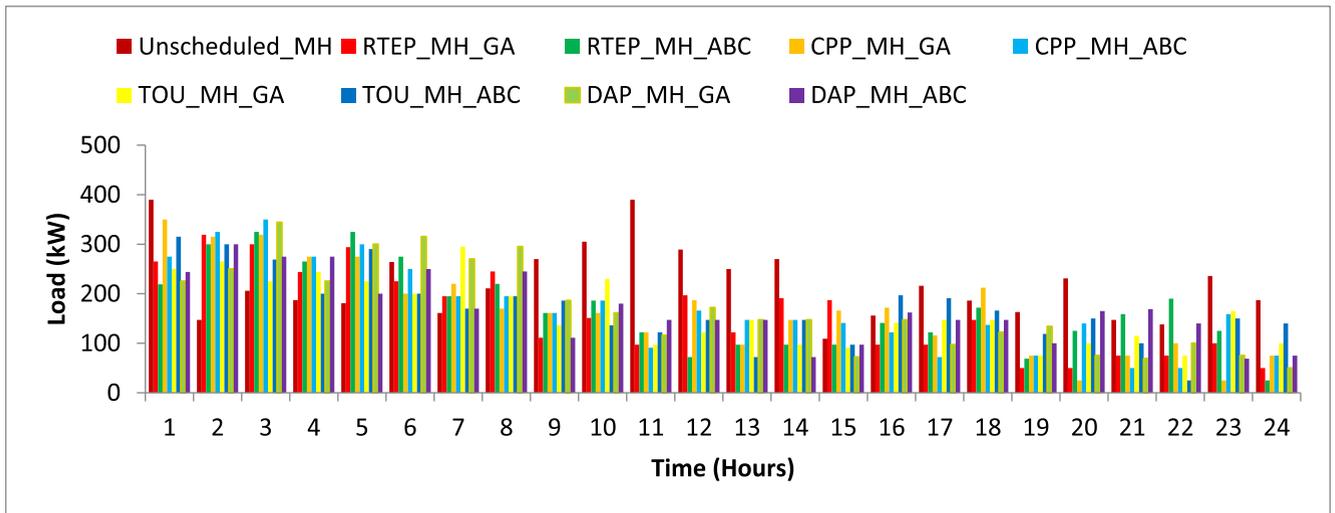


FIGURE 105. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (spring MH).

load shows minimum PAR. While PAR is higher with GA as compared to ABC.

Fig. 103 shows the hourly load scheduling of fall SH with four tariffs by using GA and proposed ABC algorithm. For SH fall load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour), 17.95 kW (at 02:00) and 20.45 kW (at 01:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.60 and 2.88, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. For SH fall load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour), 14.55 kW (at 02:00, 05:00) and 16.05 kW (at 02:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.05 and 2.26, respectively. The GA scheduled

load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. For SH fall load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour), 17.45 kW (at 06:00) and 18.95 kW (at 04:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.46 and 2.67, respectively. The GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. ABC shows highest PAR in this case. For SH fall load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 18.17 kW (at 13:00 hour), 12.05 kW (at 20:00) and 13.90 kW (at 07:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 1.70 and 1.96, respectively. The GA scheduled load shows minimum PAR. While PAR is lower with GA as

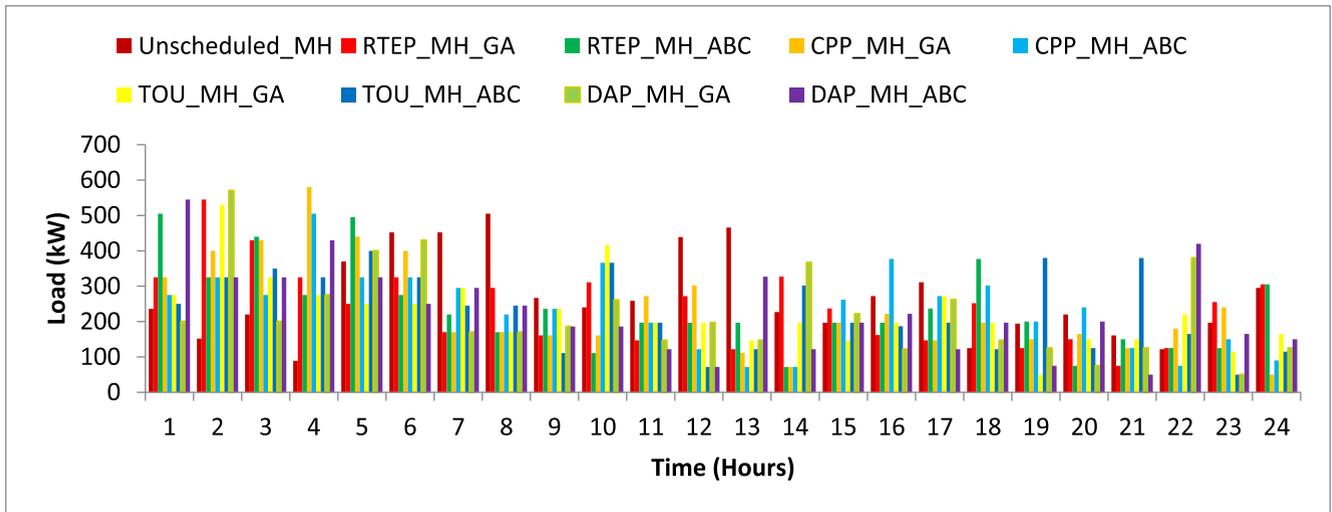


FIGURE 106. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (summer MH).

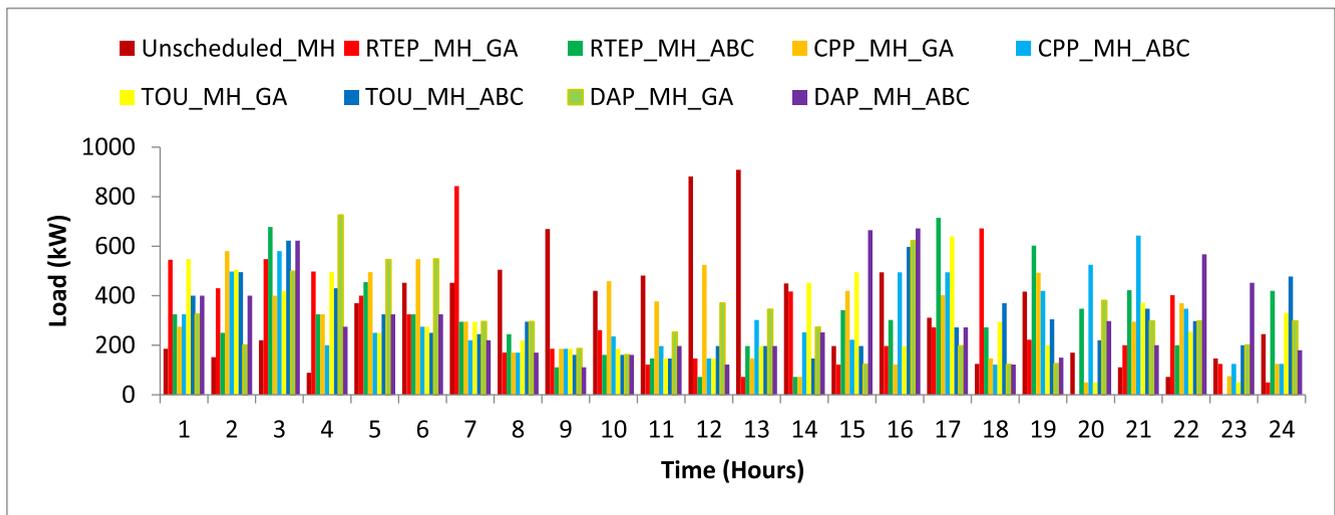


FIGURE 107. Comparison of hourly load scheduling with four tariffs using GA and proposed ABC algorithm (fall MH).

compared to ABC scheduled and unscheduled load. Unscheduled load shows highest PAR in this case.

Fig. 104 shows the hourly load scheduling of winter MH with four tariffs by using GA and proposed ABC algorithm. For MH winter load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour), 578.50 kW (at 10:00) and 567.50 kW (at 19:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.59 and 2.65, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. Unscheduled load shows lowest PAR in this case. For MH winter load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour), 447.50 kW (at 03:00) and 639.50 kW (at 17:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC

scheduled load are 2.34, 2.12 and 2.86, respectively. The GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. ABC scheduled load shows highest PAR in this case. For MH winter load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour), 520.00 kW (at 01:00) and 542.50 kW (at 19:00 and 21:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.36 and 2.46, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. ABC scheduled load shows highest PAR in this case. For MH winter load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 628.50 kW (at 13:00 hour), 497.50 kW (at 04:00) and 517.50 kW (at 23:00 hour), respectively. The PAR for

TABLE 7. Result comparison of GA and ABC algorithm for SH.

Tariff	Parameter	Algorithm		
		Unscheduled	GA	ABC
winter load with RTEP tariff	Average Waiting time (Hours)	3.7917	2.2083	2.8333
	PAR (%)	2.3393	2.8567	2.0378
	Net Cost → Average daily cost (€/h)	182.030	146.61	142.665
winter load with CPP tariff	Average Waiting time (Hours)	3.7917	2.1667	2.8750
	PAR (%)	2.3393	2.0285	2.1123
	Net Cost → Average daily cost (€/h)	326.460	186.13	183.990
winter load with TOU tariff	Average Waiting time (Hours)	3.7917	2.6667	2.7083
	PAR (%)	2.3393	2.7636	2.4845
	Net Cost → Average daily cost (€/h)	71.798	43.644	40.139
winter load with DAP tariff	Average Waiting time (Hours)	3.7917	2.4167	2.6250
	PAR (%)	2.3393	2.4845	2.3070
	Net Cost → Average daily cost (€/h)	45.729	39.864	39.086
Spring load with RTEP tariff	Average Waiting time (Hours)	2.5833	2.7917	4.0417
	PAR (%)	1.7694	2.0166	1.8113
	Net Cost → Average daily cost (€/h)	95.236	54.456	53.713
Spring load with CPP tariff	Average Waiting time (Hours)	2.5833	3.7500	3.2500
	PAR (%)	1.7694	2.3547	1.9623
	Net Cost → Average daily cost (€/h)	220.760	135.45	133.700
Spring load with TOU tariff	Average Waiting time (Hours)	2.5833	2.9583	2.9583
	PAR (%)	1.7694	2.0770	2.2591
	Net Cost → Average daily cost (€/h)	97.005	63.165	62.262
Spring load with DAP tariff	Average Waiting time (Hours)	2.5833	3.4167	3.0833
	PAR (%)	1.7694	1.7751	2.4616
	Net Cost → Average daily cost (\$/h)	36.936	26.561	26.729
Fall load with RTEP tariff	Average Waiting time (Hours)	4.0000	3.4583	3.4583
	PAR (%)	2.5575	2.5265	2.1043
	Net Cost → Average daily cost (€/h)	252.710	194.72	185.310
Fall load with CPP tariff	Average Waiting time (Hours)	4.0000	3.2083	3.3750
	PAR (%)	2.5575	2.0480	2.3717
	Net Cost → Average daily cost (€/h)	459.810	228.52	228.030
Fall load with TOU tariff	Average Waiting time (Hours)	4.0000	2.9167	3.2917
	PAR (%)	2.5575	2.4562	2.2591
	Net Cost → Average daily cost (€/h)	97.005	61.3084	60.900
Fall load with DAP tariff	Average Waiting time (Hours)	4.0000	2.8333	3.0000
	PAR (%)	2.5575	1.6961	1.9564
	Net Cost → Average daily cost (€/h)	58.711	53.244	55.402
Summer load with RTEP tariff	Average Waiting time (Hours)	3.4167	2.5000	2.3333
	PAR (%)	1.8738	1.8738	2.1521
	Net Cost → Average daily cost (€/h)	179.780	153.45	148.060
Summer load with CPP tariff	Average Waiting time (Hours)	3.4167	2.3333	2.5000
	PAR (%)	1.8738	2.0380	2.1521
	Net Cost → Average daily cost (€/h)	296.700	200.29	195.910
Summer load with TOU tariff	Average Waiting time (Hours)	3.4167	2.4583	2.1250
	PAR (%)	1.8738	2.1521	2.1521

TABLE 7. (Continued.) Result comparison of GA and ABC algorithm for SH.

	Net Cost→ Average daily cost (¢/h)	62.538/ 61.600	44.024	42.377
Summer load with DAP tariff	Average Waiting time (Hours)	3.4167	1.9583	2.1667
	PAR (%)	1.8738	1.8738	2.0562
	Net Cost→ Average daily cost (¢/h)	43.351	42.477	41.823

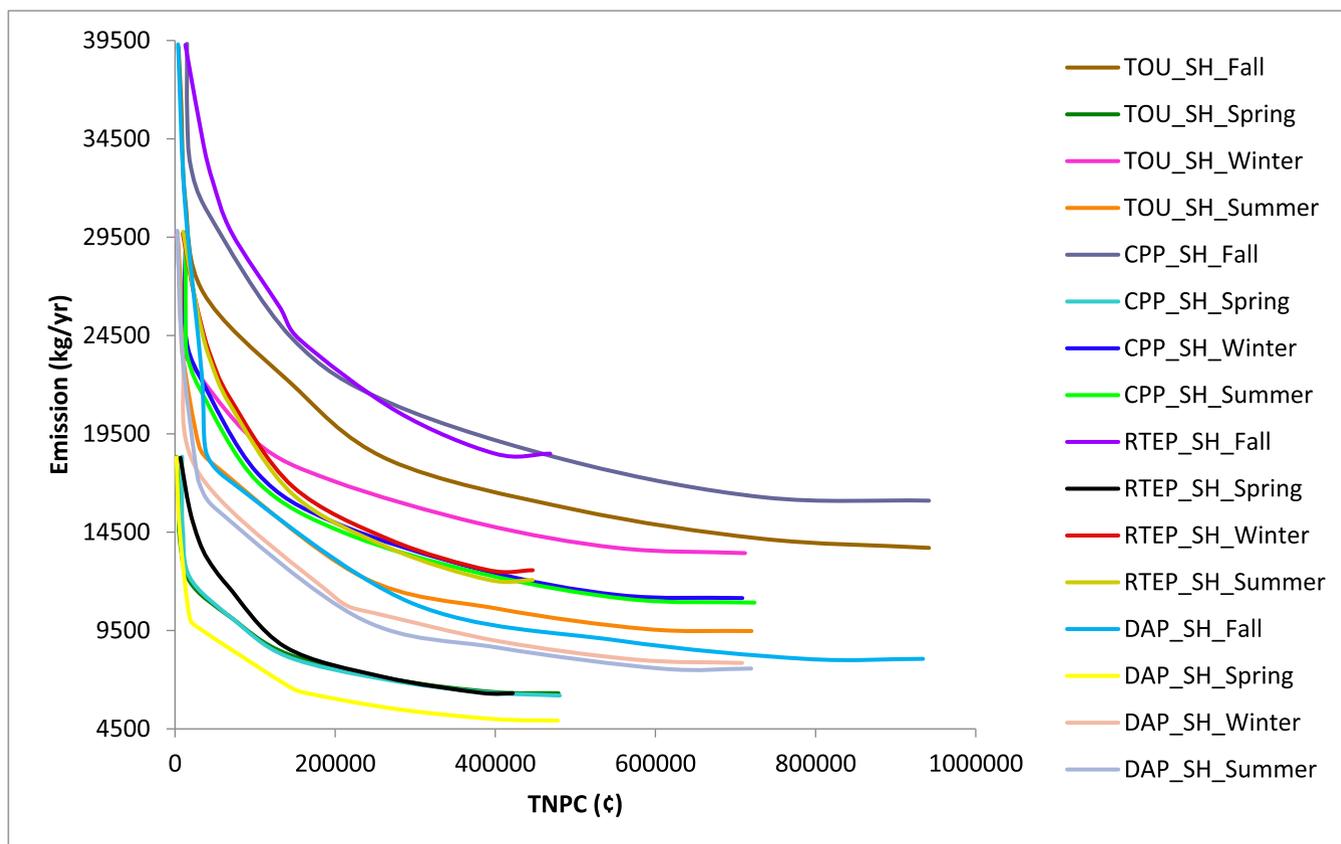


FIGURE 108. Results comparison of single home TNPC and emission with different Tariffs and seasons.

unscheduled, GA scheduled and ABC scheduled load are 2.34, 2.23 and 2.32, respectively. The GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. Unscheduled load shows highest PAR in this case.

Fig. 105 shows the hourly load scheduling of spring MH with four tariffs by using GA and proposed ABC algorithm. For MH spring load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour), 319.00 kW (at 02:00) and 325.00 kW (at 03:00, 05:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 1.97 and 1.91, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. Unscheduled load shows lowest PAR in this case. For MH spring load with CPP tariff, the unscheduled,

GA scheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour), 350.00 kW (at 01:00) and 350.00 kW (at 03:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 2.08 and 2.06, respectively. The ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. ABC scheduled load shows lowest PAR in this case. For MH spring load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour), 295.00 kW (at 07:00) and 315.00 kW (at 01:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 1.82 and 1.85, respectively. The unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. ABC scheduled load shows highest PAR in this case. For MH spring load with DAP tariff, the unscheduled,

**TABLE 8. Result of multi-objective optimization based on TNPC and emission for single home (RTEP winter, scaled annual average = 128.96 kWh/d, LF=0.4).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	46980 (98.3)	805 (1.68)	-	-	709 (1.48)	0.418	-	-	-	0.0216
2	42998 (90.9)	-	4311 (9.11)	-	239 (0.50)	-	3	-	-	-
3	39736 (82.2)	-	8623 (17.8)	-	1288 (2.66)	-	6	-	-	-
4	37184 (74.2)	-	12934 (25.8)	-	3048 (6.08)	-	9	-	-	-
5	33789 (61.1)	-	21557 (38.9)	-	8275 (15.0)	-	15	-	-	-
6	26594 (17.4)	82720 (54.3)	43114 (28.3)	-	105231 (69.0)	43.0	30	-	-	21.0
7	22314 (11.7)	82720 (43.2)	86228 (45.1)	-	144094 (75.3)	43.0	60	-	-	21.0
8	19892 (8.58)	82720 (35.7)	129341 (55.8)	-	184802 (79.7)	43.0	90	-	-	7.0
9	19881 (5.0)	248159 (62.4)	129341 (32.5)	0 (0.0)	350229 (88.1)	129.0	90	15	30	7.0

**TABLE 9. Result of multi-objective optimization based on TNPC and emission for single home (RTEP summer, scaled annual average = 129.36 kWh/d, LF=0.53).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	47126 (98.31)	811 (1.69)	-	-	715 (1.49)	0.422	-	-	-	0.0216
2	42915 (90.9)	-	4311 (9.1)	-	9.86 (0.02)	-	3	-	-	-
3	39302 (82.0)	-	8623 (18.0)	-	709 (1.48)	-	6	-	-	-
4	36690 (73.9)	-	12934 (26.1)	-	2407 (4.85)	-	9	-	-	-
5	33241 (60.7)	-	21557 (39.3)	-	7581 (13.8)	-	15	-	-	-
6	25944 (17.0)	83361 (54.7)	43114 (28.3)	-	105069 (68.9)	43.3	30	-	-	21.0
7	21627 (11.3)	83361 (43.6)	86228 (45.1)	-	143893 (75.3)	43.3	60	-	-	21.0
8	19113 (8.24)	83361 (36.0)	129341 (55.8)	-	184508 (79.6)	43.3	90	-	-	7.0
9	19095 (4.79)	250083 (62.8)	129341 (32.5)	0 (0.0)	351210 (88.1)	130	90	12	30	7.0

GA scheduled and ABC scheduled peak loads are 390.00 kW (at 01:00, 11:00 hour), 344.00 kW (at 03:00) and 300.00 kW (at 02:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.77, 2.02 and 1.78, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case.

Fig. 106 shows the hourly load scheduling of summer MH with four tariffs by using GA and proposed ABC algorithm. For MH summer load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are

505.00 kW (at 08:00 hour), 545.00 kW (at 02:00) and 505.00 kW (at 01:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.24 and 2.12, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. Unscheduled load shows lowest PAR in this case. For MH summer load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour), 580.00 kW (at 04:00) and 505.00 kW (at 04:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.46 and 2.12, respectively. The unscheduled load shows minimum

**TABLE 10.** Result of multi-objective optimization based on TNPC and emission for single home (RTEP spring, scaled annual average = 79.50 kWh/d, LF=0.55).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	28930 (98.3)	499 (1.7)	-	-	406 (1.38)	0.259	-	-	-	0.0216
2	24859 (85.2)	-	4311 (14.8)	-	153 (0.53)	-	3	-	-	-
3	22311 (72.1)	-	8623 (27.9)	-	1917 (6.20)	-	6	-	-	-
4	20709 (61.6)	-	12934 (38.4)	-	4626 (13.7)	-	9	-	-	-
5	18650 (46.4)	-	21557 (53.6)	-	11189 (27.8)	-	15	-	-	-
6	13692 (12.7)	51299 (47.5)	43114 (39.9)	-	78978 (73.1)	26.7	30	-	-	3.5
7	11302 (7.59)	51299 (34.5)	86228 (57.9)	-	119728 (80.4)	26.7	60	-	-	3.5
8	10017 (5.25)	51299 (26.9)	129341 (67.8)	-	161573 (84.7)	26.7	90	-	-	3.5
9	9986 (3.41)	153897 (52.5)	129341 (44.1)	0 (0.0)	264138 (90.1)	80	90	6.60	30	7.0

**TABLE 11.** Result of multi-objective optimization based on TNPC and emission for single home (RTEP fall, scaled annual average = 170.51 kWh/d, LF=0.35).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	62144 (98.3)	1067 (1.69)	-	-	970 (1.53)	0.555	-	-	-	0.0216
2	54179 (86.3)	-	8623 (13.7)	-	565 (0.90)	-	6	-	-	-
3	51202 (79.8)	-	12934 (20.2)	-	1900 (2.96)	-	9	-	-	-
4	47035 (68.6)	-	21557 (31.4)	-	6356 (9.27)	-	15	-	-	-
5	41057 (48.8)	-	43114 (51.2)	-	21934 (26.1)	-	30	-	-	-
6	38421 (20.1)	109652 (57.4)	43114 (22.6)	-	128811 (67.4)	57.0	30	-	-	14.0
7	32653 (14.3)	109652 (48.0)	86228 (37.7)	-	166186 (72.7)	57.0	60	-	-	14.0
8	29270 (10.9)	109652 (40.9)	129341 (48.2)	-	205934 (76.8)	57.0	90	-	-	14.0
9	29258 (6.0)	328955 (67.5)	129341 (26.5)	0 (0.0)	425224 (87.2)	171	90	23.0	30	7.0

PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case. For MH summer load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 505.00 kW (at 08:00 hour), 530.00 kW (at 02:00) and 400.00 kW (at 05:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.35 and 1.73, respectively. The ABC scheduled shows minimum PAR. While PAR is higher with GA as compared to ABC. ABC scheduled load shows lowest PAR in this case. For MH summer load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 505.00 kW

(at 08:00 hour), 570.00 kW (at 02:00) and 545.00 kW (at 01:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 1.87, 2.56 and 2.35, respectively. The unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case.

Fig. 107 shows the hourly load scheduling of fall MH with four tariffs by using GA and proposed ABC algorithm. For MH fall load with RTEP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour), 842.50 kW (at 07:00) and 714.50 kW

**TABLE 12.** Result of multi-objective optimization based on TNPC and emission for single home (CPP winter, scaled annual average = 128.96 kWh/d, LF=0.5).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	47070 (100)	-	-	-	0 (0.0)	-	-	-	3	0.188
2	42701 (86.9)	6427 (13.1)	-	-	1828 (3.72)	3.34	-	-	-	1.38
3	38314 (64.9)	20680 (35.1)	-	-	11463 (19.4)	10.8	-	-	-	2.83
4	35568 (30.1)	82720 (69.9)	-	-	70611 (59.7)	43.0	-	-	-	5.67
5	27707 (27.9)	41360 (41.7)	30180 (30.4)	-	51933 (52.3)	21.5	7*3	-	-	2.83
6	23714 (14.2)	82720 (49.6)	60359 (36.2)	-	119510 (71.7)	43.0	14*3	-	-	5.67
7	19924 (8.75)	82720 (36.3)	125030 (54.9)	-	180453 (79.3)	43.0	29*3	-	-	5.67
8	17885 (6.25)	82720 (28.9)	185389 (64.8)	-	238799 (83.5)	43.0	43*3	-	-	5.67
9	17643 (3.91)	248159 (55.0)	185389 (41.1)	-	403983 (89.5)	129.0	43*3	12	215	17.0

**TABLE 13.** Result of multi-objective optimization based on TNPC and emission for single home (CPP summer, scaled annual average = 129.36 kWh/d, LF=0.43).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	46175 (96.6)	1618 (3.39)	-	-	523 (1.09)	0.841	-	-	-	0.321
2	39067 (76.3)	12113 (23.7)	-	-	3535 (6.91)	6.30	-	-	-	2.74
3	37219 (64.1)	20840 (35.9)	-	-	10317 (17.8)	10.8	-	-	-	3.17
4	34482 (29.3)	83361 (70.7)	-	-	69957 (59.4)	43.3	-	-	-	6.33
5	26989 (27.3)	41680 (42.2)	30180 (30.5)	-	51351 (51.9)	21.7	7*3	-	-	3.17
6	22870 (13.4)	83361 (48.8)	64671 (37.8)	-	123446 (72.2)	43.3	15*3	-	-	6.33
7	19606 (8.60)	83361 (36.6)	125030 (54.8)	-	180604 (79.2)	43.3	29*3	-	-	6.33
8	17556 (6.04)	83361 (28.7)	189701 (65.3)	-	243258 (83.7)	43.3	44*3	-	-	6.33
9	17277 (3.78)	250083 (54.7)	189701 (41.5)	0 (0.0)	409685 (89.6)	130	44*3	14	216	19.0

(at 17:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.80 and 2.35, respectively. ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC and unscheduled load. ABC scheduled load shows lowest PAR in this case. For MH fall load with CPP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour), 580.00 kW (at 04:00) and 642.50 kW (at 21:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 1.89 and 2.10, respectively. GA scheduled load shows minimum PAR. While PAR is lower with GA as compared

to ABC scheduled and unscheduled load. GA scheduled load shows lowest PAR in this case. For MH fall load with TOU tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour), 639.50 kW (at 17:00) and 622.50 kW (at 03:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.13 and 2.03, respectively. ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. ABC scheduled load shows lowest PAR in this case. For MH fall load with DAP tariff, the unscheduled, GA scheduled and ABC scheduled peak loads are 908.50 kW (at 13:00 hour), 725.00 kW (at 04:00)

**TABLE 14. Result of multi-objective optimization based on TNPC and emission for single home (CPP spring, scaled annual average = 79.50 kWh/d, LF=0.49).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	29018 (100)	-	-	-	0 (0.0)	-	-	-	-	-
2	26231 (86.8)	3986 (13.2)	-	-	1052 (3.48)	2.07	-	-	-	0.894
3	23109 (64.3)	12825 (35.7)	-	-	6606 (18.4)	6.67	-	-	-	1.83
4	19265 (27.3)	51299 (72.7)	-	-	41034 (58.2)	26.7	-	-	-	3.67
5	15976 (25.3)	25649 (40.6)	21557 (34.1)	-	33980 (53.8)	13.3	5*3	-	-	1.83
6	12942 (12.1)	51299 (47.8)	43114 (40.2)	-	78134 (72.8)	26.7	10*3	-	-	3.67
7	11099 (7.47)	51299 (34.5)	86228 (58.0)	-	119457 (80.4)	26.7	20*3	-	-	3.67
8	10083 (5.29)	51299 (26.9)	129341 (67.8)	-	161582 (84.7)	26.7	30*3	-	-	3.67
9	9800 (3.34)	153897 (52.5)	129341 (44.1)	0 (0.0)	263882 (90.1)	80.0	30*3	7.5	133	11.0

**TABLE 15. Result of multi-objective optimization based on TNPC and emission for single home (CPP fall, scaled annual average = 170.51 kWh/d, LF=0.44).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	62236 (100)	-	-	-	0 (0.0)	-	-	-	-	-
2	56586 (86.9)	8519 (13.1)	-	-	2571 (3.95)	4.43	-	-	-	2.03
3	52361 (65.6)	27413 (34.4)	-	-	17018 (21.3)	14.3	-	-	-	4.17
4	48684 (30.7)	109652 (69.3)	-	-	95386 (60.2)	57.0	-	-	-	8.33
5	38573 (28.3)	54826 (40.2)	43114 (31.6)	-	74013 (54.2)	28.5	10*3	-	-	4.17
6	33273 (14.8)	109652 (48.8)	81916 (36.4)	-	162344 (72.2)	57.0	19*3	-	-	8.33
7	28517 (9.44)	109652 (36.3)	163832 (54.2)	-	239568 (79.3)	57.0	38*3	-	-	8.33
8	25751 (6.76)	109652 (28.8)	245749 (64.5)	-	318750 (83.6)	57.0	57*3	-	-	8.33
9	25480 (4.25)	328955 (54.8)	245749 (40.9)	0 (0.0)	537767 (89.6)	171	57*3	18	284	25.0

and 672.00 kW (at 16:00 hour), respectively. The PAR for unscheduled, GA scheduled and ABC scheduled load are 2.56, 2.27 and 2.19, respectively. ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled. ABC scheduled load shows lowest PAR in this case.

Table 7 shows the comparison of GA and proposed ABC algorithm. For SH winter load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. Average waiting time (AWT) is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. Average daily cost (ADC) is minimized with the

proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH winter load with CPP tariff, PAR is minimized by 13.7% with the proposed ABC scheduling. While PAR is higher with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH winter load with TOU tariff, PAR is not minimized with the proposed ABC scheduling. While PAR is same with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared

**TABLE 16.** Result of multi-objective optimization based on TNPC and emission for single home (TOU winter, scaled annual average = 128.96 kWh/d, LF=0.36).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	47010 (99.9)	64.3 (0.1)	-	-	0.904 (0.002)	0.0335	-	-	-	0.0272
2	39781 (65.8)	20680 (34.2)	-	-	13006 (21.5)	10.8	-	-	-	1.92
3	38308 (64.9)	20680 (35.1)	-	-	11457 (19.4)	10.8	-	-	-	3.83
4	37013 (47.2)	41360 (52.8)	-	-	30774 (39.3)	21.5	-	-	-	3.83
5	30295 (29.7)	41360 (40.6)	30180 (29.6)	-	54524 (53.5)	21.5	7*3	-	-	3.83
6	27063 (15.9)	82720 (48.6)	60359 (35.5)	-	122868 (72.2)	43.0	14*3	-	-	7.67
7	23625 (10.2)	82720 (35.8)	125030 (54.0)	-	184158 (79.6)	43.0	29*3	-	-	7.67
8	21675 (7.48)	82720 (28.5)	185389 (64.0)	-	242589 (83.7)	43.0	43*3	-	-	7.67
9	21257 (4.67)	248159 (54.6)	185389 (40.8)	-	407589 (89.6)	129	43*3	17	215	23.0

**TABLE 17.** Result of multi-objective optimization based on TNPC and emission for single home (TOU summer, scaled annual average = 129.36 kWh/d, LF=0.46).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	47051 (99.1)	417 (0.9)	-	-	243 (0.51)	0.217	-	-	-	0.0444
2	39877 (60.5)	26050 (39.5)	-	-	18324 (27.8)	13.5	-	-	-	1.88
3	37446 (64.2)	20840 (35.8)	-	-	10555 (18.1)	10.8	-	-	-	3.00
4	29852 (26.4)	83361 (73.6)	-	-	65083 (57.5)	43.3	-	-	-	12.0
5	28337 (14.5)	166722 (85.5)	-	-	146849 (75.3)	86.7	-	-	-	12.0
6	19378 (7.73)	166722 (66.5)	64671 (25.8)	-	203125 (81.0)	86.7	15*3	-	-	12.0
7	16774 (5.44)	166722 (54.0)	125030 (40.5)	-	260974 (84.6)	86.7	29*3	-	-	12.0
8	15157 (4.08)	166722 (44.9)	189701 (51.1)	-	324082 (87.2)	86.7	44*3	-	-	12.0
9	14989 (3.30)	250083 (55.0)	189701 (41.7)	-	407266 (89.6)	130	44*3	13	216	18.0

to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH winter load with DAP tariff, PAR is minimized by 2.1% with the proposed ABC scheduling. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH spring load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is

lower with GA as compared to ABC. AWT is not minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. Unscheduled load shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH spring load with CPP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. AWT is not minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. Unscheduled load shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC

**TABLE 18. Result of multi-objective optimization based on TNPC and emission for single home (TOU spring, scaled annual average = 79.50 kWh/d, LF=0.45).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	29010 (99.9)	25 (0.1)	-	-	17.7 (0.06)	0.013	-	-	-	0.00179
2	25427 (66.5)	12825 (33.5)	-	-	9045 (23.6)	6.67	-	-	-	0.917
3	22712 (63.9)	12825 (36.1)	-	-	6187 (17.4)	6.67	-	-	-	1.83
4	18963 (27.0)	51299 (73.0)	-	-	40715 (57.9)	26.7	-	-	-	7.33
5	16114 (25.4)	25649 (40.5)	-	-	34110 (53.9)	13.3	5*3	-	-	1.83
6	13139 (12.2)	51299 (47.7)	43114 (40.1)	-	78323 (72.8)	26.7	10*3	-	-	7.33
7	11082 (5.54)	102598 (51.3)	86228 (43.1)	-	170716 (85.4)	53.3	20*3	-	-	7.33
8	10086 (4.17)	102598 (42.4)	129341 (53.4)	-	212863 (88.0)	53.3	30*3	-	-	7.33
9	9989 (3.41)	153897 (52.5)	129341 (44.1)	0 (0.0)	264060 (90.1)	80.0	30*3	8.10	133	11.0

**TABLE 19. result of multi-objective optimization based on TNPC and emission for single home (TOU fall, scaled annual average = 170.51 kWh/d, LF=0.37).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	61981 (99.1)	549 (0.877)	-	-	280 (0.499)	0.285	-	-	-	0.0715
2	57645 (80.8)	13706 (19.2)	-	-	8874 (12.4)	7.13	-	-	-	1.21
3	49722 (64.5)	27413 (35.5)	-	-	14240 (18.5)	14.3	-	-	-	4.83
4	42257 (27.8)	109652 (72.2)	-	-	88621 (58.3)	57.0	-	-	-	9.67
5	35170 (26.4)	54826 (41.2)	43114 (32.4)	-	70462 (52.9)	28.5	10*3	-	-	4.83
6	28759 (13.1)	109652 (49.8)	81916 (37.2)	-	157626 (71.5)	57.0	19*3	-	-	9.67
7	24755 (8.30)	109652 (36.8)	163832 (54.9)	-	235643 (79.0)	57.0	38*3	-	-	9.67
8	22421 (5.93)	109652 (29.0)	245749 (65.0)	-	315280 (83.4)	57.0	57*3	-	-	9.67
9	21681 (3.64)	328955 (55.2)	245749 (41.2)	0 (0.0)	533804 (89.5)	171	57*3	21.0	284	29.0

shows lowest ADC. For SH spring load with TOU tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. AWT is not minimized with the proposed ABC scheduling. While AWT is same with GA as compared to ABC. Unscheduled load shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH spring load with DAP tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. AWT is not minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. Unscheduled load shows lowest AWT. ADC is minimized with the proposed ABC

scheduling. While ADC is lower with GA as compared to ABC. ABC shows lowest ADC. For SH summer load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH summer load with TOU tariff, the unscheduled load shows minimum PAR. While PAR is same with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. ABC shows lowest AWT. ADC is

**TABLE 20.** Result of multi-objective optimization based on TNPC and emission for single home (DAP winter, scaled annual average = 128.96 kWh/d, LF=0.44).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	46898 (99.1)	414 (0.9)	-	-	232 (0.49)	0.215	-	-	-	0.0468
2	37092 (64.2)	20680 (35.8)	-	-	10176 (17.6)	10.8	-	-	-	3.17
3	27545 (25.0)	82720 (75.0)	-	-	62166 (56.4)	43.0	-	-	-	12.7
4	17579 (10.9)	82720 (51.5)	60359 (37.6)	-	113136 (70.4)	43.0	14*3	-	-	12.7
5	16857 (6.95)	165439 (68.2)	60359 (24.9)	-	195095 (80.4)	86.0	14*3	-	-	12.7
6	16452 (5.06)	248159 (76.4)	60359 (18.6)	0 (0.0)	277389 (85.4)	129	14*3	14	-	19.0
7	14166 (4.65)	165439 (54.3)	125030 (41.0)	-	257204 (84.4)	86.0	29*3	-	-	12.7
8	12686 (3.49)	165439 (45.5)	185389 (51.0)	-	316144 (87.0)	86.0	43*3	-	-	12.7
9	12423 (2.79)	248159 (55.6)	185389 (41.6)	0 (0.0)	398586 (89.4)	129	43*3	14	215	19.0

**TABLE 21.** Result of multi-objective optimization based on TNPC and emission for single home (DAP summer, scaled annual average = 129.36 kWh/d, LF=0.49).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	47199 (99.9)	48.9 (0.1)	-	-	30.9 (0.07)	0.0254	-	-	-	0.0045
2	37286 (64.1)	20840 (35.9)	-	-	10388 (17.9)	10.8	-	-	-	2.83
3	28417 (25.4)	83361 (74.6)	-	-	63572 (56.9)	43.3	-	-	-	5.67
4	26889 (24.4)	83361 (75.6)	-	-	61964 (56.2)	43.3	-	-	-	11.3
5	24913 (13.0)	166722 (87.0)	-	-	143245 (74.7)	86.7	-	-	-	11.3
6	15952 (6.45)	166722 (67.4)	64671 (26.1)	-	199613 (80.7)	86.7	15*3	-	-	11.3
7	13651 (4.47)	166722 (54.6)	125030 (40.9)	-	257785 (84.4)	86.7	29*3	-	-	11.3
8	11971 (2.65)	250083 (55.4)	189701 (42.0)	-	404191 (89.5)	130	44*3	-	-	11.3
9	11971 (2.65)	250083 (55.4)	189701 (42.0)	0 (0.0)	404191 (89.5)	130	44*3	13	216	17.0

minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH summer load with DAP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH fall load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. AWT is minimized with the proposed ABC scheduling. While AWT

is same with GA as compared to ABC. GA and ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH fall load with CPP tariff, GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. AWT is not minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH fall load with TOU tariff, GA scheduled load shows minimum

**TABLE 22.** Result of multi-objective optimization based on TNPC and emission for single home (DAP spring, scaled annual average = 79.50 kWh/d, LF=0.52).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	28966 (99.3)	200 (0.7)	-	-	146 (0.50)	0.104	-	-	-	0.013
2	23043 (64.2)	12825 (35.8)	-	-	6535 (18.2)	6.67	-	-	-	1.67
3	16059 (23.8)	51299 (76.2)	-	-	37658 (55.9)	26.7	-	-	-	6.67
4	15214 (12.9)	102598 (87.1)	-	-	88068 (74.8)	53.3	-	-	-	6.67
5	10599 (10.1)	51299 (48.9)	43114 (41.1)	-	75705 (72.1)	26.7	10*3	-	-	6.67
6	10001 (4.83)	153897 (74.3)	43114 (20.8)	-	177673 (85.8)	80.0	10*3	-	-	6.67
7	8732 (4.42)	102598 (51.9)	86228 (43.6)	-	168304 (85.2)	53.3	20*3	-	-	6.67
8	7916 (3.30)	102598 (42.8)	129341 (53.9)	-	210643 (87.8)	53.3	30*3	-	-	6.67
9	7787 (2.68)	153897 (52.9)	129341 (44.4)	0 (0.0)	261806 (90.0)	80.0	30*3	7.10	133	10.0

**TABLE 23.** Result of multi-objective optimization based on TNPC and emission for single home (DAP fall, scaled annual average = 170.51 kWh/d, LF=0.51).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	62192 (99.9)	85.5 (0.1)	-	-	38.5 (0.06)	0.0444	-	-	-	0.0128
2	49643 (64.4)	27413 (35.6)	-	-	14157 (18.4)	14.3	-	-	-	3.50
3	35758 (24.6)	109652 (75.4)	-	-	81780 (56.2)	57.0	-	-	-	7.0
4	29424 (21.2)	109652 (78.8)	-	-	75113 (54.0)	57.0	-	-	-	14.0
5	27291 (11.1)	219303 (88.9)	-	-	182519 (74.0)	114	-	-	-	14.0
6	17234 (5.41)	219303 (68.9)	81916 (25.7)	-	255369 (80.2)	114	19*3	-	-	14.0
7	14222 (2.81)	328955 (64.9)	163832 (32.3)	-	444107 (87.6)	171	38*3	-	-	14.0
8	12754 (2.17)	328955 (56.0)	245749 (41.8)	-	524667 (89.3)	171	57*3	-	-	14.0
9	12754 (2.17)	328955 (56.0)	245749 (41.8)	0 (0.0)	524667 (89.3)	171	57*3	16	284	21.0

PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. ABC shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For SH fall load with DAP tariff, GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. Unscheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to

ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC. ABC shows lowest ADC.

It is surprising to note two cases that for SH spring load with DAP tariff; ADC is lower with GA as compared to ABC. For SH fall load with DAP tariff, ADC is again lower with GA as compared to ABC.

Fig. 108 shows the comparison of SH TNPC vs emission with four tariffs by using proposed ABC algorithm. Table 8 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH RTEP winter load. Table 9

**TABLE 24. Result comparison of GA and ABC algorithm for MH.**

Tariff	Parameter	Algorithms			
		Unscheduled	GA	ABC	
winter load with RTEP tariff	Average Waiting time (Hours)		3.7917	5.0000	3.2917
	PAR (%)		2.3393	2.5901	2.6521
	Net Cost→ Average daily cost (£/h)		9101.578	7052.900	5717.525
winter load with CPP tariff	Average Waiting time (Hours)		3.7917	2.9167	3.1667
	PAR (%)		2.3393	2.1213	2.8632
	Net Cost→ Average daily cost (£/h)		16322.769	10078.000	9817.230
winter load with TOU tariff	Average Waiting time (Hours)		3.7917	3.3333	3.3750
	PAR (%)		2.3393	2.3589	2.4633
	Net Cost→ Average daily cost (£/h)		3589.894	2032.100	1890.055
Winter load with DAP tariff	Average Waiting time (Hours)		3.7917	4.0417	3.2917
	PAR (%)		2.3393	2.2284	2.3169
	Net Cost→ Average daily cost (£/h)		2286.500	1827.300	1768.7
Spring load with RTEP tariff	Average Waiting time (Hours)		2.5833	6.000	3.2500
	PAR (%)		1.7694	1.9712	1.9099
	Net Cost→ Average daily cost (£/h)		6970.807	7763.600	5127.309
Spring load with CPP tariff	Average Waiting time (Hours)		2.5833	6.000	2.6667
	PAR (%)		1.7694	2.0792	2.0568
	Net Cost→ Average daily cost (\$/h)		11038.000	7818.100	7875.758
Spring load with TOU tariff	Average Waiting time (Hours)		2.5833	2.2500	3.4167
	PAR (%)		1.7694	1.8228	1.8511
	Net Cost→ Average daily cost (£/h)		2545.400	1502.300	1602.251
Spring load with DAP tariff	Average Waiting time (Hours)		2.5833	4.0417	3.6667
	PAR (%)		1.7694	2.0166	1.7848
	Net Cost→ Average daily cost (£/h)		1846.8	1413.700	1395.9
Fall load with RTEP tariff	Average Waiting time (Hours)		4.000	6.000	3.9167
	PAR (%)		2.5575	2.7984	2.3553
	Net Cost→ Average daily cost (£/h)		12635.502	12807.000	8050.634
Fall load with CPP tariff	Average Waiting time (Hours)		4.000	6.000	3.8750
	PAR (%)		2.5575	1.8937	2.0964
	Net Cost→ Average daily cost (£/h)		22990.000	14263.000	12918.300
Fall load with TOU tariff	Average Waiting time (Hours)		4.000	5.5000	3.8750
	PAR (%)		2.5575	2.1300	2.0311
	Net Cost→ Average daily cost (£/h)		4850.227	3174.600	2846.394
Fall load with DAP tariff	Average Waiting time (Hours)		4.000	5.8750	3.8750
	PAR (%)		2.5575	2.2669	2.1926
	Net Cost→ Average daily cost (£/h)		2935.6	2651.800	2405.1
Summer load with RTEP tariff	Average Waiting time (Hours)		3.4167	5.000	2.7500
	PAR (%)		1.8738	2.2405	2.1252
	Net Cost→ Average daily cost (£/h)		8988.955	7222.5	6818.099
Summer load with CPP tariff	Average Waiting time (Hours)		3.4167	5.000	2.8333
	PAR (%)		1.8738	2.4559	2.1252
	Net Cost→ Average daily cost (\$/h)		14834.98	9994.700	10022.558
Summer load with TOU tariff	Average Waiting time (Hours)		3.4167	3.6667	2.8333
	PAR (%)		1.8738	2.3455	1.7288
	Net Cost→ Average daily cost (£/h)		3080.023	2238.000	2293.922

TABLE 24. (Continued.) Result comparison of GA and ABC algorithm for MH.

Summer load with DAP tariff	Average Waiting time (Hours)		3.4167	4.6667	3.1250
	PAR (%)		1.8738	2.5556	2.3555
	Net Cost → Average daily cost (€/h)		2167.6	1820.300	1940.4

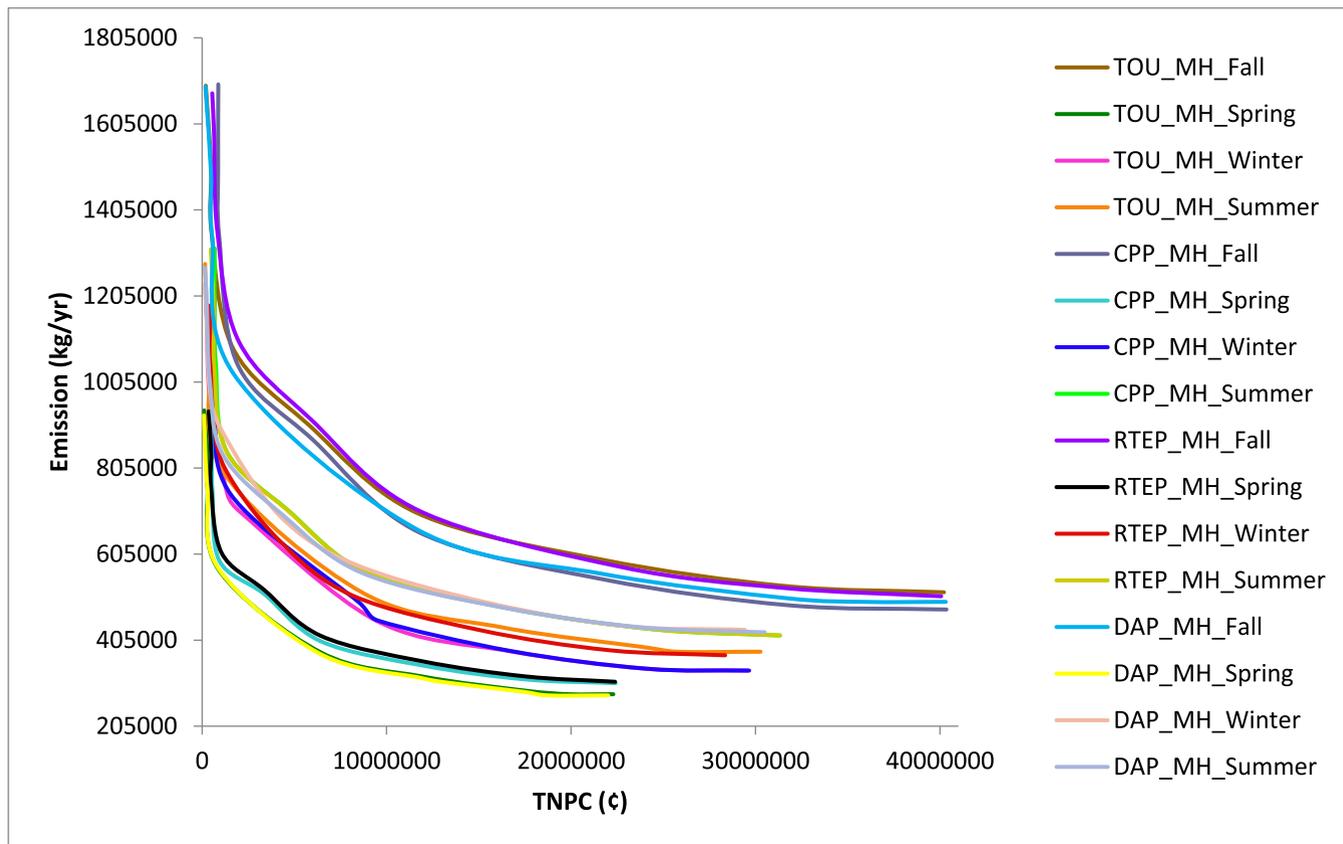


FIGURE 109. Results comparison of multiple Home TNPC and emission with different tariffs and seasons.

shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH RTEP summer load. Table 10 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH RTEP spring load. Table 11 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH RTEP fall load.

Table 12 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH CPP winter load. Table 13 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH CPP summer load. Table 14 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH CPP spring load.

Table 15 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH CPP fall load.

Table 16 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH TOU winter load. Table 17 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH TOU summer load. Table 18 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH TOU spring load. Table 19 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH TOU fall load.

Table 20 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH DAP winter load.

**TABLE 25. Result of multi-objective optimization based on TNPC and emission for multiple home (RTEP winter, scaled annual average = 5135.5 kWh/d, LF=0.38).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1871045 (99.7)	6020 (0.3)	-	-	2428 (0.13)	3.13	-	-	-	1.01
2	1601890 (66.1)	823349 (33.9)	-	-	536436 (22.1)	428	-	-	-	71
3	1483149 (64.3)	823349 (35.7)	-	-	411445 (17.8)	428	-	-	-	142
4	1274368 (27.9)	3293395 (72.1)	-	-	2661722 (58.3)	1712	-	-	-	284
5	1007858 (26.0)	1646697 (42.4)	1228744 (31.6)	-	1996219 (51.4)	856	285*3	-	-	142
6	805521 (12.3)	3293395 (50.2)	2461799 (37.5)	-	4673107 (71.2)	1712	571*3	-	-	284
7	677225 (7.62)	3293395 (37.0)	4919286 (55.3)	-	7005678 (78.8)	1712	1141*3	-	-	284
8	603719 (5.35)	3293395 (29.2)	7381085 (65.4)	-	9395699 (83.3)	1712	1712*3	-	-	284
9	585150 (3.28)	9880184 (55.4)	7381085 (41.4)	0 (0.0)	15962941 (89.4)	5136	1712*3	630	8553	852

**TABLE 26. Result of multi-objective optimization based on TNPC and emission for multiple home (RTEP summer, scaled annual average = 5703 kWh/d, LF=0.47).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2077716 (99.3)	14288 (0.68)	-	-	10205 (0.49)	7.43	-	-	-	0.987
2	1833364 (66.7)	914404 (33.3)	-	-	653108 (23.8)	475	-	-	-	63.2
3	1658173 (64.5)	914404 (35.5)	-	-	468697 (18.2)	475	-	-	-	126
4	1337630 (26.8)	3657617 (73.2)	-	-	2874496 (57.5)	1901	-	-	-	253
5	1118508 (25.9)	1828809 (42.4)	1366708 (31.7)	-	2217764 (51.4)	951	317*3	-	-	126
6	887520 (12.2)	3657617 (50.3)	2733416 (37.6)	-	5180846 (71.2)	1901	634*3	-	-	253
7	756517 (7.66)	3657617 (37.0)	5466831 (55.3)	-	7787386 (78.8)	1901	1268*3	-	-	253
8	680729 (5.43)	3657617 (29.2)	8200247 (65.4)	-	10447235 (83.3)	1901	1902*3	-	-	253
9	658030 (3.32)	10972852 (55.3)	8200247 (41.4)	0 (0.0)	17738577 (89.4)	5704	1902*3	560	9498	758

Table 21 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH DAP summer load. Table 22 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH DAP spring load. Table 23 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with SH DAP fall load.

Table 24 shows the comparison of GA and proposed ABC algorithm. For MH winter load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is lower with

GA as compared to ABC. Unscheduled load shows lowest PAR in this case. Average waiting time (AWT) is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. ABC shows lowest AWT. Average daily cost (ADC) is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH winter load with CPP tariff, GA scheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. ABC scheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC.

**TABLE 27. Result of multi-objective optimization based on TNPC and emission for multiple home (RTEP spring, scaled annual average = 4084 kWh/d, LF=0.52).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1482279 (96.7)	51331 (3.35)	-	-	42509 (2.77)	26.7	-	-	-	2.05
2	1329343 (67.0)	654864 (33.0)	-	-	485056 (24.4)	340	-	-	-	40.7
3	1199610 (64.7)	654864 (35.3)	-	-	348496 (18.8)	340	-	-	-	81.3
4	961093 (26.8)	2619454 (73.2)	-	-	2062016 (57.6)	1362	-	-	-	325
5	827507 (26.6)	1309727 (42.0)	978684 (31.4)	-	1615774 (51.9)	681	227*3	-	-	81.3
6	656764 (12.5)	2619454 (50.1)	1957367 (37.4)	-	3731793 (71.3)	1362	454*3	-	-	163
7	562635 (7.93)	2619454 (36.9)	3914734 (55.2)	-	5597744 (78.9)	1362	908*3	-	-	163
8	507347 (5.64)	2619454 (29.1)	5872101 (65.3)	-	7501285 (83.4)	1362	1362*3	-	-	163
9	487621 (3.43)	7858363 (55.3)	5872101 (41.3)	-	12719429 (89.5)	4085	1362*3	360	6802	488

**TABLE 28. Result of multi-objective optimization based on TNPC and emission for multiple home (RTEP fall, scaled annual average = 7280.5 kWh/d, LF=0.42).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2651952 (99.3)	18238 (0.68)	-	-	12521 (0.47)	9.48	-	-	-	1.40
2	2485823 (82.2)	539315 (17.8)	-	-	358725 (11.9)	280	-	-	-	44.5
3	2147399 (64.8)	1167212 (35.2)	-	-	630387 (19.0)	607	-	-	-	179
4	1740029 (27.2)	4668848 (72.8)	-	-	3703213 (57.8)	2427	-	-	-	715
5	1451686 (26.2)	2334424 (42.2)	1746109 (31.6)	-	2857912 (51.7)	1214	405*3	-	-	179
6	1116210 (12.0)	4668848 (50.3)	3487907 (37.6)	-	6595503 (71.1)	2427	809*3	-	-	715
7	909680 (5.28)	9337697 (54.2)	6975815 (40.5)	-	14549599 (84.5)	4854	1618*3	-	-	715
8	832717 (5.22)	4668848 (29.2)	10463722 (65.5)	-	13295616 (83.3)	2427	2427*3	-	-	715
9	802137 (3.17)	14006545 (55.4)	10463722 (41.4)	0 (0.0)	22601123 (89.4)	7281	2427*3	790	12125	1072

GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH winter load with TOU tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. ABC scheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH winter load with DAP tariff, GA scheduled load shows minimum PAR. While PAR is lower with

GA as compared to ABC scheduled and unscheduled load. Unscheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH spring load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. Unscheduled load shows lowest PAR in this case. AWT is not minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. Unscheduled load

**TABLE 29. Result of multi-objective optimization based on TNPC and emission for multiple home (CPP winter, scaled annual average = 5360.5 kWh/d, LF=0.35).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1956582 (100)	-	-	-	0 (0.0)	-	-	-	-	-
2	1761404 (88.1)	238151 (11.9)	-	-	32700 (164)	124	-	-	-	69.8
3	1530574 (64.0)	859418 (36.0)	-	-	410988 (17.2)	447	-	-	-	160
4	1177180 (25.5)	3437673 (74.5)	-	-	2617249 (56.7)	1787	-	-	-	640
5	778994 (11.5)	3437673 (50.7)	2569583 (37.9)	-	4813208 (70.9)	1787	596*3	-	-	320
6	712519 (7.01)	6875346 (67.7)	2569583 (25.3)	-	8180907 (80.5)	3574	596	-	-	640
7	599770 (4.76)	6875346 (54.5)	5134855 (40.7)	-	10638537 (84.4)	3574	1191*3	-	-	640
8	769487 (9.08)	7704438 (90.9)	-	-	6517342 (76.9)	1787	2976*3	-	-	640
9	528867 (2.85)	10313019 (55.6)	7704438 (41.5)	0 (0.0)	16577077 (89.4)	5361	1787*3	710	8928	960

**TABLE 30. RESULT of multi-objective optimization based on TNPC and emission for multiple home (CPP summer, scaled annual average = 5703 kWh/d, LF=0.47).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2081595 (100)	-	-	-	0 (0.0)	-	-	-	-	-
2	1836585 (83.1)	373417 (16.9)	-	-	115512 (5.23)	194	-	-	-	77
3	1658173 (64.5)	914404 (35.5)	-	-	468697 (18.2)	475	-	-	-	126
4	1337630 (26.8)	3657617 (73.2)	-	-	2874496 (57.5)	1901	-	-	-	253
5	1118508 (25.9)	1828809 (42.4)	1366708 (31.7)	-	2217764 (51.4)	951	317*3	-	-	126
6	887520 (12.2)	3657617 (50.3)	2733416 (37.6)	-	5180846 (71.2)	1901	634*3	-	-	253
7	756517 (7.66)	3657617 (37.0)	5466831 (55.3)	-	7787386 (78.8)	1901	1268*3	-	-	253
8	680729 (5.43)	3657617 (29.2)	8200247 (65.4)	-	10447235 (83.3)	1901	1902*3	-	-	253
9	658030 (3.32)	10972852 (55.3)	8200247 (41.4)	0 (0.0)	17738577 (89.4)	5704	1902*3	560	9498	758

shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC and unscheduled load. ABC shows lowest ADC. For MH spring load with CPP tariff, ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. ABC scheduled load shows lowest PAR in this case. AWT is not minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC. Unscheduled load shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH spring load with TOU

tariff, the unscheduled load shows minimum PAR. While PAR is lower with GA as compared to ABC. ABC scheduled load shows highest PAR in this case. AWT is not minimized with the proposed ABC scheduling. While AWT is lower with GA as compared to ABC and unscheduled load. GA shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH spring load with DAP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case. AWT is minimized with

**TABLE 31.** Result of multi-objective optimization based on TNPC and emission for multiple home (CPP spring, scaled annual average = 4084 kWh/d, LF=0.49).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1487965 (99.3)	10232 (0.68)	-	-	7396 (0.49)	5.32	-	-	-	0.684
2	1318135 (83.1)	267428 (16.9)	-	-	85822 (5.41)	139	-	-	-	53.3
3	1182638 (64.4)	654864 (35.6)	-	-	330630 (18.0)	340	-	-	-	87.5
4	932960 (26.3)	2619454 (73.7)	-	-	2032402 (57.2)	1362	-	-	-	175
5	810908 (26.2)	1309727 (42.3)	978684 (31.6)	-	1598191 (51.6)	681	227*3	-	-	87.5
6	636620 (12.2)	2619454 (50.2)	1957367 (37.5)	-	3710575 (71.2)	1362	454*3	-	-	175
7	547333 (7.73)	2619454 (37.0)	3914734 (55.3)	-	5581661 (78.8)	1362	908*3	-	-	175
8	496402 (5.52)	2619454 (29.1)	5872101 (65.3)	-	7489731 (83.3)	1362	1362*3	-	-	175
9	482512 (3.39)	7858363 (55.3)	5872101 (41.3)	0 (0.0)	12714019 (89.5)	4085	1362*3	390	6802	525

**TABLE 32.** Result of multi-objective optimization based on TNPC and emission for multiple home (CPP fall, scaled annual average = 7355.5 kWh/d, LF=0.48).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2684758 (100)	-	-	-	0 (0.0)	-	-	-	-	-
2	2369816 (83.1)	481567 (16.9)	-	-	150050 (5.26)	250	-	-	-	97.9
3	2119490 (64.3)	1179235 (35.7)	-	-	584216 (17.7)	613	-	-	-	161
4	1655645 (26.0)	4716941 (74.0)	-	-	3633665 (57.0)	2452	-	-	-	643
5	1379114 (25.1)	2358471 (42.9)	1763355 (32.1)	-	2797188 (50.8)	1226	409*3	-	-	161
6	1035819 (11.2)	4716941 (50.9)	3522398 (38.0)	-	6568544 (70.8)	2452	817*3	-	-	643
7	863573 (6.84)	4716941 (37.3)	7049108 (55.8)	-	9928821 (78.6)	2452	1635*3	-	-	643
8	769132 (4.79)	4716941 (29.4)	10571507 (65.8)	-	13359727 (83.2)	2452	2452*3	-	-	643
9	753474 (2.96)	14150824 (55.5)	10571507 (41.5)	0 (0.0)	22777126 (89.4)	7356	2452*3	710	12250	964

the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH summer load with RTEP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. Unscheduled load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA

as compared to ABC. ABC shows lowest ADC. For MH summer load with CPP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC. GA shows lowest ADC. For MH summer load with TOU tariff, The ABC scheduled shows minimum PAR. While PAR is higher with GA as compared to ABC. ABC scheduled

**TABLE 33. Result of multi-objective optimization based on TNPC and emission for multiple home (TOU winter, scaled annual average = 5360.5 kWh/d, LF=0.35).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1951830 (99.3)	13428 (0.7)	-	-	8426 (0.429)	6.98	-	-	-	1.25
2	1804511 (80.8)	429709 (19.2)	-	-	269634 (12.1)	223	-	-	-	40.0
3	1530574 (64.0)	859418 (36.0)	-	-	410988 (17.2)	447	-	-	-	160
4	1177180 (25.5)	3437673 (74.5)	-	-	2617249 (56.7)	1787	-	-	-	640
5	1106929 (13.9)	6875346 (86.1)	-	-	5980973 (74.9)	3574	-	-	-	640
6	712519 (7.01)	6875346 (67.7)	2569583 (25.3)	-	8180907 (80.5)	3574	596	-	-	640
7	599770 (4.76)	6875346 (54.5)	5134855 (40.7)	-	10638537 (84.4)	3574	1191*3	-	-	640
8	535813 (3.54)	6875346 (45.5)	7704438 (51.0)	-	13146716 (87.0)	3574	1787*3	-	-	640
9	528867 (2.85)	10313019 (55.6)	7704438 (41.5)	0 (0.0)	16577077 (89.4)	5361	1787*3	710	8929	960

**TABLE 34. Result of multi-objective optimization based on TNPC and emission for multiple home (TOU summer, scaled annual average = 5553 kWh/d, LF=0.58).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2024213 (99.7)	6510 (0.3)	-	-	3739 (0.18)	3.38	-	-	-	0.710
2	1947711 (93.2)	142100 (6.80)	-	-	58800 (2.81)	73.9	-	-	-	23.2
3	1667439 (65.2)	890358 (34.8)	-	-	512036 (20.0)	463	-	-	-	100
4	1254804 (26.1)	3561432 (73.9)	-	-	2748757 (57.1)	1851	-	-	-	401
5	813715 (11.6)	3561432 (50.6)	-	-	4991249 (70.9)	1851	617*3	-	-	401
6	687288 (7.18)	3561432 (37.2)	5324556 (55.6)	-	7533506 (78.7)	1851	1235*3	-	-	401
7	615912 (5.06)	3561432 (29.3)	7984678 (65.7)	-	10124467 (83.2)	1851	1852*3	-	-	401
8	598193 (3.10)	10684295 (55.5)	7984678 (41.4)	0 (0.0)	17228679 (89.4)	5554	1852*3	440	-	601
9	598193 (3.10)	10684295 (55.5)	7984678 (41.4)	0 (0.0)	17228679 (89.4)	5554	1852*3	440	9248	601

load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC. GA shows lowest ADC. For MH summer load with DAP tariff, the unscheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows highest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC

is minimized with the proposed ABC scheduling. While ADC is lower with GA as compared to ABC. GA shows lowest ADC. For MH fall load with RTEP tariff, ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC and unscheduled load. ABC scheduled load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC and unscheduled load. ABC shows lowest ADC. For MH fall load with CPP tariff, GA scheduled load shows

**TABLE 35. Result of multi-objective optimization based on TNPC and emission for multiple home (TOU spring, scaled annual average = 4084 kWh/d, LF=0.54).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1485761 (98.6)	20464 (1.36)	-	-	15308 (1.02)	10.6	-	-	-	1.23
2	1333896 (67.1)	654864 (32.9)	-	-	489849 (24.6)	340	-	-	-	39.4
3	1206052 (64.8)	654864 (35.2)	-	-	355277 (19.1)	340	-	-	-	78.8
4	899153 (25.6)	2619454 (74.4)	-	-	1996816 (56.8)	1362	-	-	-	315
5	595299 (11.5)	2619454 (50.6)	1957367 (37.8)	-	3668448 (70.9)	1362	454*3	-	-	315
6	506320 (7.19)	2619454 (37.2)	3914734 (55.6)	-	5539983 (78.7)	1362	908*3	-	-	315
7	454630 (5.08)	2619454 (29.3)	5872101 (65.6)	-	7447377 (83.2)	1362	1362*3	-	-	315
8	441857 (3.12)	7858363 (55.4)	5872101 (41.4)	-	12672840 (89.4)	4085	1362*3	-	2267	315
9	441857 (3.12)	7858363 (55.4)	5872101 (41.4)	-	12672840 (89.4)	4085	1362*3	350	6802	473

**TABLE 36. Result of multi-objective optimization based on TNPC and emission for multiple home (TOU fall, scaled annual average = 7355.5 kWh/d, LF=0.49).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2679959 (99.3)	18426 (0.7)	-	-	13374 (0.50)	9.58	-	-	-	1.22
2	2377625 (66.8)	1179235 (33.2)	-	-	855938 (24.1)	613	-	-	-	77.8
3	2134332 (64.4)	1179235 (35.6)	-	-	599840 (18.1)	613	-	-	-	156
4	1714280 (26.7)	4716941 (73.3)	-	-	3695386 (57.5)	2452	-	-	-	623
5	1434361 (25.8)	2358471 (42.4)	-	-	2853727 (51.4)	1226	409*3	-	-	156
6	1108534 (11.9)	4716941 (50.5)	3522398 (37.7)	-	6642588 (71.1)	2452	817*3	-	-	623
7	936939 (7.38)	4716941 (37.1)	7049108 (55.5)	-	10003067 (78.7)	2452	1635*3	-	-	623
8	839530 (5.21)	4716941 (29.2)	10571507 (65.5)	-	13430793 (83.3)	2452	2452*3	-	-	623
9	816677 (3.20)	14150824 (55.4)	10571507 (41.4)	0 (0.0)	22840619 (89.4)	7356	2452*3	690	12250	934

minimum PAR. While PAR is lower with GA as compared to ABC scheduled and unscheduled load. GA scheduled load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH fall load with TOU tariff, ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC. ABC scheduled load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as

compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC. For MH fall load with DAP tariff, ABC scheduled load shows minimum PAR. While PAR is higher with GA as compared to ABC scheduled. ABC scheduled load shows lowest PAR in this case. AWT is minimized with the proposed ABC scheduling. While AWT is higher with GA as compared to ABC and unscheduled load. ABC shows lowest AWT. ADC is minimized with the proposed ABC scheduling. While ADC is higher with GA as compared to ABC. ABC shows lowest ADC.

**TABLE 37.** Result of multi-objective optimization based on TNPC and emission for multiple home (DAP winter, scaled annual average = 5360.5 kWh/d, LF=0.43).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1951285 (99.6)	3357 (0.2)	4311 (0.2)	-	2320 (0.12)	1.75	1*3	-	3	0.253
2	1830422 (81.0)	429709 (19.0)	-	-	296908 (13.1)	223	-	-	-	32.4
3	1567091 (64.6)	859418 (35.4)	-	-	449427 (18.5)	447	-	-	-	130
4	1407682 (29.1)	3437673 (70.9)	-	-	2859883 (59.0)	1787	-	-	-	259
5	1407682 (29.1)	3437673 (70.9)	-	-	2859883 (59.0)	1787	-	-	5952	518
6	917373 (13.2)	3437673 (49.6)	2569583 (37.1)	-	4957316 (71.6)	1787	596*3	-	-	259
7	775806 (8.30)	3437673 (36.8)	5134855 (54.9)	-	7383887 (79.0)	1787	1191*3	-	-	259
8	692307 (5.85)	3437673 (29.0)	7704438 (65.1)	-	9871420 (83.4)	1787	1787*3	-	-	259
9	679060 (3.63)	10313019 (55.2)	7704438 (41.2)	0 (0.0)	16732822 (89.5)	5361	1787*3	570	8928	777

**TABLE 38.** Result of multi-objective optimization based on TNPC and emission for multiple home (DAP summer, scaled annual average = 5553 kWh/d, LF=0.42).

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2010270 (97.3)	55647 (2.69)	-	-	38200 (1.85)	28.9	-	-	-	4.26
2	1895940 (82.2)	411393 (17.8)	-	-	273598 (11.9)	214	-	-	-	33.9
3	1589717 (64.1)	890358 (35.9)	-	-	430223 (17.3)	463	-	-	-	136
4	1322117 (27.1)	3561432 (72.9)	-	-	2819613 (57.7)	1851	-	-	-	273
5	1302830 (26.8)	3561432 (73.2)	-	-	2799311 (57.5)	1851	-	-	6165	545
6	888137 (12.5)	3561432 (50.1)	2660122 (37.4)	-	5067590 (71.3)	1851	617*3	-	-	273
7	761584 (7.89)	3561432 (36.9)	5324556 (55.2)	-	7609355 (78.9)	1851	1235*3	-	-	273
8	688034 (5.62)	3561432 (29.1)	7984678 (65.3)	-	10197971 (83.4)	1851	1852*3	-	-	273
9	669507 (3.46)	10684295 (55.2)	7984678 (41.3)	0 (0.0)	17301332 (89.5)	5554	1852*3	600	9248	818

It is surprising to note that for MH spring load with RTEP tariff, ADC is higher with GA as compared to ABC and unscheduled load. For MH spring load with CPP tariff, ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH spring load with TOU tariff, ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH summer load with DAP tariff, ADC is lower with GA as compared to ABC. GA shows lowest ADC. For MH fall load with RTEP tariff, ADC is higher with GA as compared to ABC and unscheduled load.

Fig. 109 shows the comparison of MH TNPC vs emission with four tariffs by using proposed ABC algorithm.

Table 25 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH RTEP winter load. Table 26 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH RTEP summer load. Table 27 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH RTEP spring load. Table 28 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH RTEP fall load.

**TABLE 39. Result of multi-objective optimization based on TNPC and emission for multiple home (DAP spring, scaled annual average = 4034 kWh/d, LF=0.56).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	1467726 (98.6)	20214 (1.36)	-	-	15283 (1.03)	10.5	-	-	-	1.17
2	1197998 (64.9)	646848 (35.1)	-	-	357994 (19.4)	336	-	-	-	75.2
3	901952 (25.8)	2587392 (74.2)	-	-	1986910 (56.9)	1345	-	-	-	301
4	591065 (11.6)	2587392 (50.6)	1931499 (37.8)	-	3624901 (70.9)	1345	448*3	-	-	301
5	501635 (7.21)	2587392 (37.2)	3867309 (55.6)	-	5474327 (78.7)	1345	897*3	-	-	301
6	484987 (4.0)	7762177 (64.1)	3867309 (31.9)	0 (0.0)	10631587 (87.8)	4035	897*3	340	-	451
7	451423 (5.11)	2587392 (29.3)	5798808 (65.6)	-	7357285 (83.2)	1345	1345*3	-	-	301
8	437537 (3.13)	7762177 (55.4)	5798808 (41.4)	0 (0.0)	12517452 (89.4)	4035	1345*3	340	-	451
9	437537 (3.13)	7762177 (55.4)	5798808 (41.4)	0 (0.0)	12517452 (89.4)	4035	1345*3	340	6718	451

**TABLE 40. Result of multi-objective optimization based on TNPC and emission for multiple home (DAP fall, scaled annual average = 7355.5 kWh/d, LF=0.46).**

Case	Production (kWh/yr, %)				Excess Energy (kWh/yr, %)	Optimal Sizes				
	Grid	PV	Wind	Diesel		PV (kW)	Wind (kW)	Diesel (kW)	Battery (kWh)	Converter (kW)
1	2676233 (99.5)	8622 (0.3)	4311 (0.2)	-	4186 (0.16)	4.48	1*3	-	-	1.19
2	2355606 (66.6)	1179235 (33.4)	-	-	832760 (23.6)	613	-	-	-	84.0
3	2128476 (64.3)	1179235 (35.7)	-	-	593676 (17.9)	613	-	-	-	168
4	1615826 (25.5)	4716941 (74.5)	-	-	3591750 (56.7)	2452	-	-	-	672
5	1045599 (11.3)	4716941 (50.8)	3522398 (37.9)	-	6576801 (70.8)	2452	817*3	-	-	672
6	884089 (6.99)	4716941 (37.3)	7049108 (55.7)	-	9948007 (78.6)	2452	1635*3	-	-	672
7	794783 (4.94)	4716941 (29.3)	10571507 (65.7)	-	13384162 (83.2)	2452	2452*3	-	-	672
8	781635 (3.06)	14150824 (55.5)	10571507 (41.5)	-	22804205 (89.4)	7356	2452*3	-	4083	672
9	781635 (3.06)	14150824 (55.5)	10571507 (41.5)	0 (0.0)	22804205 (89.4)	7356	2452*3	740	12250	1008

Table 29 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH CPP winter load. Table 30 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH CPP summer load. Table 31 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH CPP spring load. Table 32 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH CPP fall load.

Table 33 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH TOU winter load. Table 34 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH TOU summer load. Table 35 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH TOU spring load. Table 36 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH TOU fall load.

Table 37 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH DAP winter load. Table 38 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH DAP summer load. Table 39 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH DAP spring load. Table 40 shows the optimal sizing based on minimization of emission and TNPC for grid-connected DERs by using proposed ABC algorithm with MH DAP fall load.

## VI. CONCLUSION

In this paper a DSM has been proposed to simultaneously minimize electricity cost, PAR, user discomfort, TNPC and environmental emissions using ABC algorithm for a SH and MH with RTEP, CPP, TOU and DAP tariffs. Two test cases were formed and investigated. In the first test case, three objectives, including electricity cost, PAR and user discomfort were simultaneously minimized by using ABC algorithm, and results were compared with standard heuristic algorithms including WDO, HSA, GA and GHSA. It has been observed that proposed ABC algorithm outperforms these algorithms. In the second test case, five objectives, including electricity cost, PAR, user discomfort, TNPC and environmental emissions were simultaneously minimized by using ABC algorithm, and results were compared with GA. It has been observed that in terms of electricity cost both algorithms have major differences except some cases where almost same performance is observed. For PAR and user discomfort, ABC algorithm outperforms GA except multiple cases where GA performance is better. As of TNPC and environmental emissions are concerned, ABC algorithm is applied for the optimal sizing of grid-connected DERs with four tariffs such as RTEP, CPP, TOU and DAP. There is a trade-off between TNPC and emissions for optimal sizing of grid-connected DERs. Following points can be concluded from this research article:

- For SH winter load with RTEP tariff, ABC shows lowest average daily cost (ADC). For SH winter load with CPP tariff, PAR is minimized with the proposed ABC scheduling. ABC shows lowest ADC. For SH winter load with TOU tariff, ABC shows lowest ADC. For SH winter load with DAP tariff, PAR is minimized with the proposed ABC scheduling. ABC shows lowest ADC. For SH spring load with RTEP tariff, ABC shows lowest ADC. For SH spring load with CPP tariff, ABC shows lowest ADC. For SH spring load with TOU tariff, ABC shows lowest ADC. For SH spring load with DAP tariff, ABC shows lowest ADC. For SH summer load with RTEP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For SH summer load with TOU tariff, ABC shows lowest AWT. ABC shows lowest ADC. For SH summer load with DAP tariff, ABC shows lowest ADC.

For SH fall load with RTEP tariff, both GA and ABC shows lowest AWT. ABC shows lowest ADC. For SH fall load with CPP tariff, ABC shows lowest ADC. For SH fall load with TOU tariff, ABC shows lowest ADC. For SH fall load with DAP tariff, ABC shows lowest ADC.

- For SH spring load with DAP tariff; ADC is lower with GA as compared to ABC. For SH fall load with DAP tariff, ADC is again lower with GA as compared to ABC.
- For MH winter load with RTEP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For MH winter load with CPP tariff, ABC shows lowest ADC. For MH winter load with TOU tariff, ABC shows lowest ADC. For MH winter load with DAP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For MH spring load with RTEP tariff, ABC shows lowest ADC. For MH spring load with CPP tariff, ABC scheduled load shows lowest PAR. For MH spring load with TOU tariff, ABC shows inferior performance for PAR, AWT and ADC. For MH spring load with DAP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For MH summer load with RTEP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For MH summer load with CPP tariff, ABC shows lowest AWT. For MH summer load with TOU tariff, ABC scheduled load shows lowest PAR. ABC shows lowest AWT. For MH summer load with DAP tariff, ABC shows lowest AWT. For MH fall load with RTEP tariff, ABC scheduled load shows lowest PAR. ABC shows lowest AWT. ABC shows lowest ADC. For MH fall load with CPP tariff, ABC shows lowest AWT. ABC shows lowest ADC. For MH fall load with TOU tariff, ABC scheduled load shows lowest PAR. ABC shows lowest AWT. ABC shows lowest ADC. For MH fall load with DAP tariff, ABC scheduled load shows lowest PAR. ABC shows lowest AWT. ABC shows lowest ADC.
- For MH spring load with RTEP tariff, ADC is higher with GA as compared to ABC and unscheduled load. For MH spring load with CPP tariff, ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH spring load with TOU tariff, ADC is lower with GA as compared to ABC and unscheduled load. GA shows lowest ADC. For MH summer load with DAP tariff, ADC is lower with GA as compared to ABC. GA shows lowest ADC. For MH fall load with RTEP tariff, ADC is higher with GA as compared to ABC and unscheduled load.
- Out of thirty-two case studies, thirty case studies shows minimum average daily cost (ADC) with ABC algorithm. Only two case of single home (SH) are not minimized with ABC. This shows better performance of ABC over GA.
- Residential loads' peak hours, which are at night, are reduced when demand response (DR) programs alter the load curve, but daytime demand is increased. These operations lower the value of maximum loads while

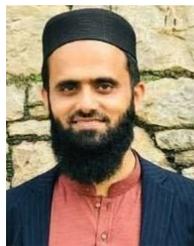
raising the load factor. These plans also boost PV and WG capacity, which is especially useful for systems without any storage facility integration in the morning and afternoon.

- By implementing DR programs, grid power consumption is reduced while renewable energy shares of PV and WG increase. Environmental emissions are also reduced.
- Through DR initiatives, PV and WG capacity are raised, and the maximum amount of grid electricity purchased is decreased.
- According to the results, it is preferable to manage consumer participation levels before system establishment and system sizing to manage the hybrid system's configuration, the anticipated system cost, emissions, and revenues in the event that a grid connection is available.
- Developers can meet the required system configuration and preferred DR participation percentages based on the intended priorities in system planning, such as cost and emissions.

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