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Implementation of real-time optimal load scheduling for IoT-based intelligent smart energy management system using new decisive algorithm

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Abstract

This paper presents the implementation of a real-time optimal load scheduling system for an IoT-based intelligent smart energy management system (SEMS) using a novel decisive algorithm. The increasing use of electrical equipment by consumers often leads to a mismatch between demand and supply, posing significant challenges to the energy sector. The proposed system addresses these challenges by optimizing load distribution and enhancing energy efficiency through advanced demand-side management techniques. By leveraging real-time data from IoT sensors and incorporating user preferences, the new algorithm dynamically adjusts power consumption to avoid peak-hour overloads, thus preventing widespread power outages. Experimental results demonstrate that the system effectively reduces overall energy consumption while maintaining user comfort and optimizing costs. The innovative approach of controlled partial load shedding based on consumer priorities ensures a balanced and resilient energy supply. This study highlights the potential of IoT and advanced algorithms in transforming energy management practices and providing sustainable solutions for the future.

Keywords: Demand response, Renewable energy, Internet of things, Sensor, Smart energy management systems, Smart grid, Smart plug

Introduction

The rise in electrical equipment consumption has heightened environmental concerns and underscored the urgency for alternative energy sources, a pressing issue for the scientific community [1]. Meeting the escalating demand for electricity poses significant challenges. In underdeveloped regions, inadequate power supply during peak hours often results in unplanned load shedding, compelling consumers to invest in fuel generators and battery storage, stunting economic growth. Moreover, utilities face the dilemma of investing more in infrastructure to sustain peak-hour operations, leading to resource underutilization. A dependable power network is vital for balancing supply and demand across production, transmission, and distribution sectors [2]. The energy sector is swiftly transitioning to the smart grid, facilitating peak load shifting, fault management, and responsive demand-side management during outages. This transition also promotes the adoption of renewable energy sources, empowering consumers to trim electricity expenses and optimize available power resources [3].

DR programs are essential in demand-side energy management, enabling efficient energy control for utilities and consumers. Smart meters facilitate two-way communication between them, allowing tailored energy management schemes. Utilities offer varied tariffs based on energy usage and business types, implementing load shedding strategically to balance the system and minimize outages [4]. Energy management systems optimize power utilization, considering constraints in power scheduling and classifying appliances based on environmental factors. Research aims to integrate algorithms in energy management systems with DR approaches to enhance efficiency. Energy-saving measures include adjusting appliance settings and implementing real-time scheduling. Intelligent systems utilize environmental sensors and user comfort metrics to optimize energy usage, enhancing customer satisfaction while reducing costs [5]. Optimal energy management combines load shedding and demand-side scheduling, managing renewable energy with mixed-integer linear programming. Combining DR with battery storage reduces costs, while a hierarchical control method enhances demand-side management. Communication technologies like Wi-Fi enable effective communication, and IoT integration allows remote monitoring [6]. Research focuses on integrating distributed energy systems, deploying adaptable systems with reliable communication, and designing real-time hardware prototypes for customizable smart energy management [7].

The paper follows a structured organization, beginning with an overview of the recommended architecture and a detailed breakdown of the system in "Illustration of the energy management system" section. "Algorithm for demand side energy management" section discusses the recommended control approach and optimization techniques. "Practical implementation of SEM" section explains the experimental setup and system organization. Findings and observations from the control systems are detailed in "Demonstration and result analysis" section, while "Conclusion" section serves as the conclusion, summarizing key insights and study implications.

Table 1 outlines various demand-side management (DSM) strategies along with their respective features, merits, and demerits. Firstly, "Peak Shaving" involves reducing energy consumption during periods of high demand, effectively addressing daily electrical needs while lowering costs per kWh. However, this may impose financial burdens on customers and compromise convenience, particularly in systems with predictable energy demands like traditional grids [24]. "Valley Filling," on the other hand, focuses on increasing demand during times of surplus electricity generation, minimizing energy restrictions, and significantly reducing wastage. Nevertheless, there is a risk of customer dissatisfaction with this approach. "Load Shifting" aims to balance demand profiles, reducing the need for system upgrades, although it may not be as effective in standalone systems [25]. Similarly, "Load Leveling" shifts demands based on criticality, offering high system autonomy but requiring flexible load classifications. "Energy Arbitrage" involves economically saving energy for future use or sale, enhancing supply system reliability but necessitating efficient energy storage management. "Strategic Conservation" initiatives encourage efficient energy use but can be impacted by demand predictions [26]. "Strategic Load Growth" focuses on smart

Table 1 Demand-side energy management strategies and its importance

DSM strategies	Features	Merits	Demerits	Remarks
Peak shaving [8]	Cutting back on some of the energy use at times of higher demand to prevent overstretching supply	Ways to address the many daily electrical demands Lower cost per kWh of electricity	Customers often shoulder financial difficulties, and consumer conveniences are violated	Mostly appropriate for highly predictable systems, as vertically arranged traditional grids
Valley filling [8]	Increasing demand at times of high electricity generation	The burdens associated with energy restrictions are abolished, dump energies are significantly reduced, and customers frequently profit from the cheap cost of energy	Soon-to-be-used storage facilities Load categories indicate the degree of flexibility and criticality required	Energy losses are prevented through valley filling, but customer satisfaction is put at risk
Load shifting[8]	Attempts to lessen the disparity between profiles with high and low demand	Lessens the need for system expansions or upgrades	Mostly advantageous for utilities	Like a blend of valley filling and peak shaving
Load leveling [9]	A technique for shifting demands from one load to another that is often based on a criticality factor	High level of system autonomy attained	Only possible with flexible and important load classifications	Displays traits found in other DSM techniques
Energy arbitrage [10]	Economically saving less expensive energy sources to consume or sell when prices are higher	Boost the dependability of the supply system Reduce the amount of wasted energy	It is necessary to handle energy storage effectively Events of fully charged ESS are likely to favor dump energies	For intermittent RE systems, very suited
Strategic conservation [11]	Utility-based DR initiative to encourage users to alter their consumption patterns	A plan for using energy efficiently	Demand predictions are impacted by consumer preferences	Typically focusing on less energy use
Strategic load growth [12]	The adoption of smart energy appliances is to blame for the anticipated increase in energy needs	Reduce waste energy and save money on energy	Only possible with dump-loading systems It must always be combined with other tactics, such as valley filling, and is never effective on its own	The plan raises utility revenues while enhancing consumer productivity
Flexible load scheduling [13]	A plan with incentives for system dependability degradation but no clear shapes	Good for enhancing the autonomy of the DG system	In systems of uniform tariffs, such as standalone, this may not be possible	Most effective in multi-tariff integrated systems
Valley filling [14]	Increasing demand at times of high electricity generation	Customers frequently benefit from the cheap cost of energy, which reduces the burdens associated with energy curtailments and significantly reduces dump energies	Soon-to-be-used storage facilities Load categories indicate the degree of flexibility and criticality required	Energy losses are prevented through valley filling, but customer satisfaction is put at risk

Table 1 (continued)

DSM strategies	Features	Merits	Demerits	Remarks
Load shifting [15]	Attempts to lessen the disparity between profiles with high and low demand	Lessens the need for system expansions or upgrades	Mostly advantageous for utilities	Like a blend of valley filling and peak shaving
Load leveling [16]	A technique for shifting demands from one load to another that is often based on a criticality factor	High level of system autonomy attained	Only possible with flexible and important load classifications	Displays traits found in other DSM techniques
Energy arbitrage [17]	Economically saving less expensive energy sources to consume or sell when prices are higher	Boost the dependability of the supply system Reduce the amount of wasted energy	It is necessary to handle energy storage effectively Events of fully charged ESS are likely to favor dump energies	For intermittent RE systems, very suited
Strategic conservation [18]	Utility-based DR initiative to encourage users to alter their consumption patterns	A plan for using energy efficiently	Demand predictions are impacted by consumer preferences	Typically focusing on less energy use
Strategic load growth [19]	The adoption of smart energy appliances is to blame for the anticipated increase in energy needs	Reduce waste energy and save money on energy	Only possible with dump-loading systems It must always be combined with other tactics, such as valley filling, and is never effective on its own	The plan raises utility revenues while enhancing consumer productivity
Flexible load scheduling [20]	A plan with incentives for system dependability degradation but no clear shapes	Good for enhancing the autonomy of the DG system	In systems of uniform tariffs, such as standalone, this may not be possible	Most effective in multi-tariff integrated systems
Valley filling [21]	Increasing demand at times of high electricity generation	Customers frequently benefit from the cheap cost of energy, which reduces the burdens associated with energy curtailments and significantly reduces dump energies	Soon-to-be-used storage facilities Load categories indicate the degree of flexibility and criticality required	Energy losses are prevented through valley filling, but customer satisfaction is put at risk
Load shifting [22]	Attempts to lessen the disparity between profiles with high and low demand	Lessens the need for system expansions or upgrades	Mostly advantageous for utilities	Like a blend of valley filling and peak shaving
Load leveling [23]	A technique for shifting demands from one load to another that is often based on a criticality factor	High level of system autonomy attained	Only possible with flexible and important load classifications	Displays traits found in other DSM techniques

energy appliance adoption to meet increasing energy needs, reducing waste energy, and enhancing utility revenues but requires integration with other tactics. Finally, "Flexible Load Scheduling" offers incentives for system dependability but may not be feasible in systems with uniform tariffs, being most effective in multi-tariff integrated systems. Each strategy addresses specific challenges and trade-offs, emphasizing the importance of considering system requirements and user preferences in DSM implementation [27].

Illustration of the energy management system

The proposed SEMS and its main algorithms are fully described in this section.

Outline of the energy management system

Figure 1 depicts a recommended smart energy management system's conceptual design. The SEM unit is a part of the overall system that offers user and other end-user monitoring and control capabilities. Smart sockets can locally control following the command signals they get from the SEM unit to the electrical characteristics of the appliances they gather [28].

In addition, the SEM unit serves as a gateway connecting a utility and a user. In this instance, the gateway obtains information about the permitted maximum demand limit from the utility and inputs it into the SEM unit. In contrast, the utility collects and evaluates data on energy use from every SEM unit in a city to adjust the maximum demand limit for every user [29]. The gathered data would be used for billing purposes, and each residence would get an electronic bill as a consequence [30].

The structural design of smart energy management

SEM gateway is generally made up of the components listed below.

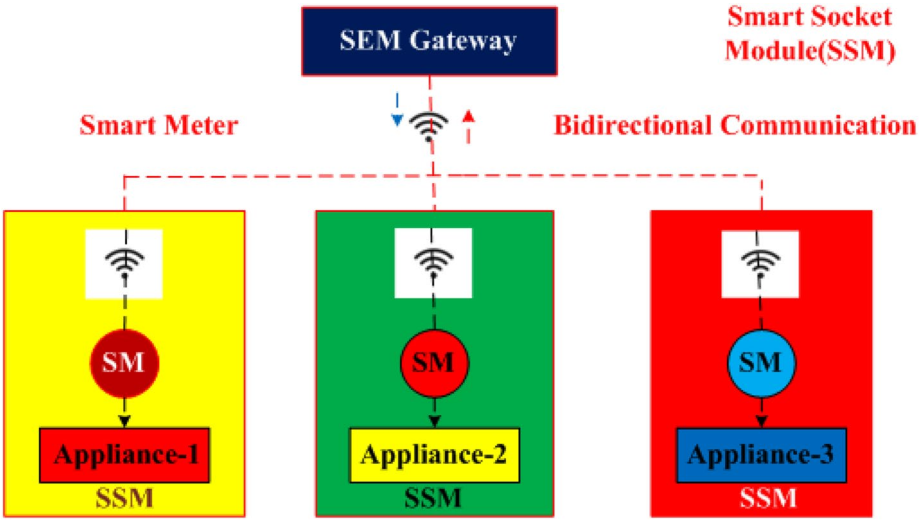

Fig. 1 Block diagram of smart energy management system [10]

Central controller for the SEM gateway

The main control element is the SEM, and a decisive algorithm is employed as the decision-making mechanism. Between the utility and the user, the SEM system's brain acts as a middleman. It decides whether to ON or OFF a certain collection of consumer data based on the utility signal it receives and the domestic user load priority selections [31]. To avoid paying tariff fees, the SEM unit alerts the user when they turn on a gadget that consumes a lot of power during peak load times. All load controllers using the XBee unit are required to have an LCD, so it is also in charge of gathering data on energy use from each of these devices so that it can view real-time data on energy use, change an appliance's priority based on its needs, and provide real-time data on energy use [32].

Communication module

Between a coordinator and a router, a wireless connection is created. In this instance, an XBee Series-2 device serves as the communication unit. An XBee unit is linked to each end of the SEM system to facilitate communication [33]. One XBee module is configured as a router and the other as a coordinator in a load controller. The coordinator and router are linked inside the SEM system to improve performance in terms of power usage and data transmission, and the coordinator connected to it sends control signals to the router. The SEM unit then uses the power consumption information acquired to carry out the power negotiation algorithm [34]. Only a selected handful of the numerous available communication technologies include Bluetooth, Wi-Fi, ZigBee, and Power Line Carrier. Depending on the connection and data throughput requirements, any one of these technologies or a combination of them can be utilized for a home area network based on an assessment learning of several message technologies, ZigBee, looks to be a viable choice for our application and provides low cost, low power, and ease of deployment [35].

Algorithm for demand-side energy management

Smart plug units are used in the proposed SEMS management system to enable individual consumer apparatus to connect to the gateway and communicate via XBee units in AT mode. In the recommended method, the SEM gateway receives energy consumption data from each installed smart socket as well as the utility's authorized maximum demand limit. Furthermore, each appliance is effectively scheduled by SEM using a reliable power negotiation technique [36]. The smart socket module (SSM) and SEM gateway of the proposed SEMS contain the following algorithms to regulate demand-side energy management used for effective power utilization.

- Central controller gateway
    - Demand response uses a decision-making technique
    - Self-diagnostic function for non-responding appliances

- Smart plug (appliance end)
    - Organize commands sent from the device end
    - Cost optimization method

The decisive algorithm, which is used in the SEMS main controller, is the foundation of the recommended SEMS strategy. The important algorithm also supervises all control operations [37].

Decisive algorithm through demand response

A recommended SEMS technique includes a decisive algorithm that considers customer priorities for appliances and keeps running at the most critical level, while the utility's energy supply is insufficient to fulfill the greatest demand [38]. Figure 2 depicts an absolute flowchart of the recommended SEMS approach using the power intercession method. This section contains a thorough, step-by-step explanation of the used approach.

Step 1 The initial step in the SEM decisive strategy involves compiling information regarding the power consumption of each item, gathered in a specific sequence. If a load controller fails to respond, a self-diagnostic process is initiated [39].

Step 2 Once power usage information is organized based on client priorities, the SEM gateway checks for any additional violations of the demand limit. This includes verifying if the sum of apparent power used exceeds the maximum demand limit (MDL).

Step 3 Before instructing the switching off of other devices, the SEM gateway sends a command to activate as many high-priority appliances as possible to ensure the MDL is not exceeded.

Step 4 Each appliance that is activated undergoes a peak load analysis by the decision-making algorithm. If the total appliance power exceeds 1/4 of the highest apparent power for the preceding month, the gateway notifies the load controller. This serves to warn the customer about excessive energy usage during peak load hours, thereby avoiding high tariff expenditure. Additionally, the load controller activates a buzzer and LED for one second to alert the customer.

Step 5 Following the transmission of correct command signals to each piece of equipment, the SEM gateway pauses for 30 s before sampling the next batch of data. During this interval, customers have the option to adjust device priorities as they see fit. After this pause, the process repeats steps 1 through 5 [40].

Figure 2 provides a high-level overview of the SEM decision-making process for managing "n" loads in a household. The flowchart utilizes variables "J" and "P" to collect energy usage data from appliances, with "J" increasing based on priority order and "P" following a predetermined sequence. If a load controller fails to respond even after data flow resumes due to a disruption, the SEM gateway initiates a self-diagnostic procedure. This involves querying the load controller repeatedly over the next 5 s [41]. If there is still no response after this six-second interval, the gateway assumes the load controller is permanently inactive and directs requests to other controllers.

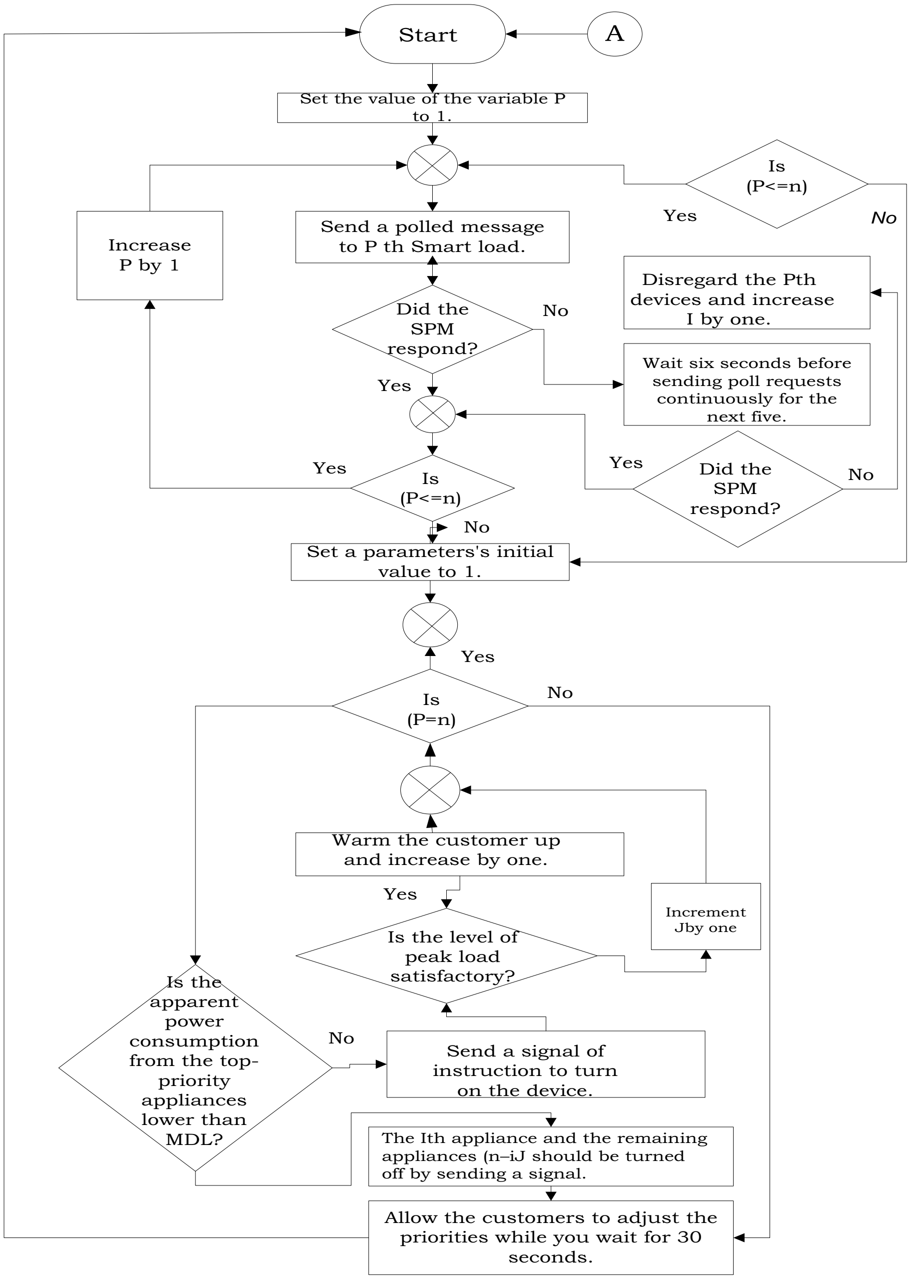

Fig. 2 Decision algorithm with self-diagnostic capability [20]

This ensures that the system's performance is not significantly impacted by a few non-responsive load controllers.

Cost optimization algorithm

Energy expenses for customers are significantly influenced by time-of-use (ToU) tariffs, making reduced energy costs a key objective of load scheduling algorithm development. However, not all devices in a household are compatible with this algorithm, as it depends on the consumer's preference for allowing schedulable processes on their devices [42].

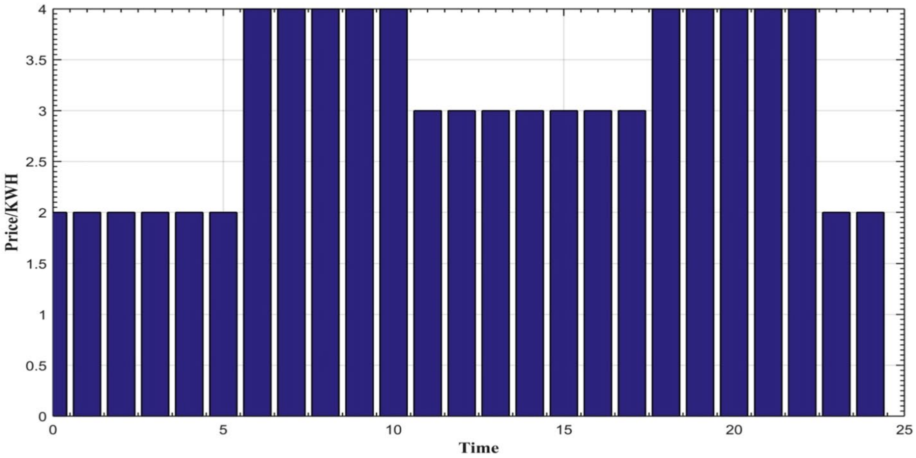

Fig. 3 Time-of-usage tariff for consumers

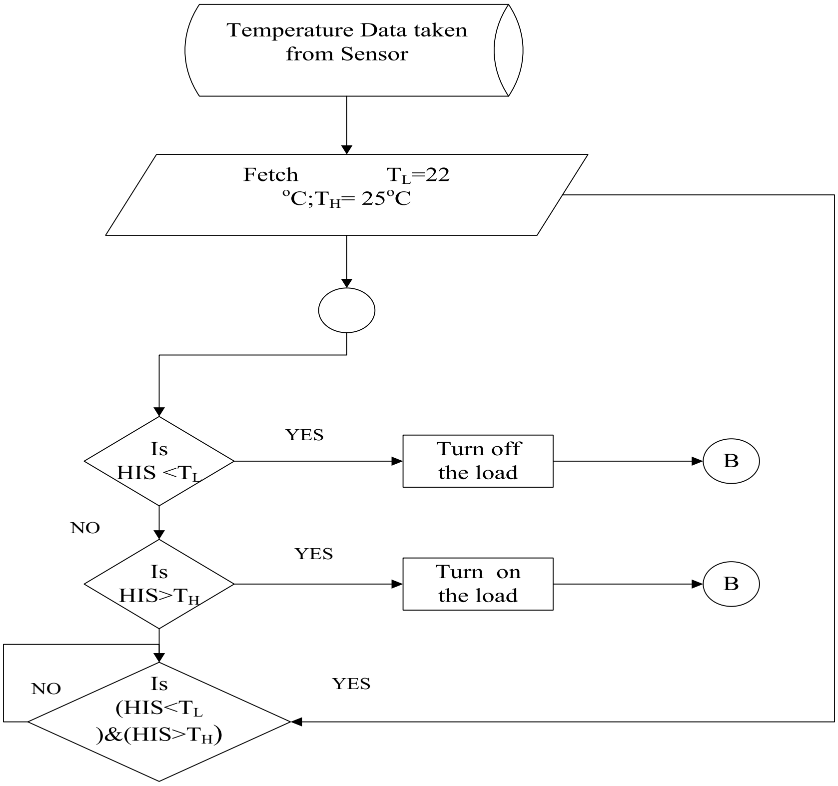

Fig. 4 Temperature controller of a schedulable device [42]

The load controller employs this technique in any schedulable device, with the load arrangement method established in the load controller and the SEM decision-making procedures jointly regulating all schedulable devices. Figure 3 illustrates TPCODL in India, the ToU Tariff for the 2023 financial year, relevant to low tension businesses, guiding the load scheduling algorithm to save costs [43]. Each schedulable device equipped with a SEM unit receives time information, enabling the load controller to determine the device's operating condition based on the time zone, as shown in Fig. 4. The appliance's daily usage requirement is determined by the customer's daily usage pattern [44]. As shown in Fig. 6, the algorithm aims to activate the appliance as much as possible between 22:30 and 06:30 to benefit from an incentive of Indian rupees 1.50 per unit. However, regardless of the required operating period, the appliance must be switched off during peak load times to avoid penalties. If the required operating time exceeds 8 h, it can run from 10:00 to 18:00 without reward or penalty during off-peak load hours. Otherwise, it operates between 22:00 and 6:00, receiving a reward before being shut off. The SEM decision algorithm may prevent the appliance from operating for the required time on any given day if generated power is insufficient [45]. In such cases, the algorithm compensates by allowing the appliance more time to run the following day. The unmet demand from the previous day is added to the current day's requirement, updating the daily demand every day at 10:00 PM.

Controller activities at the device end

A flowchart for an algorithm may be seen in Fig. 5, and its purpose is explained in the sections that follow. There is much information on the internal workings of the smart plug. Any requests from the coordinator end for the provision of power usage statistics are continuously reviewed by the smart plug decision-making mechanism [46]. RMS current, voltage, actual power, and power factor data are computed and sent by the microcontroller unit connected to the smart plug. The coordinator provides a command

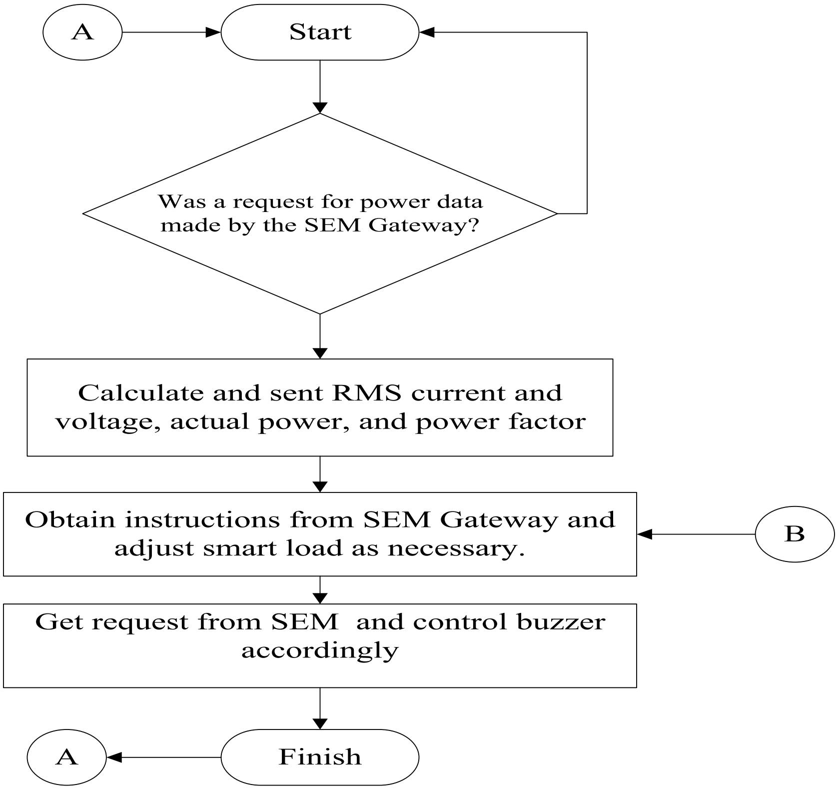

Fig. 5 Implemented algorithm in the smart plug module [2]

signal to the smart plug, which receives it and uses it to activate the relay to modify the state of an appliance. The coordinator also sends signals to smart plug informing it of any usage-related cautions.

Practical implementation of SEM

The laboratory setup and SEMS improvement are presented in this section.

The general setup of SEM

Figure 5 shows the whole SEM system, which is set up in the laboratory with general loads like lights, fans, and charging laptops as shown in Fig. 6. The SEM algorithms are activated during demand response events, prioritizing devices based on assigned precedence while considering the maximum demand limit [47]. To fit the appliance within the lowest slab rate, the algorithms schedule it while taking into account the time of usage.

In the laboratory experimental activity, a bank of incandescent lights is used as Load A. To show how the algorithms are connected to the user comfort condition, in this arrangement, the Load B appliance is a fan. This device includes a variable speed feature and is linked to humidity and temperature sensors [48]. The load, designated as Load C, is a laptop that is now charging. It was specially chosen to show how charged loads may be planned while taking the time of use (ToU) into consideration.

User end interface through the LCD

An LCD that indicates essential electrical characteristics like the priority of the loads and their energy consumption is a component of the SEM unit. Using the available switch buttons, the user may adjust the appliance's priority to suit their needs. Figure 7 depicts the SEM unit's experimental laboratory setup.

A smart plug serving as a load controller

The laboratory setup, known as a "smart plug," is seen in Fig. 8 and uses three identical load controllers. These are general-purpose plugs used to test the vital electrical

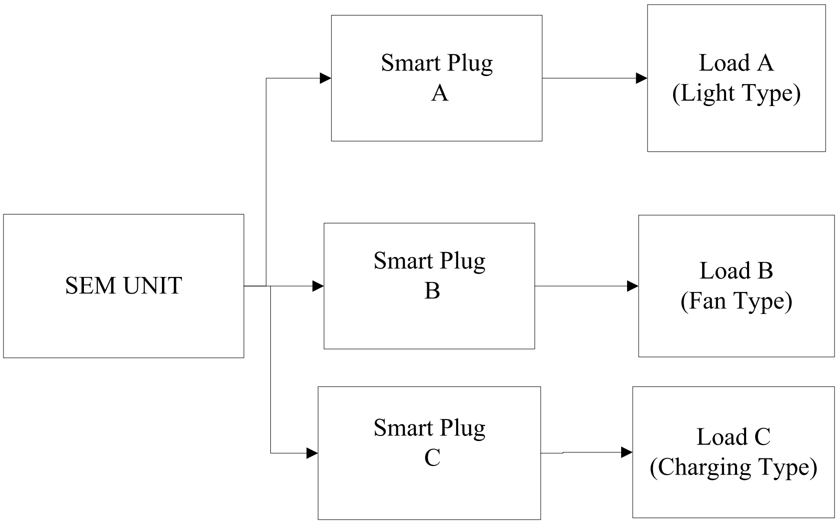

Fig. 6 Practical implementation of a smart energy management system [10]

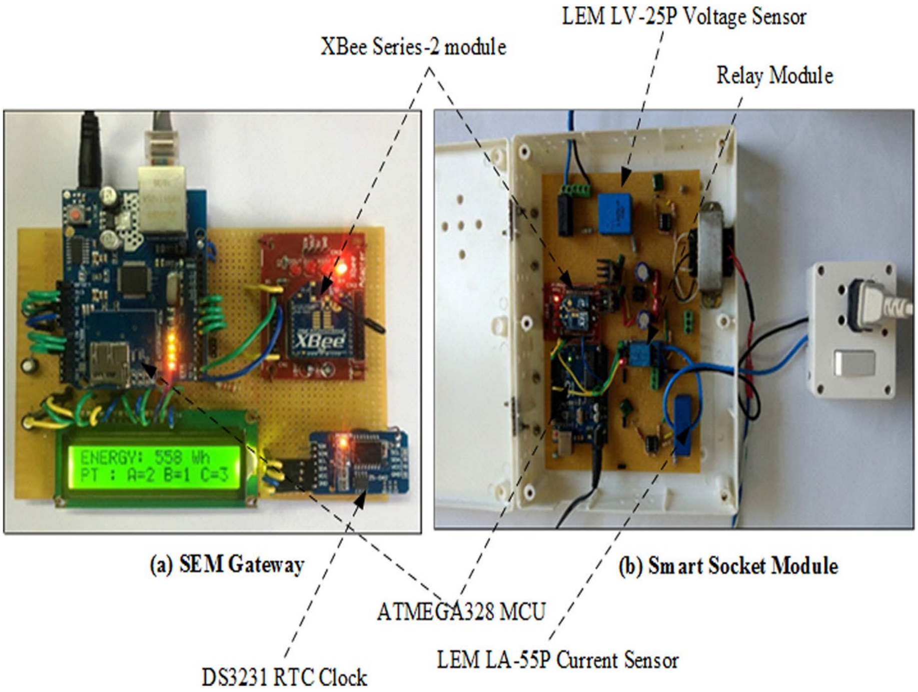

Fig. 7 Laboratory implementation of SEM and smart plug

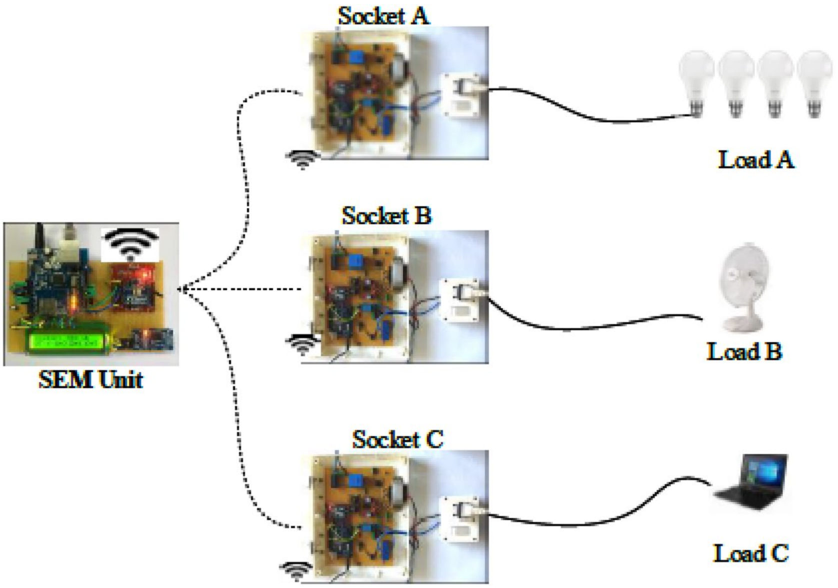

Fig. 8 IoT-based energy monitoring system [39]

characteristics of the connected loads for sub-metering applications as well as switch loads under received control signals [49]. The module has an XBee series-2 module for two-way communication, a 20A relay module for switching jobs, a LEM LV-25P and LA-55P current and voltage sensor unit, an ATMEGA328 microprocessor unit, and loads

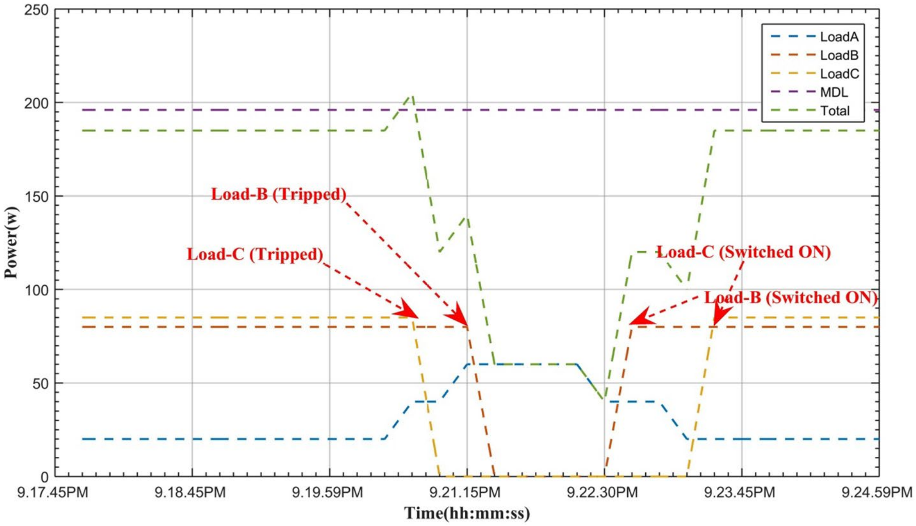

Fig. 9 High-priority devices with MDL limitation

linked to the smart plug as shown in Fig. 9. The SEM unit's coordinator then sends the router the control signal. The data were obtained in string format from the router [50]. To determine the real values of the electrical parameters, they are then translated to a suitable decimal form.

Communication unit

SEM provides two similar XBee units to communicate over ZigBee, one in the HEM serving as the coordinator and the other in the smart plug serving, while at the load end, a router. In the laboratory configuration, ZigBee messages are sent in the application transparent mode.

The SEM coordinator sends a message with a data request to collect all the data in the correct order to the built-in routers of the linked loads' energy consumption by using the smart plugs [50]. The SEM unit gets the control signal from the SEM unit coordinator after receiving the string-formatted data from the router. It is also converted to the equivalent decimal format in order to obtain the accurate values of the electrical parameters.

User priority setting options that can be configured

Appliance changes periodically depending on the user's priorities. For instance, lights would be preferred over AC at night, whereas AC would be more useful during the day. Therefore, priority settings are made flexible and are subject to alter at any moment by the customer under his or her preferences to allow the client flexibility in such scenarios of shifting requirements. On an LCD monitor, the priority of each load is shown in real time.

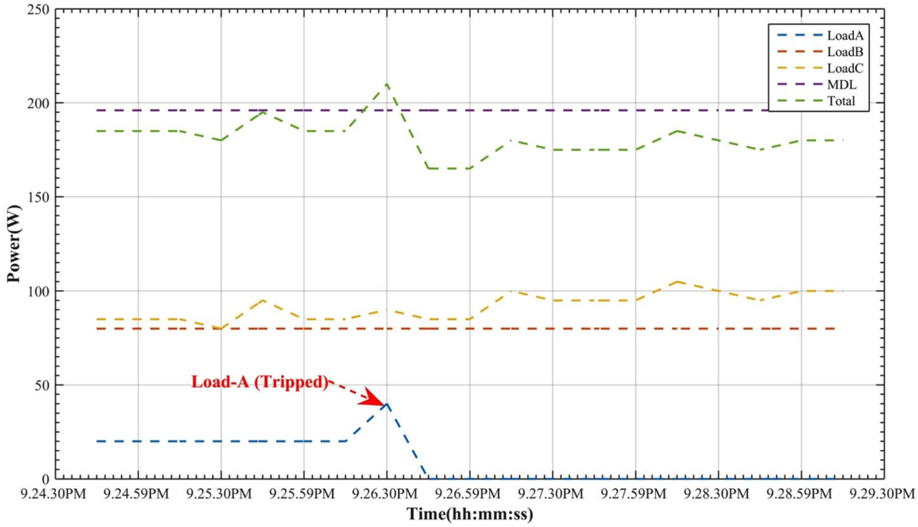

Fig. 10 High-precedence devices with modifications in the order of precedence allowing for MDL limitation

IoT-based energy monitoring system

Smart meters fitted in housing complexes provide real-time monitoring of energy use. Following a successful Ethernet shield connection, the produced SEMS data might be transferred to the server. A data monitoring system or data monitoring devices may be used to monitor and track additional given data. Figure 10 displays the system's whole graphical perspective. To investigate the management of energy systems, substantial amounts of metering data may be collected. Several research teams are now concentrating on energy costing solutions, machine learning, big data analytics, and real-time energy management systems.

Data gathering and real-time monitoring are made possible by the server and database management system employed by the energy monitoring system. The web pages of the web portal are only accessible to approved persons with the correct login credentials. Additionally, Sect. "Demonstration and result analysis" contains results and trend graphs.

Demonstration and result analysis

The outcomes for numerous scenarios are presented and examined in this section. To illustrate the efficiency of the energy management system, experiments are carried out by rating an appliance with various settings, a user comfort scenario, and a cost optimization approach.

Operational plan for a load with an established precedence

Test-I: Operation approach through active utilization of "Load A" (one Light)

In this case, the bank of luminous lights is given top priority and is designated as Load A. A mid-priority assignment is made for a fan load. Because battery charging may be

Table 2 Device state of operation behind load arrangement

Devices	Device status	Priority	VA power (kW)	Power demanded (kW)	MDL (kW)	Device position
Load A	Turn on the switch (one light)	High	0.02	0.185	0.196	Turn on the switch
Load B	Turn on the switch	Medium	0.08	0.185	0.196	Turn on the switch
Load C	Turn on the switch	Low	0.085	0.185	0.196	Turn on the switch

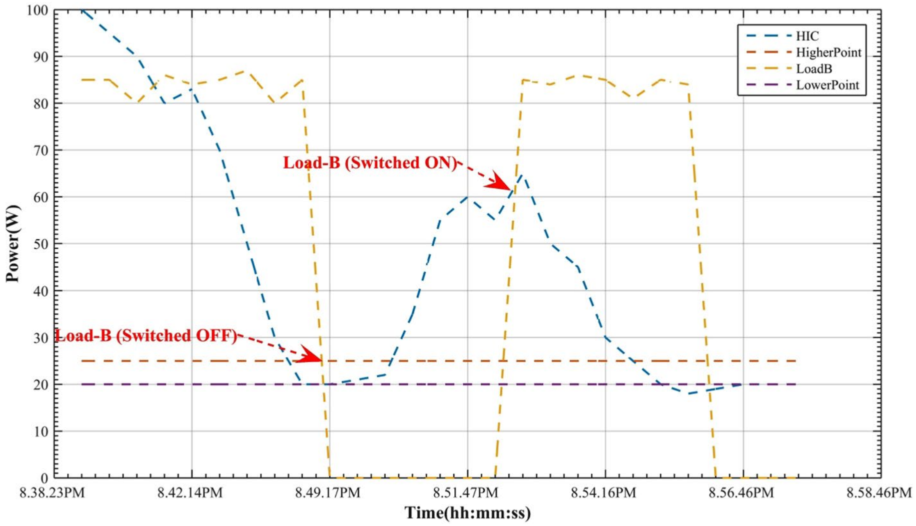

Fig. 11 User comfort level with the detected value

planned, it is given little consideration. Figure 12 depicts the SEM load scheduling procedure in this case.

Following is a step-by-step breakdown of the load preparation with selected priority.

Step 1 The data request signal "PA" was transmitted by the SEM unit.

Step 2 When asked about its power usage, Load "A" provides details like RMS voltage and current, power factor, apparent, real, and reactive power, and energy.

Step 3 A signal for an information request with the string "PB" was sent by the SEM.

Step 4 Load "B" response by providing information on the amount of power it consumes.

Step 5 A data request signal in the form of the letter "PC" was then sent by the SEM unit.

Step 6 Data about the power consumption of load "C" are returned.

Step 7 According to Table 2, the amount of power requested is less than the permitted maximum demand. The decision process, therefore, determines that all three loads should stay "Switched On." The SEM unit uses command signals in the form of the strings "paag," "pbbg," and "pccg" to turn on the relays for all three loads since the combined power consumption is below the maximum demand limit.

The highest demand is indicated to be 196 W in Fig. 11. All three loads were turned on from 9.17.45 to 9.20.45 since the highest power usage was below the MDL

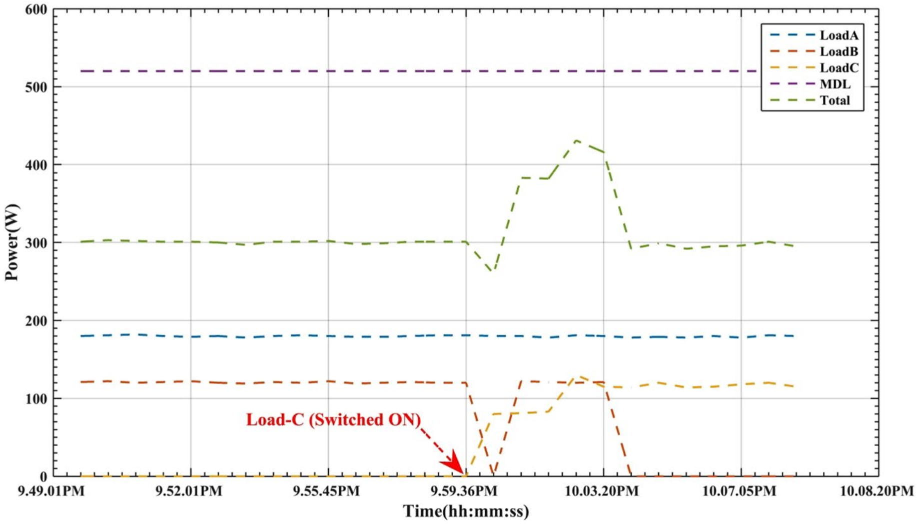

Fig. 12 Scheduling operation with ToU

Table 3 Device state of operation behind load arrangement

Devices	Device status	Priority	VA power (kW)	Power demanded (kW)	MDL (kW)	Device state of operation
Load A	Turn on the switch (two light)	High	0.04	0.205	0.196	Turn on the switch
Load B	Turn on the switch	Medium	0.08	0.205	0.196	Turn on the switch
Load C	Turn on the switch	Low	0.085	0.205	0.196	Turn off the switch

(maximum demand limit). At 9:20:45 PM, two additional incandescent lamps in the bank are switched on, causing the power bank's overall power usage to exceed the MDL. In response, the proposed SEM controller instantly eliminates the battery charging load (Load C) as shown in Table 4. Moreover, by turning on the additional bulb, the lighting load's power usage was at 9:21:30 PM. Taking into account that the lighting load consumes 60 W out of the total 196 W MDL. To keep supply and demand in balance, the controller also disconnects the second load (Load B). Then, in order of priority, Load B and Load C are switched on when Load A consumption decreases. In this instance, Tables 1 and 2 provide the SEM system's appliance scheduling and power usage information.

> Test-II: Operational Plan for Dynamic Utilization "Load A" (Two Light)
> Test-III: Order of Load precedence (Low) the Load A (Medium) (Highest) Loads B and C

As with Test-I, but as shown visually in Fig. 12, with the different ratings of the significance of the loads, the SEM compares a 196 W demand limit with the combined apparent power of the three loads (196 W; 060 + 080 + 085 W). Given that the total power consumption of the top two priority loads (080 + 085 = 165 W) is less than the maximum

Table 4 Device state of operation following load arrangement

Devices	Device status	Priority	VA power (kW)	Power demanded (kW)	MDL (kW)	Device state of operation
Load A	Turn on the switch (3 light)	High	0.06	0.225	0.196	Turn on the switch
Load B	Turn on the switch	Medium	0.08	0.225	0.196	Turn on the switch
Load C	Turn on the switch	Low	0.085	0.225	0.196	Turn off the switch

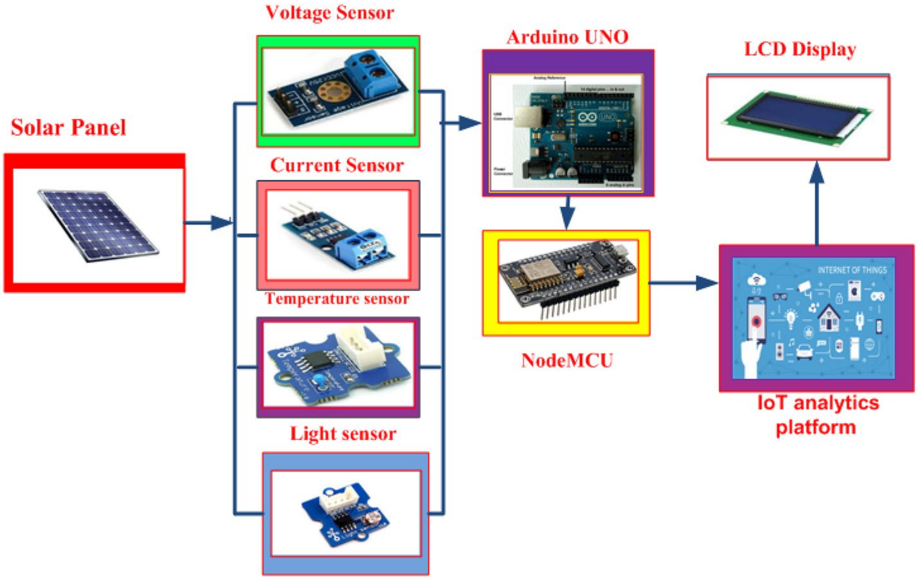

Fig. 13 SEMS system

demand limit, the SEM sends a signal instructing the relays for Loads C and B to turn on, while the relay for Load A is switched off as shown in Table 3.

In Fig. 12, a decisive algorithm-based appliance operation with assigned priority orders is shown. Imagine a situation where the user wants to activate each of the three loads as shown in Tables 3 and 4. Since there is no MDL violation, all of the loads are initially turned. It is seen that as Load A consumption rises, Load A itself is tripped off at 9:26:15 PM to avert an MDL violation since it is given a lesser priority in circumstance as shown in Fig. 13.

Using perceived sensor data to set user preferences

Since most heating and cooling units are built to operate within a specific temperature range or at a fixed temperature, they must be frequently turned on and off. An air-conditioner, for instance, creates the needed temperature based on the consumer's temperature setting. The air-conditioners compressor begins to operate as soon as the interior temperature reaches the set point. The compressor shuts off when the target temperature is attained and stays off until the outside temperature rises once again. The compressor requires a lot of electricity to run an air-conditioner each time it is used. The power required to run the air-conditioner constantly is far greater than this wattage. As a result, the air-conditioners efficiency is reduced by its frequent short cycles. On the other hand, when an air-conditioner runs for longer periods or over longer cycles, its efficiency increases.

The recommended approach allows customers to specify a wider range of temperatures, enhancing appliance efficiency and using less energy. The load controller checks for any deviations from the comfort criteria whenever the SEM delivers the signal to turn on a heating or cooling device. The appliance is moreover managed so that the temperature is continually maintained within the parameters of the user's comfort levels. In this instance, the heat index in Celsius, humidity temperature sensor data, and the threshold value are computed. As shown in Fig. 10, the lowest (21 °C) and highest (25 °C) temperatures also control the load status. The outdoor temperature is below 21 °C as of 8:44:21 PM. As a consequence, the controller shut off the fan load. Similar to this, the controller eventually turned on the fan load (i.e., at 08.52.17 PM) when the temperature exceeded the upper limit, which is 25 °C.

Scheduling allowing for ToU

Two categories of home appliances, such as schedulable and non-schedulable, may exist, as was previously mentioned in the sections above. The recommended controller lowers the cost of power during the ToU tariff by moving loads that can be scheduled at off-peak hours. In this instance, the controller makes use of both RTC module data and peak usage data from the utility. Figure 11 displays the load scheduling choices for the ToU pricing scheme. Battery charging is shifted by the controller to the peak-off hours, which in this case begin at 10 PM, to save power costs.

Conclusion

In a laboratory setting, the hardware for the SEMS prototype is developed and built, and tests are conducted to show how well the controller's power optimization algorithms work. The SEM controller and smart socket unit enable wireless ZigBee connectivity by utilizing XBee series-2 modules. It also has brand new modern self-diagnostic technology to create a trustworthy network. In the initial test, three different loads are used to demonstrate the new customizable priority features. A provision also allows customers to change the priority order for appliances. In this paper, numerous experimental scenarios are provided to demonstrate how only higher-priority appliances may operate in DR situations under MDL constraints. Using cost optimization methods, the SEM controller also plans the utilization of certain equipment for off-peak hours. It employs the lower slab rate and takes into consideration the ToU tariff to cut the cost of electricity. The consumer is informed of the increased power usage that takes place during peak hours via a buzzer and LED indications. To gather information on the power usage of particular loads, an IoT environment is connected to a secure internet gateway. On a GUI, a database for an energy management system is available with the option to be used for further data analysis, and it displays the daily and monthly power consumption of certain equipment.

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Author contributions
Challa Krishna Rao was involved in conceptualization, formal analysis, investigation, methodology, supervision, validation, and writing—original draft. Prof. Sarat Kumar Sahoo was involved in conceptualization, formal analysis, investigation, methodology, supervision, validation, and writing—original draft. Franco Fernando Yanine was involved in conceptualization, data curation, formal analysis, investigation, methodology, software, validation, and writing—original draft.

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Declarations

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