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ORIGINAL RESEARCH

A new Internet of Things based optimization scheme of residential demand side management system

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Abstract

The steady increase in the energy demand and the growing carbon footprint has forced electricity-based utilities to shift from their use of non-renewable energy sources to renewable energy sources. Furthermore, there has been an increase in the integration of renewable energy sources in the electric grid. Hence, one needs to manage the energy consumption needs of the consumers, more effectively. Consumers can connect all the devices and houses to the internet by using Internet of Things (IoT) technology. In this study, the researchers have developed and proposed a novel 2-stage hybrid method that schedules the power consumption of the houses possessing a distributed energy generation and storage system. Stage 1 modeled the non-identical Home Energy Management Systems (HEMSs) that can contain the DGS like WT and PV. The HEMS organise the controllable appliances after taking into consideration the user preferences, electricity prices and the amount of energy produced /stored. The set of optimal consumption schedules for every HEMS was estimated using a BPSO and BSA. On the other hand, Stage 2 includes a Multi-Agent-System (MAS) based on the IoT. The system comprises two portions: software and hardware. The hardware comprises the Base Station Unit (BSU) and many Terminal Units (TUs).

1 | INTRODUCTION

A conventional power grid system includes numerous interconnected alternate current (AC) grids [1]. It is used for carrying out three major functions, that is, electric energy generation, transmission, and distribution, wherein the electric energy only flows in a single direction, that is, from the service provider to a consumer. In Step 1, that is, power generation, many power plants generate electric energy, primarily by burning uranium and carbon-based fuels. In Step 2, that is, power transmission, electricity can be transmitted from the power plants to remote load centres using high voltage transmission lines. However, in Step 3, that is, power distribution, the electrical distribution systems help in distributing the electrical energy to the final consumers at a lower voltage. Every grid is monitored and controlled centrally for ensuring that the power plants produce electric energy as per the consumer needs, based on the constraints of the power systems. All the electric energy generation, distribution, and transmission, processes are owned by energy utility companies that supply electric energy to the users and then bill them as per their consumption to earn profits [1]. The power grids undergo a lot of electric energy wastage owing to many factors, like the use of inefficient appliances, lack of smart technologies, unreliable communication and observing, ineffective routing and dispensation of electrical energy, and lastly, a lack of an effective mechanism that helps in storing the electric energy that is generated [1, 2]. Additionally, the power grids also have to face some challenges like an increasing energy demand, emerging renewable energy sources, security, reliability, and infrastructural issues.

For solving the above-mentioned challenges, many researchers regarded the smart grid (SG) model as an effective solution that contained a lot of information and included some communication tools. These technologies improved the efficiency, effectiveness, security, reliability, stability scalability and, sustainability, and of the conventional power grids. The smart grid different from the conventional power grid in several aspects. For example, the smart grid allowed a bi-directional communication flow to the consumers from a service providers, whereas the conventional power grid only offered a unidirectional communication flow from the service providers to a customers. Furthermore, smart grid provided a smart meter, unauthorised usage detection, fault tolerance, smart meters, load balancing, along with self-healing, that is, detection and recovery from the faults.

Smart grid makes use of different appliances for monitoring and controlling the power grids. These monitoring appliances can be used at different transmission lines, power plants, distribution centres, and consumer premises. The major concern for every SG includes automation, connectivity, and tracking of numerous devices that require their monitoring, control, and analysis using universal, high-speed, and 2-way digital communication devices. This requires a distributed automation of the smart grid for these "things" or appliances. This has been realised in real-time using IoT technology. IoT processes are defined as the network that connects a device with the internet using the protocol for exchanging the information and communication processes amongst the different smart devices for monitoring, tracking, managing, and locating the identification things. In the last few years, IoT technology has garnered a lot of attention in different applications, which has permitted the interconnection between the different network-embedded devices and the Internet [3]. One of the potential benefits of smart grid is the role they can play in making the electric grid more flexible and efficient, driven by the integration of distributed-energy resource (DER) units and controllable loads. A DER unit is either a distributed generator (DG) unit or an energy storage system (ESS). DG units are usually renewable-energy-sources (RES), that is, solar (PV) and wind power sources [4–6].

To manage problems and overcome energy-saving the IoT-based demand side management system is essentially needed. This system must have the ability to avoiding power peak and keep continuous energy surviving with future trends [7, 8].

In [9] the authors suggested a new robust intelligent energy management and demand reduction for intelligent households based on energy internet. However, the HEMS operation based on BPSO and BSA and augmented with ToU, CPP, RTP, simultaneous regulation are not investigated. Also, the data storage and processing using the ThingSpeak platform is not considered. In [10] the authors proposed a home energy management system with energy storage and renewable energy using main grid and electricity selling. However, the optimal cost-effective DSMS operation based on Artificial Intelligence (AI) optimization problem and augmented with ToU, CPP, RTP, simultaneous regulation are not investigated. In [11] the authors proposed demand-side management of multi-micro grids based on the game theory method in the existence of demand response, renewable energy resources, and energy storage system. However, a stable, accurate, and efficient performance is achieved at the cost of high execution time. In [12, 13] the authors proposed supervisory control and data acquisition (SCADA) controlled smart home using Raspberry Pi3. However, the optimal cost-effective DSMS operation based on Artificial Intelligence (AI) optimization problem and augmented with ToU, CPP, RTP, simultaneous regulation are not investigated. In [14] proposed a cooperative Stackelberg game-based energy management considering risk assessment and price discrimination. However, this reference did not consider the trade-offs between user discomfort and minimizing electricity bills. In [15] the authors proposed novel demand side management of off-grid / on-grid utilizing an neuro-fuzzy system. However, the data storage and processing using IoT is not considered. In [16] proposed an method based coalition model for hybrid micro grid system considering demand response programs. However, the data storage and processing using IoT is not considered. In [17] the authors introduced a demand management scheme based on optimisation for multi micro grid. However, in this reference, a stable, accurate, and efficient performance is achieved at the cost of high execution time.

In [18] the authors proposed artificial intelligence-based scheduling system for energy management in intelligent households. However, data storage and processing using IoT is not considered. In [19] authors suggested novel robust demand management and control scheme for a hybrid micro grid scheme. However, the data storage and processing via IoT is not considered. In [20] the authors introduced a Stochastic optimal power flow in islanded micro grids with correlated load and solar uncertainties. However, in this reference, accuracy is enhanced at expense of the increased complexity of the system. In [21] the authors introduced optimisation procedure is proposed based on the integrated demand response (IDR) and degree of tolerance for home energy management. However, the researchers did not account for real-time changes in user demand. In [22] a directed acyclic graph-based fog-cloud layer construction for distributed energy management in intelligent power grids in the existence of plug in electric vehicles. However, in this reference, the researchers did not use a meta-heuristic method to minimize the cost. In [23] the authors suggested new intelligent energy management as a service over the cloud for nano grid devices. However, the optimal cost-effective DSMS operation based on AI optimization problem and augmented with the ToU, RTP, CPP simultaneous regulation are not investigated. In [24] the authors proposed optimum power scheduling in microgrids combined with renewable energy sources for the demand management system. However, this reference didn't consider the trade-offs between minimizing electricity bills and user discomfort. In [25] the authors suggested novel IoT enabled trust distributed energy management system. However, the optimal cost-effective DSMS operation based on AI optimization problem and augmented with the ToU, RTP, CPP simultaneous regulation are not investigated. In [26] the authors introduced a new dynamic appliance clustering system in the community household energy management system for improved stability and resiliency of micro grids. However, in this reference, cloud for energy management systems in the smart grid is not investigated.

In [27] the authors proposed an adaptive demand management scheme for smart micro grids. However, the data storage and processing using IoT layer the platform is not considered. In [28, 29] the authors introduced fair and balance demand response application in distribution networks. However, the HEMS operation based on BPSO and BSA and augmented with ToU, CPP, RTP, simultaneous regulation are not investigated. In [30] the authors introduced wireless controlled smart home system. However, the HEMS operation based on BPSO and BSA and augmented with ToU, CPP, RTP, simultaneous regulation are not investigated. In [31, 32] The authors introduced neuro-fuzzy controller using FPGA for sun tracking system. However, in this reference, the researchers did not use a meta-heuristic method to minimize the cost. In [33] a coordinated control of hybrid microgrids with renewable energy resources under variable loads and generation conditions. However, in this reference, cloud for energy management systems in the smart grid is not investigated.

To overcome the aforementioned difficulties, this paper proposes a new IoT based optimization scheme of residential demand side management system, we can summarize the main advantages of the proposed method as follows:

- In this paper, the optimal cost-effective DSMS operation based on AI optimization problem and augmented with the ToU, RTP, and CPP simultaneous regulation are investigated.
- This research proposed an optimization algorithm-based real-time optimal schedule controller for home EMS to energy savings and limit home peak-demand in the household on the basis of scheduled operation of several devices according to a resident comfort constraint, priority, and specific time.
- This paper also makes a contribution by proposing a multi-agent system for micro grid representation that incorporates IoT appliances for energy management in smart homes. The proposed multi-agent system was created with low-end hardware in mind. This allows agents to be deployed in low-cost, compact hardware in the electrical switchboard of a building. The suggested multi-agent system, on the other hand, makes extensive use of IoT equipment to carry out EMS solutions within homes. This is the most important addition made possible by this paper.
- The two-layer hierarchical communications architecture, based on the MQTT protocol and utilizing a cloud server called Thing Speak, is implemented to realize global and local communication required for neighbourhood devices controllers.

2 | DESCRIPTION OF PROPOSED SYSTEM

Here, the proposed smart micro grid system consisted of renewable energy sources, loads, a utility power grid, and communication in the Energy Internet realm, as shown in Figure 1.

Therefore to continuously watch the cost profile and power and quantify power losses, a microgrid would require a communication system and effective measuring The data processing process is divided into various parts.

This work includes measuring units (MU) for the distribution network proposed. The control centre receives regularly, at the specified time, power and cost information. The controlling centre is designed to manage and analyse virtual data. A communication approach is considered concerning the proposed device topology. The case adopts a Cloud technology that sends its measuring data to a cloud-connected via the measuring units.

To model proposed communication architectures, data transfer between the Raspbery Pi3 and ThingSpeak is used. Due to his following benefits, ThingSpeak was chosen to simulate real-time cloud communication [34, 35]:

1. Tracking of data and aggregation in ThingSpeak Cloud IoT platform. The power profile on several ThingSpeak channels is monitored in real-time and graphically displayed in micro-grid.
2. Security: password and username allow the authentication of the user, as each channel may be private, public or private (seen by other users). Two keys to the application programming interface are available in each channel (API). A read and write key of the API generated by random means. These keys can save or retrieve data from things on the LAN or internet from each channel.

3 | PROPOSED INTERNET OF ENERGY COMMUNICATION PLATFORM

Cloud-enabled IoT is used to communicate between agents in the microgrid and data storage. The data is transmitted between

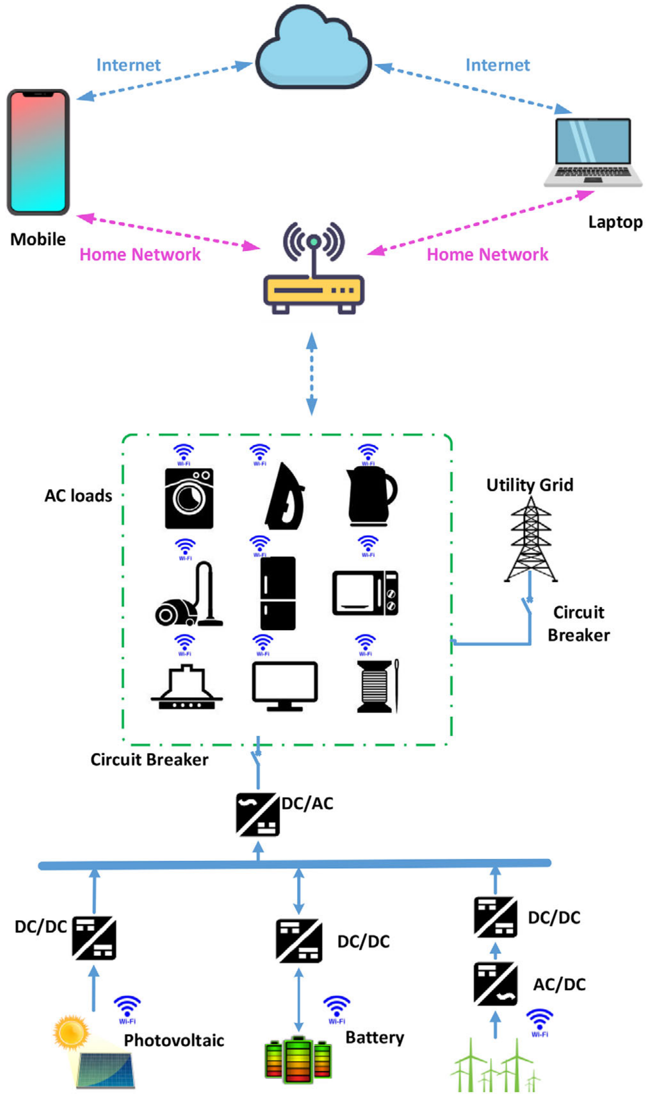


FIGURE 1 Structure of the proposed system

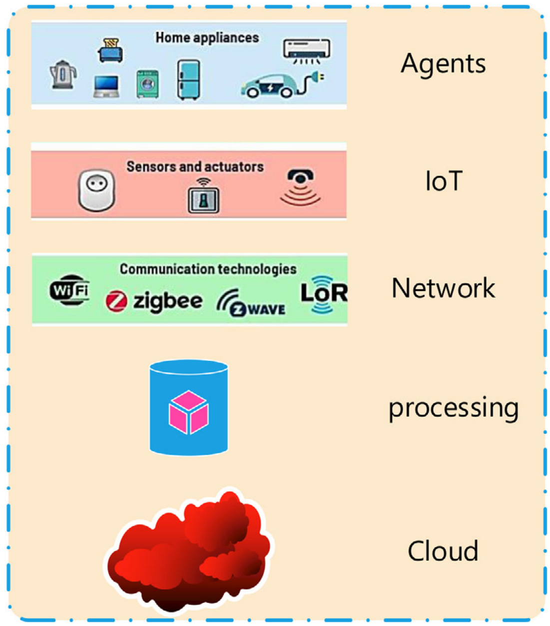


FIGURE 2 Proposed Internet of Energy platform architecture

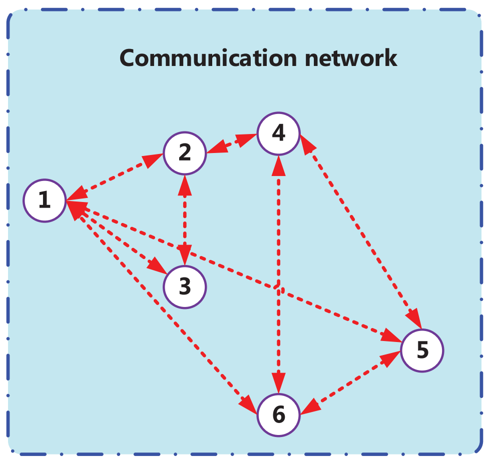


FIGURE 3 Exchange information among agents [52]

neighbours using the IoT platform, and then processed in cloud computing layer. As shown inFigure 2, the proposed IoE communications network is made up of five layers.

(a) Agent layer
The layer of distinct components was referred to as the device or perception layer [36, 37]. The device layer includes a variety of IoT users, such as smart homes, as well as DGs such as PVs and WTs.

(b) IoT layer
The IoT layer is a sensors layer. Furthermore, this layer supports various sensors for monitoring and real-time adjustment of the connected actors' environmental or physical conditions.

(c) Network layer
The results from agent layer and IoT devices platform layer are assembled in this layer and sent to higher layer for processing and storage.

(d) The layer of processing data
This layer enables powerful computers to store and process a significant volume of data from preceding layers [36].

(e) The layer of the cloud
This layer is used to allow a local process to work with least amount of latency possible. Microprocessors in cloud layer can perform real-time local operations [38, 39].

4 | FORMULATION OF PROBLEM

The suggested demand-side management system shifts the charge on a scheduling basis day-to-day and in real-time. In view of the two planning procedures, has been concentrate on achieving several targets. The day-for-day goal includes minimizing power cost, and PAR.

4.1 | Shifting of loads

The proposed algorithm schedules devices to make the consumption schedule load curve closer to goal load curve [40]:

$$C_1 = \min\left(\mathcal{N}_{\mathcal{L}}^{S^{\mathcal{H}}} - \mathcal{B}_{\mathcal{LC}}^{\mathcal{H}}\right) \tag{1}$$

The objective load curve $\mathcal{B}_{\mathcal{LC}}^{\mathcal{H}}$ have the inverse relation with $\mathcal{N}_{\mathcal{L}}^{S^{\mathcal{H}}}$, this relation is demonstrated as:

$$\mathcal{B}_{\mathcal{LC}}^{\mathcal{H}} \propto \frac{1}{\mathcal{N}_{\mathcal{L}}^{S^{\mathcal{H}}}} \tag{2}$$

where $\mathcal{N}_{\mathcal{L}}^{S^{\mathcal{H}}}$ is a per-hour scheduled power load, $\mathcal{N}_{\mathcal{L}}$ is an aggregated load of ON devices during a particular time.

$$\mathcal{N}_{\mathcal{L}} = \sum_{\mathcal{A}=1}^{\mathcal{M}} \varsigma \times \mathcal{D}ev_{\mathcal{P}_{rate}}^{\mathcal{A}} \tag{3}$$

$\varsigma = 1; 0$ is an OFF / ON status of the devices during a particular hour.

The targeted $\mathcal{B}_{\mathcal{LC}}^{\mathcal{H}}$ is achieved utilizing constraints in Fitness Function ($\mathcal{F}_{f}$).

$$\mathcal{F}_{f} = \min\left(\mathcal{F}_{p}\right) \tag{4}$$

where $\mathcal{F}_{p}$ is calculated using below equation,

$$\mathcal{F}_{p} = \begin{cases} \mathcal{N}_{\mathcal{L}}^{i\in p} \geq \mathcal{W}_{\mathcal{L}_1} & \textit{when } hour_{p}^{off} \\ \mathcal{N}_{\mathcal{L}}^{i\in p} < \mathcal{W}_{\mathcal{L}_1} & \textit{when } hour_{p}^{on} \end{cases} \tag{5}$$

$$\mathcal{W}_{\mathcal{L}imt_1} = \textit{sum}\left(\mathcal{L}_{\mathcal{N}}^{h}\right) - std\left(\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS^{\mathcal{H}}}\right) \tag{6}$$

$$\mathcal{W}_{\mathcal{L}imt_2} = \eta \times \textit{min}\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS} + std\left(\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS^{\mathcal{H}}}\right) \tag{7}$$

$$\mathcal{W}_{\mathcal{L}imt_3} = \textit{mean}\left(\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS}\right) \tag{8}$$

$$\mathcal{L}_{\mathcal{N}orm}^{\mathcal{H}} = \left(\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS} - \textit{min}\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS}\right) / \left(\textit{max}\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS} - \textit{min}\mathcal{N}_{\mathcal{L}}^{\mathcal{U}nS}\right) \tag{9}$$

The off-peak power limit ($\mathcal{W}_{\mathcal{L}imt_1}$) and on-peak power limit $\mathcal{W}_{\mathcal{L}imt_2}$ are calculated, so that fair load distribution at customer's end can be realized via house load power management scheduler. $\mathcal{N}_{\mathcal{L}}^{i\in p}$ load is calculated for a single chromosome [40–42] (Figure 3).

4.2 | Communication of multi-agent system (MAS)

The MG system is regarded as a multi-agent system with information capability transfer between the local device and the neighbours in order to generate an efficient distributed consensus controller for MG energy management. The distributed consensus controller is connected to MG elements such as inverters, loads, and DGs, and it may communicate with neighbours to determine the best option for the local element. An undirected graph with nodes and edges can be used to describe the information flow diagram between these agents. Every agent in consensus algorithm can be called as a node, and the evidence communication links between agents i and j can be demonstrated as an edge (i, j) with $w_{i,j}$ weighted factor. flow diagram of information graph can be presented as $\mathcal{G} = \{\mathcal{N}, \mathcal{E}, \mathcal{A}\}$ where $\mathcal{N} = \{1, \ldots, \mathcal{K}\}$ is agents number, $\mathcal{E}$ is communication links between two adjacent nodes $\mathcal{A} \in \mathcal{R}^{\mathcal{K}\times\mathcal{K}}$ and, $\mathcal{E}(i, j)$, is weighted matrix. he $w_{i,j}$ weighted factors can be presented as [43];

$$w_{i,j} = \begin{cases} 1/\left(\textit{max}\left[l_{ii}, l_{jj}\right] + 1\right) & j \in \mathcal{K}_i \\ 1 - \sum_{j\in\mathcal{K}_i} 1/\left(\textit{max}\left[l_{ii}, l_{jj}\right] + 1\right) & j = i \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

where i and j are number of units', $\mathcal{K}_i$ is agent set connected to unit i, and l_{ii} and l_{jj} are Laplacian matrix component. The elements of Laplacian matrix can be given as [44]–[46];

$$\begin{cases} l_{ii} = \sum_{i\neq j} a_{ij} & \text{on-diagonal elements} \\ l_{ij} = -a_{ij} & \text{off-diagonal elements} \end{cases} \tag{11}$$

5 | PROPOSED METHODOLOGY

5.1 | The backtracking search optimization algorithm

Optimization is a process that uses input information and optimisation limits to find the best possible result to this objective function to improve the structural performance and solve the numeric optimization problem that is valued. The objective of optimisation techniques is to improve applications through minimum error, low cost, maximum performance, and efficiency. The Backtracking Search optimization Algorithm (BSA) is the optimisation process proposed via Civicioglu in 2013 7. BSA dominates in the search for the greatest value of populations and space boundary searches to obtain exploitation and highly robust research capacity. It has been used in extensive research and is widely used in optimisation solutions [47].

The initialization process is the fundamental population configuration to generate the initial population value (Z_{ij}),

$$Z_{ij} = \text{rand} * \left(up_j - \text{low}_j\right) + low_j \tag{12}$$

The objective function (Obj) is calculated for each population.

The old population (old Z_{ij}) is used to calculate the search direction through:

$$\text{old } Z_{ij} = \text{rand} * \left(up_j - \text{low}_j\right) + \text{low}_j \tag{13}$$

By drawing on previous experiences and constructing a search guidance matrix, the historical population recalls a population chosen at random for previous generation to produce a new trial population. The following condition is proved via comparing the two random:

$$\text{if a } < \text{ bthenold } Z_{ij} = Z_{ij} \tag{14}$$

$$\text{old } Z_{ij} = \text{ permuting } \left(\text{ old } Z_{ij}\right) \tag{15}$$

The next method is the mutation that generates old Z_{ij} and new initial population. The BSA produces a trial population, T_{ij}, and from previous generations takes its experiences of a partial feature by,

$$\text{mutant } = Z_{ij} + \text{rand} * \left(\text{ old } Z_{ij} - Z_{ij}\right) \tag{16}$$

To regulate and schedule HEMS appliance at a specific time, the binary BSA (BBSA) proposal is employed. The suggested BBSA achieves its goal via reducing a predetermined objective function. Figure 4 is illustrated in the flow chart of the proposed BBSA. After generating the value of population (Z_{ij}), the sigmoid equation is used to convert the population to a real binary value between 0 and 1 by [47]:

$$Si = \frac{1}{1 + e^{-w}} \tag{17}$$

$$PB = \begin{cases} 0, si < 0.5 \\ 1, si \geq 0.5 \end{cases} \tag{18}$$

where Si is sigmoid function, w is population value and PB is its binary value.

If Si value is greater than 0.5 the PB is 1, otherwise, the PB is 0. Moreover, according to the flowchart shown in Figure 4, schedule controller conditions are fulfilled. In locating near-optimal planning controllers in high dimensions and non-continuous optimization problems, BSA and its binary versions have significant potential. Once the scheduling controller has been executed, the BBSA proposed running a home appliance schedule controller for each population (Z_{ij}). The energy consumption aims to enhance the performance of HEMS by minimizing the 24-hour power consumption, which results in a reduction in the power supply as shown below.

$$O_{bj} = \sum_{i=0}^{n} \text{Pt}(i) * T \tag{19}$$

where Obj is an objective function, Pt is total power consumption and T is a time.

Binary BSA is used to convert the home appliances into OFF/ON according to the appliance [47].

$$\text{OSC} = \begin{bmatrix} \text{AC}_1 & \text{WH}_1 & \text{REF}_1 \ \text{WM}_1 \\ \text{AC}_2 & \text{WH}_2 & \text{REF}_2 \ \text{WM}_2 \\ \vdots & & \\ \vdots & & \\ \vdots & & \\ \text{AC}_n & \text{WH}_n & \text{REF}_n \ \text{WM}_n \end{bmatrix} \tag{20}$$

5.2 | The binary particle swarm optimization algorithm

To find optimum solutions to problem with a continuous nature, Particle-Swarm Optimisation (PSO) is used. as a result of this technique cannot be applied directly to discrete problems. In literature extended PSO to binary particle swarm optimization (BPSO) to solve discrete problems, and they found that it worked well [48]. Based on idea of intelligence swarm, a BPSO was created. In an intelligence swarm, an emergent behaviour happens when agents interact locally with their environment and results in coherent global patterns. It is a nature inspired intelligence swarm optimisation algorithm that mimics the social behaviour. As the individuals begin their quest for food, they travel in random directions and eventually find the food supply through sharing information with each other. As a result, this phenomenon is also known as PSO social concept. People are represented by swarm particles, which move around in search space to find an optimum solution to a problem.

The BPSO working flowchart is shown in Figure 4. Initial velocity, initial position, particle individual best position, and global best position among all particles are the four main factors. The initial position and velocity of the particles are represented via $x_i = x_1 + x_2 + \cdots + x_I$ and $\mathcal{V}_i = \mathcal{V}_1 + \mathcal{V}_2 + \cdots + \mathcal{V}_I$. The particles update their velocities in each iteration through [48–50]:

$$\sum_{t=1}^{24}\sum_{i=1}^{I} \mathcal{V}_i^{t+1} = \sum_{t=1}^{24}\sum_{i=1}^{I} \left(w\mathcal{V}_j^t(j) + c_1 r_1 \left(\mathcal{X}_{\text{pbest},i}(j)\right.\right.$$
$$\left.\left. - x_j^t(j)\right) + c_2 r_2 \left(\mathcal{X}_{\text{gbest},i}(j) - x_i^t(j)\right)\right) \tag{21}$$

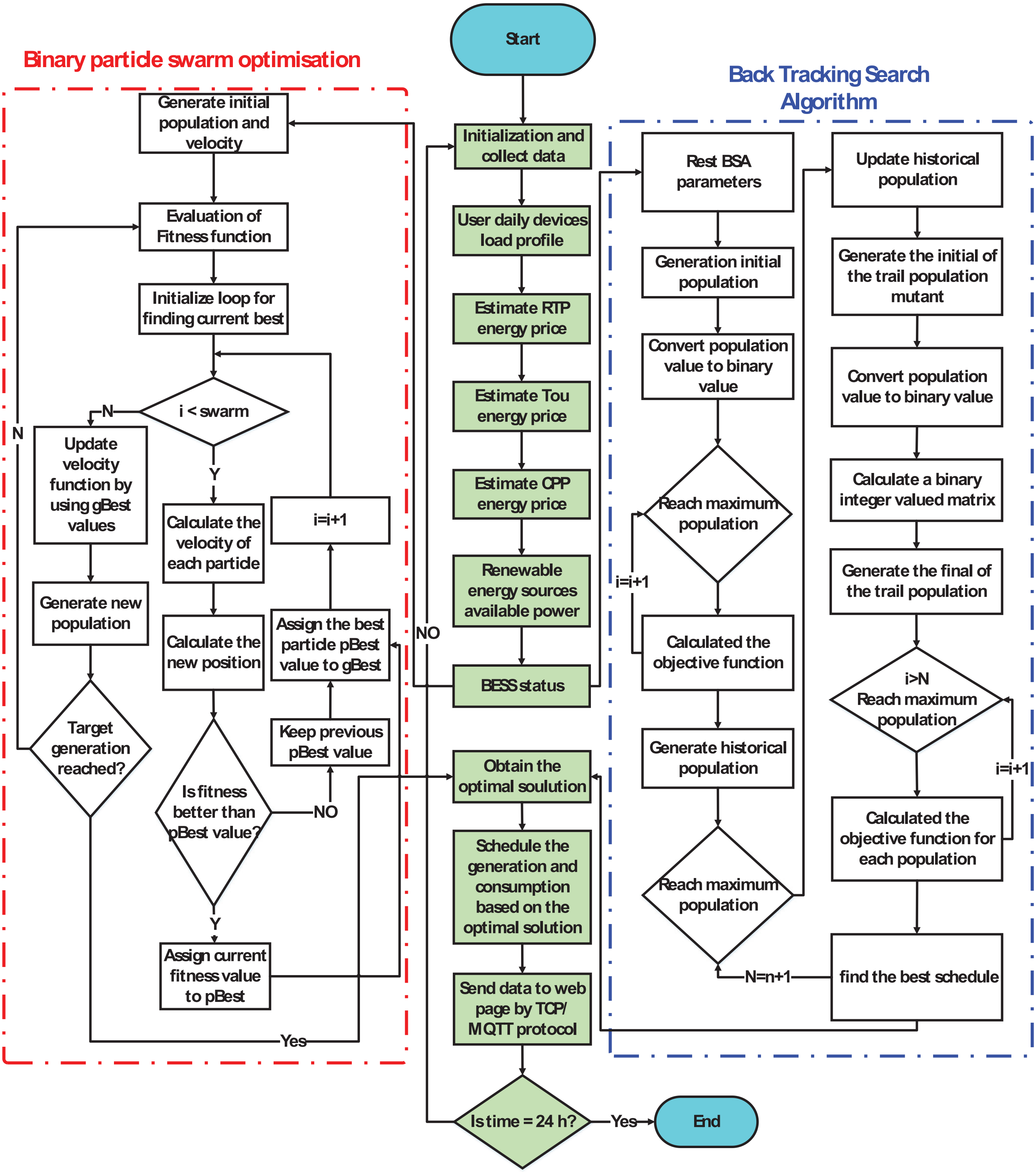


FIGURE 4 Proposed algorithm scheme

where v_i^{t+1} is velocity of device, w is the inertia factor, v_j^{t} is The current velocity, r_1 and r_2 are random number, c_1 and c_2 are local and global pulls, x_i^t is particle current position, x_{pbest} is the local best position and x_{gbest} is the global best position.

The velocities of a particles are mapped between 1 and 0 by using sigmoid [49, 50]:

$$sig\left(v_i^{t+1}(j)\right) = \frac{1}{1 + exp\left(-v_i^{t+1}(j)\right)} \tag{22}$$

To construct a binary coded population, the random values assigned to each particle in population are compared to the sigmoid function:

$$x_i^{t=1} = \left\{1\ sig\left(\mathcal{V}_i^{t=1}(j)\right) < r_{ij} 0OW \right. \quad (23)$$

The global best value is a binary coded string that indicates the devices' best OFF/ON status.

The objective function and the problem constraints are represented as follows;

$$minimize \Rightarrow (C_E) \quad (24)$$

$$C_E = \sum_{t=1}^{T} \tau(t) P_{\text{grid}}(t) \Delta t \quad (25)$$

where C_E is the energy cost at time T. $P_{grid}(t)$ is grid power, Δt represents interval time between two-time instants, and $\tau(t)$ is the price of energy at time instant t [39].

In this study, the considered constraints are the power balance, power ratings of the renewable energy resources and the grid, and energy capacity of the connected battery energy storage devices constraints. The equations of these constraints are presented as follows;

$$\sum_{t=1}^{T} \left(P_{PV}(t) + P_{Wind}(t) + P_{grid}(t) \pm P_{BESS}(t) - P_{Load}(t)\right) = 0 \quad (26)$$

$$P_{PV,min} \leq P_{PV}(t) \leq P_{PV,max}\ \forall t \in T \quad (27)$$

$$P_{Wind,min} \leq P_{Wind}(t) \leq P_{Wind,max}\ \forall t \in T \quad (28)$$

$$0 \leq P_{grid}(t) \leq P_{grid,max}\ \forall t \in T \quad (29)$$

$$E_{BESS,min} \leq E_{BESS}(t) \leq E_{BESS,max}\ \forall t \in T \quad (30)$$

$$E_{D,\ total} \leq E_{S,total} < E_{D,\ total} \quad (31)$$

Constraint (26) states the power balance equation at every time instant where $P_{PV}(t)$, $P_{Wind}(t)$, $P_{grid}(t)$ are the PV, wind, grid output power at time instant t respectively. $P_{Load}(t)$ and $P_{BESS}(t)$ are the load demand power and the charging/discharging power of the BESS, respectively. The minimum and maximum power output from the PV, wind, and utility grid are shown in (27)–(29). $P_{PV,min}$ and $P_{PV,max}$ are the limits of the PV output power, $P_{Wind,min}$ and $P_{Wind,max}$ are the boundaries of the wind output power, and $P_{grid,max}$ is the maximum power drawn from the utility grid in the case of grid-connected mode. $E_{BESS,min}$ and $E_{BESS,max}$ are the capacity limits of the BESS, as shown in (30). The energy-deficient is represented in (31). Figure 4 illustrates a flowchart of suggested method.

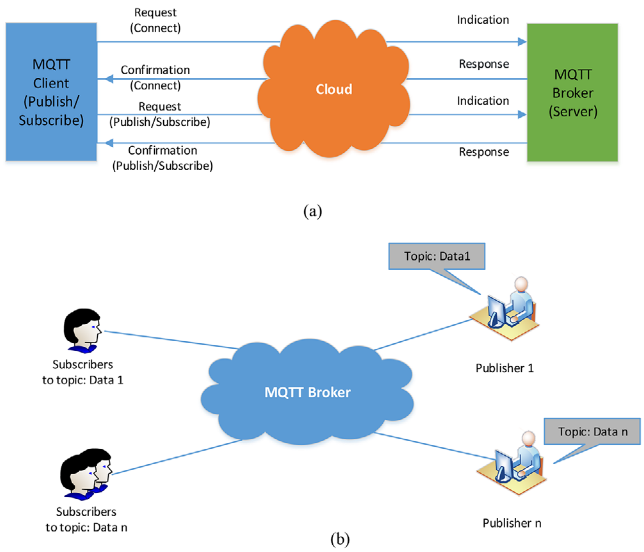


FIGURE 5 (a) Procedure of MQTT, (b) MQTT component and topic

6 | PROPOSED COMMUNICATION ARCHITECTURE

6.1 | The MQTT knowledge

MQTT messaging has three main players: MQTT broker, MQTT subscriber, and MQTT publisher. The MQTT publisher and subscriber are not directly associated by IP address and do not have to run at the same time. The MQTT broker acts as a network hub, receiving messages from publishers and filtering, prioritizing, and distributing them to thousands of continuously connected MQTT subscribers. Client authorisation and a handshake procedure for communication initialization are handled by the MQTT broker. MQTT publishers publish data using configurable topics that clients must subscribe to. The MQTT protocol does not permit the use of metadata to label messages. These topics could be repurposed to represent routing data [9, 51, 52]. The initialization of the connection by exchanging control packets between customers and the broker is shown in Figure 5a. CONNECT, CONNAC, PUBLISH, PUBACK, SUBSCRIBE, SUBACK, and other control packets convey information about the transmission's quality of service (QoS), topic, and payload. The components of MQTT communication are shown in Figure 5b.

6.2 | Proposed architecture

The suggested hierarchy of cyber layer, physical layer, and regulating layer smart structures is depicted in Figure 6. The proposed hybrid network has two communication levels. Smart structure appliances publish MQTT messages to consumer in the first layer, and they subscribe to BMC's published MQTT messages for control and protection. BMC connects to the cloud using the second (globe) layer, which is the HTTP

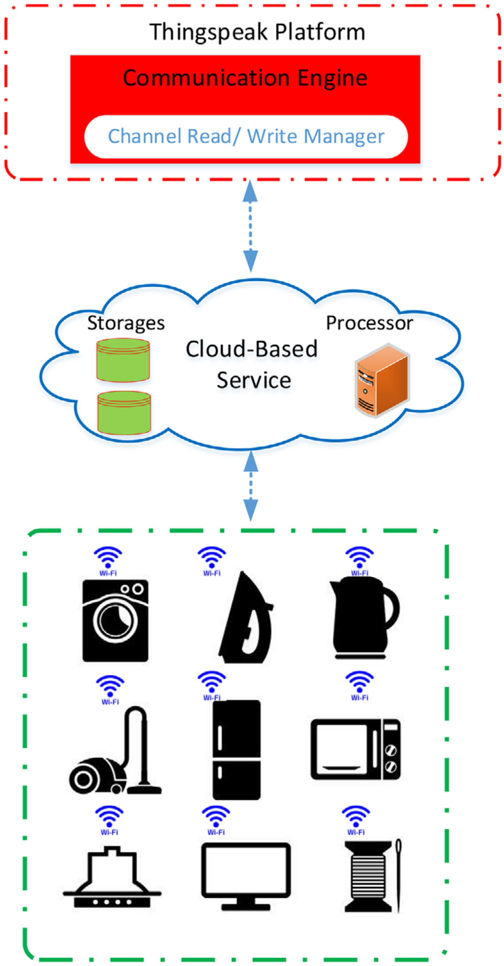


FIGURE 6 Communication building of suggested system

POST/GET architecture. Each gadget has a Wi Fi module in its suggested design, is connected to a local gateway, and releases data on the subject regularly. Both subjects are determined by the BMC and subscribe to a cloud channel. A thingspeak-based cloud interface with a built-in device algorithm can access the aggregated cloud data. BMC is used to transport the algorithm's results from the cloud to the device [9, 51].

6.3 | Proposed system hardware

The system hardware comprises many terminal units (TU) and one base station unit to connect appliances.

6.3.1 | The terminal units

The terminal unit (TU) represents a sub-unit of the Wireless Sensor Network (WSN) setup. Every TU contains a processor, and wireless communication. Figure 7 shows the terminal units.

TABLE 1 Characteristics of micro grid appliances [8]

Devices	Usage (h)
Washing machine	3
Cloth dryer	4
Vacuum cleaner	3
Water heater	6
Water pump	4
Dish washer	2
Refrigerator	24
AC	5
Oven	3

6.3.2 | Base station unit

Base Station Unit plays a key part in suggested method. The base station unit hardware comprises a Raspberry Pi3 board. The BSU is responsible for assessing and disseminating data from the terminal device to the owner's web page. The BSU must be configured in point of access mode in order to create the Wi-Fi link to which terminals will connect. BSU includes Mosquito, an open-source message broker that leverages the MQTT protocol. MQTT uses a publishing/subscription approach to provide a lightweight (2 byte fixed header) message management technique [9, 23]. Figure 8 shows the base station unit.7. Results of the proposed method

The performance of suggested demand-side management system is validated in this section by running in microcontroller and discussing the findings. The analysis is carried out for three different pricing regimes: ToU, RTP, and CPP using Binary Particle Swarm Optimization (BPSO) and Backtracking Search Algorithm (BSA)

Table 1 gives a detailed description of each instrument [8].

The effect of the micro grid communication is discussed in this section. In the presence of the communications applinces, the microgrid will exchange information such as load and energy generation.

In this test, the outcomes of smart EMS implemented with the proposed method over a cloud-platform to regulate devices in micro grid introduced and discussed. In this paper, the microcontroller is a chief command and control unit organizing a Thing Speak platform. MQTT function as a broker between the main control unit and subscribing microgrid devices In this paper, the Thing Speak platform interface that has been designed is a simple and convenient user interface (UI) that allows a house owner to interact and access home energy management as a service over cloud system. The dashboard and the UI flow architecture are illustrated in Figure 9.

The home energy management system includes a Graphical User Interface (GUI) to let consumers understand the total cost of microgrid devices and power consumption Figures 10–15 appearance the power consumption of all loads without and with corrective methods.

FIGURE 7 The TU structure of the proposed system

FIGURE 8 Structure of base station unit

Figure 10 illustrates the powerful graphical user interface of the proposed home demand-side system without and with the corrective method in the RTP scenario, Figure 11 shows the Power GUI of the proposed home demand-side system without and with the corrective method in the ToU scenario, Figure 12 shows the Power GUI of the proposed home energy demand-side system without and with the corrective method in the CPP scenario. Whereas Figure 13 illustrates the Cost GUI of the proposed house demand-side management system without and with the corrective method in the RTP scenario. Figure 14 illustrates the cost GUI of the suggested home management system without and with the corrective method in the ToU scenario. Figure 15 illustrates the Cost GUI of the suggested home management system without and with the corrective method in the CPP scenario.

7 | DISCUSSION OF RESULTS

In a microgrid efficiency analysis, the cost of electricity emission reduction and cost savings, in addition to PAR, were assessed.

In the RTP case, the price before applying the suggested algorithm is 1855 (cent). But after applying the BSA algorithm, the cost is found 1602, and after applying the BPSO algorithm, the cost is found 1509. By comparing suggested method with conventional method, the BSA algorithm saved

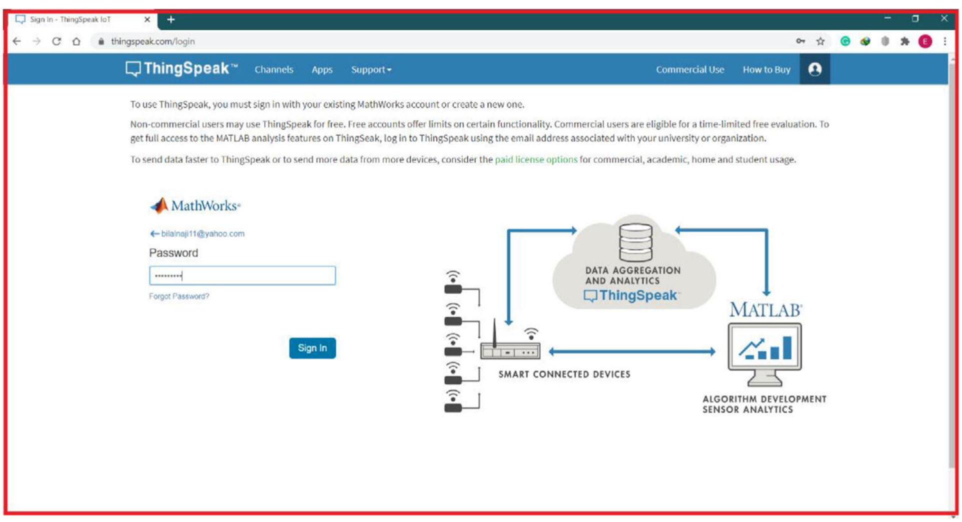
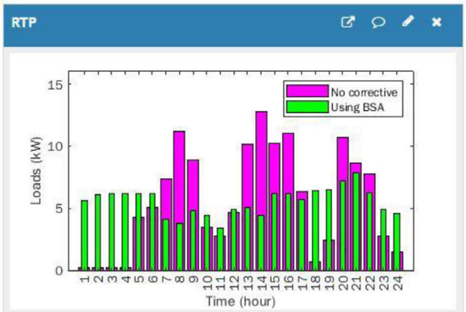
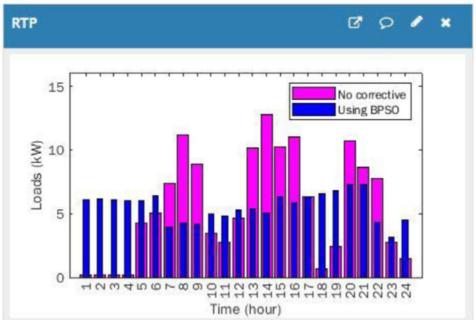


FIGURE 9 User interface design platform (Thing Speak platform)

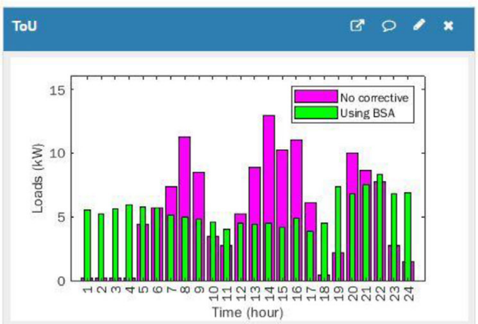


(a)



(b)

FIGURE 10 Power GUI of proposed home demand side management without and with proposed corrective method in RTP (a) using BSA algorithm, (b) using BPSO algorithm



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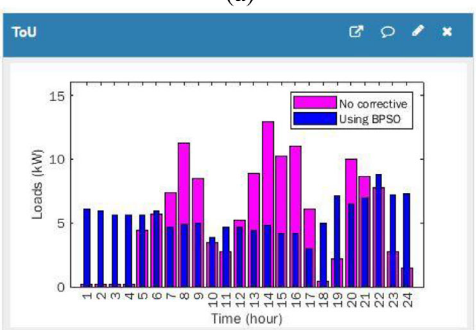
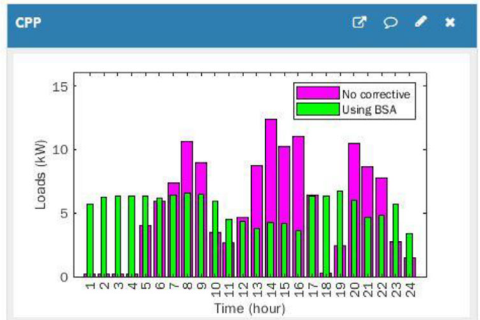


(b)

FIGURE 11 Power GUI of proposed home demand-side management without and with the proposed corrective method in ToU scenario, (a) using BSA algorithm, (b) using BPSO algorithm



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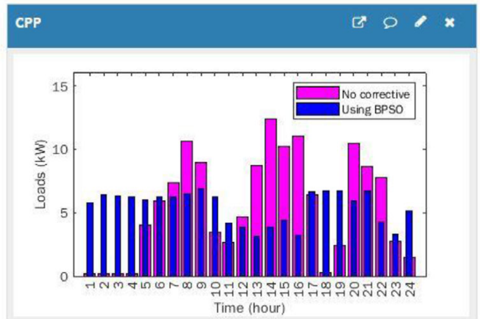
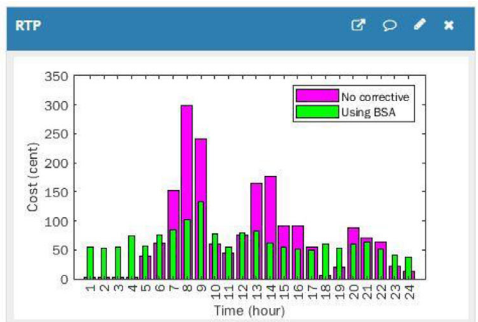


(b)

FIGURE 12 Power GUI of proposed home demand-side management without and with the proposed corrective method in CPP scenario, (a) using BSA algorithm, (b) using BPSO algorithm



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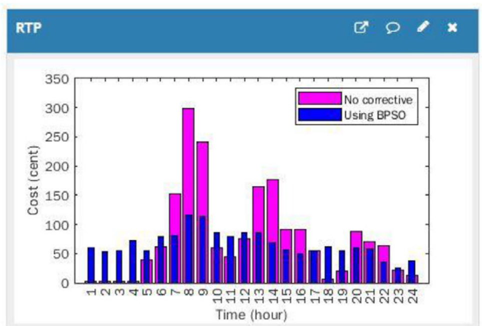
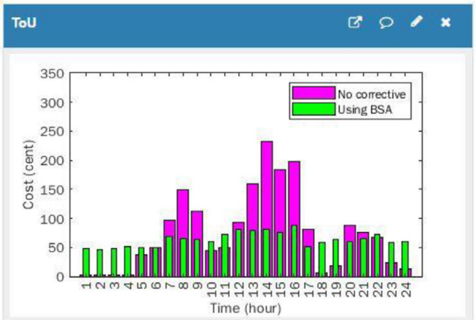


(b)

FIGURE 13 Cost GUI of proposed home demand-side management without and with the proposed corrective method in RTP scenario, (a) using BSA algorithm, (b) using BPSO algorithm



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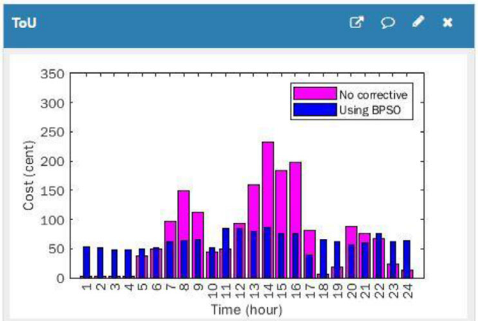

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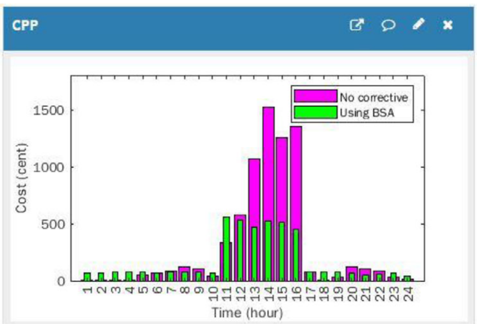
FIGURE 14 Cost GUI of proposed home demand-side management without and with the proposed corrective method in ToU scenario, (a) using BSA algorithm, (b) using BPSO algorithm



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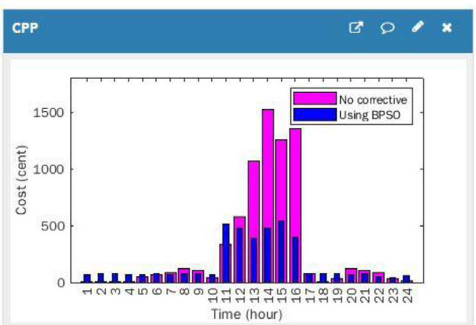
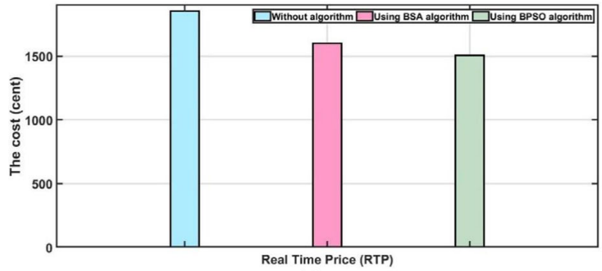


(b)

FIGURE 15 Cost GUI of suggested home demand-side management without and with the proposed corrective method in CPP scenario, (a) using BSA algorithm, (b) using BPSO algorithm



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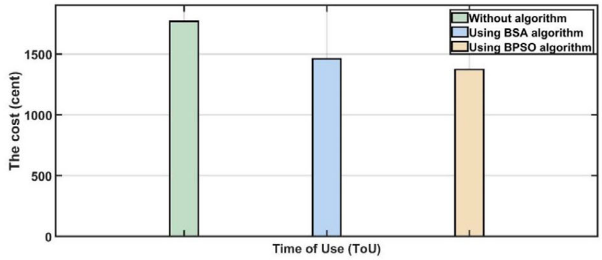

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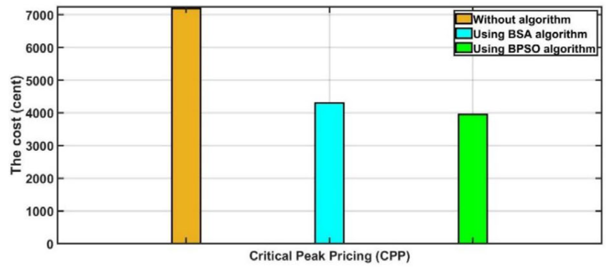

(c)

FIGURE 16 Cost comparison between without proposed EMS and with proposed EMS (a) RTP, (b) TOU, and (c) CPP

13.6% per day, and the BPSO algorithm saved 18.65% per day.

Whereas in the ToU case, the price before applying the proposed algorithm is 1769 (cent). But after applying the BSA algorithm, the cost is found 1461, and after applying the BPSO algorithm, the cost is found 1374. By comparing the suggested method with the traditional method, the BSA algorithm saved 17.4% per day, and the BPSO algorithm saved 22.32% per day.

Whereas in the CPP case, the price before applying the suggested algorithm is 7198 (cent). After applying the BSA algorithm, the cost is found 4299, and after applying the BPSO algorithm, the cost is found 3953. By comparing the suggested method with the traditional method, the BSA algorithm saved 40.2% per day, and the BPSO algorithm saved 45.08% per day.

Figure 16 illustrates cost comparison between without proposed EMS and with proposed EMS. Figure 17 illustrates the Improvement using the suggested algorithm (%) for three cases RTP, ToU, and CPP.

Our investigation revealed,, PAR improved, emission costs decreased and consumption energy costs have been reduced.

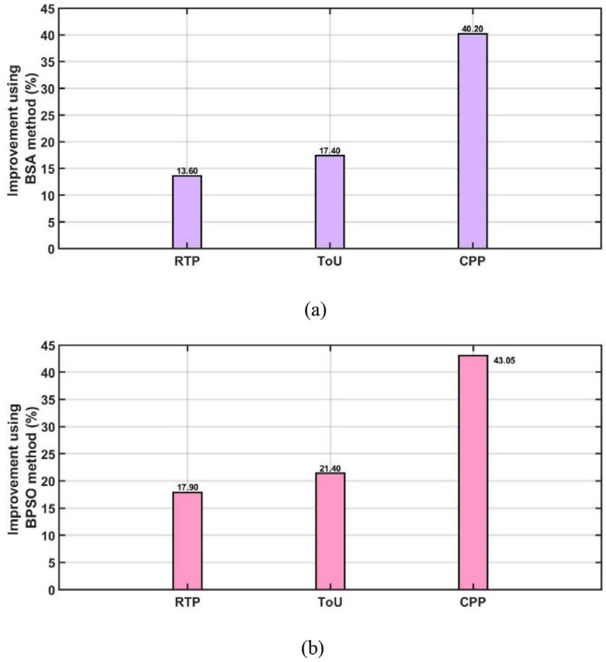

FIGURE 17 Improvement using proposed algorithm (%) for three cases RTP, ToU, and CPP (a) using BSA algorithm, (b) using BPSO algorithm

8 | CONCLUSIONS

In this paper, have been developed and proposed a novel 2-stage hybrid optimisation algorithm that schedules the power consumption of houses possessing distributed energy sources and energy storage system. Stage 1 modelled the HEMSs that can contain the distributed generation systems (DGS) like batteries, wind turbines (WT), and PV. The HEMS organise the controllable appliances after taking into consideration the user preferences, electricity prices, and the amount of energy produced/stored. The set of optimal consumption schedules for every HEMS was estimated using the backtracking search optimization algorithm (BSA) and binary particle swarm optimization (BPSO). On the other hand, Stage 2 includes a multi-agent-system (MAS) based on the IoT.

In this proposed process, the HEMS plays a vital role in optimal consumption schedules appliances, and the MAS process is seen to regulate the power fluctuations as it allows the energy transfers amongst the agents. In addition, energy management system applied to improve microgrid consumed energy cost, emission price, and PAR. To evaluate the performance of the suggested system models given in this study different experiments are performed on microcontroller. The cost analysis provided in the results shows the efficiency of the suggested distributed communication platform in comparison with the centralized operation of microgrid communications. With implementing the suggested method, it is notable that micro grid consumed saving 17% for RTP, 21% for ToU, and 43% for CPP per day.

NOMENCLATURE

Abbreviations and acronyms

IoT	Internet of Things
HEMSs	Home energy management systems
DGS	Distributed generation systems
WT	Wind turbines
PV	Photovoltaic
BPSO	Binary particle swarm optimization
BSA	Backtracking search algorithm
MAS	Multi agent system
ToU	Time-of use
RTP	Real-time price
CPP	Critical-peak price
PAR	Peak-to-average ratio
AC	Alternate current
SG	Smart grid
DR	Demand response
ESS	Energy storage system
DSO	Distribution system operator
DER	Distribution energy resource
DNO	Distribution network operator
SG	Smart grid
DR	Demand response
ESS	Energy storage system
DSO	Distribution system operator
DER	Distribution energy resource
DNO	Distribution network operator
AI	Artificial intelligent
BIVS	Built-in photovoltaic systems
MQTT	Message queuing telemetry transport
BMC	Building MQTT client
BSU	Base station unit
TU	Terminal unit
SG	Smart grid
DR	Demand response
ESS	Energy storage system
DSO	Distribution system operator
DER	Distribution energy resource
DNO	Distribution network operator
AI	Artificial intelligence

CONFLICT OF INTEREST

There is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available in article supplementary material.

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