Optimally Automated Home Management for Smart Grid System Using Sensor Networks: Gaza Strip as a Case Study

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Abstract

Smart Grid (SG) allows real-time management of electric loads via the integration of Information and Communication Technology (ICT) concepts. Therefore, Home Energy Management Systems (HEMS) have been recently developed to smartly manage the electric loads in smart homes. In this paper, the Automated Home Management (AHM) system is introduced to intelligently control and schedule the electric loads. Hardware and software implementations are achieved to remotely control, monitor, measure and manage the electricity. Hardware components include a microcontroller, electric current sensor, electric voltage sensor, and Ethernet module. The Internet of Things (IoT) platform using Message Queuing Telemetry Transport (MQTT) protocol is embraced to connect the AHM system at homes with the data center at the operator of electricity. Thus, two electric energy management algorithms are introduced. Firstly, the Power Limit Management (PLM) algorithm is proposed to control the electric loads according to the available electrical energy. Secondly, Smart Electrical Task Scheduling (SETS) algorithm is developed to schedule the electric loads, so that the electricity daily cost, and the user comfort are improved. Simulation results show that the introduced SETS and PLM algorithms save energy consumption, and daily electrical cost with reasonable user comfort. Unlike other approaches, the proposed SETS uses a weighting parameter that can tune the level of comfort and daily price. When the weighting parameter is equal to half, user dissatisfaction is improved by 91.5% compared by the case of using a weighting parameter of unity. Furthermore, daily price is improved by 11.4% compared by the case of using a weighting parameter of zero.

Keywords Energy management · Microcontroller · Optimization · Sensor networks · Smart grid · Smart home

Introduction

The real-time electric power monitoring, measuring and control have driven the electricity operators to integrate the electrical grid with Information and Communication Technologies (ICT). Hence, Smart Grid (SG) is defined as the electrical grid that includes ICT. Therefore, ICT is employed in SG through using information management,

bidirectional communication, embedded measurements using sensors, and computational intelligence in all electricity supply phases including electricity generation, transmission, and distribution [1]. Advanced metering infrastructure (AMI) considers the first concept of SG. AMI aims to improve demands and energy efficiency. AMI also provides self-healing of errors, and reliable protection of grid against malicious damage, and regular disasters [2]. The tradition power grid is essentially used to deliver electrical power to the end customers. Conventional power grid only implies one-way power distribution without any use of ICT [3]. Unlike the conventional power grid, the electric power generation, transmission, and distribution in SG are integrated with ICT to be more flexible and efficient. Furthermore, SG is an automated system that uses the two-way flow of electrical power and information [4]. SG interconnects the electricity consumers and electricity suppliers in the levels of data exchange and electrical power.

The communication connectivity and data exchange among meters, sensors, applications, end-users and other

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entities of SG are achieved in smart grid communication infrastructure. The communication infrastructure must satisfy the Quality of Service (QoS) of data due to the importance of collecting information in automatic actions [5]. Reliability of communication infrastructure is also a crucial feature to guarantee the seamless connectivity among different SG components and devices. In addition, ubiquitous availability, high coverage, data security and customers privacy are vital for communication infrastructure.

Home Energy Management System (HEMS) have been recently developed to smartly manage the electric loads. Demand Side Management (DSM) allows the clients to alter their demands of using electric power so that the electricity price is reduced. Consequently, electricity can be utilized based on the available power. In addition, the usage of electricity is reduced in the peak hours during which the electricity price is high. DSM is used to use the available energy efficiently without using extra power generation. This is beneficial for countries with limited power sources such as Gaza Strip [6].

In this paper, Automated Home Management (AHM) system is proposed to smartly manage, control, count and schedule the consumer loads. The proposed AHM contains two algorithms which are Power Limit Management (PLM) to ensure that the overall load does not exceed the available supplied power, and Smart Electrical Task Scheduling (SETS) to schedule the loads so that the daily cost and user dissatisfaction are minimized. The main contributions for this paper are: (1) AHM consists of hardware, software, and algorithm parts; (2) The proposed SETS algorithm is a heuristic approach that schedules the electrical loads to improve the user comfort and electricity cost with a level of improvement that is based on a tuning weighting parameter; (3) The PLM algorithm solves the problem of electricity scarcity in area with crises, such as Gaza Strip.

This paper is organized into six sections including this section. In Section 2, the related work is discussed. In Section 3, the proposed Automated Home Management (AHM) system is introduced. A detailed description of the proposed AHM system is presented in Section 4. In Section 5, the simulation results are illustrated. Finally, Section 6 summarizes the paper.

Related Work

In [7], home automation using Internet of Things (IoT) based on Message Queuing Telemetry Transport (MQTT) protocol is proposed to remotely monitor and control some areas of the house such as doors, light and windows from anywhere. The system in [7] consists of two NodeMCU, sensors, and user notifications ways such as buzzer alarm. MQTT is used to communicate through the Internet. In [8], WiFi and

microcontroller are adopted using ESP8266. Low energy-consumption sensors and actuators are connected to ESP8266 to remotely control and monitor the home using MQTT protocol. Home energy management system is developed in [9] to manage the electrical loads of houses. WiFi and MQTT protocol are used to connect the appliances. However, all the above research does not consider the shortages in the electricity supply. Additionally, the scheduling the electrical tasks to reduce the electricity cost is not also considered.

In [10], scheduling algorithm for electric loads in case of using Real Time Price (RTP) is introduced to get the scheduling of electric loads that minimize the electricity cost. The loads used in [10] are ventilating, air conditioning, heating, and pumps. In [11], Demand Response (DR) solution is presented to schedule the electric load so that the total cost of the power consumed in the smart home is minimized. Genetic Algorithm (GA) is used in [12] for load scheduling so that the electricity cost and peak to average ratio are reduced. However, consumer satisfaction is not considered in above research.

Optimal scheduling pattern for electric load is obtained in [13, 14] for home energy management so that the Electricity Cost (EC), and Peak to Average Ratio (PAR) are reduced, and User Comfort (UC) is improved. Electric loads are divided into interruptible and non-interruptible loads. The interruptible loads or interruptible appliances can be disturbed during their operation, while the non-interruptible loads or non-interruptible appliances cannot be shifted during their operation. However, the same operational time interval for all loads is considered. In addition, the objective function for the proposed methods is not stated. In [15], Home Energy Management System (HEMS) is developed to optimize the energy consumption, and reduce the electricity cost using a hybrid algorithm that is inspired from Genetic Algorithm (GA), and Bat Algorithm (BA). The reduction of cost is achieved by shifting the operation of devices from high price hours to low price hours. However, consumer satisfaction is not considered in above research.

Demand management of energy for smart home is developed in [16] using fuzzy logic to manage the electric demand and reduce its cost. The inputs of fuzzy controller are electricity price, predicted load demand, battery charge level, and available power. The output of fuzzy controller is the rate of charge, switching to grid decision, and switching to battery source decision. However, the specific loads for smart home are not considered. In addition, the user comfort is not taken into account.

In [17], current sensors are attached for each electric outlet of smart home to monitor and control its electric load. The users can control the energy consumption of the outlets. The user can add financial limit or time limit for the operation of outlet. After exceeding of these limits, the electricity is disconnected from the outlet. However, the proposed technique in [17] considers only the outlet rather than considering the

load type. Moreover, user comfort and electricity price are not considered.

An energy management controller (EMC) is proposed in [18] to improve energy consumption, User Comfort (UC), Peak to Average Ratio (PAR), and curtail load demand. Real Time Price (RTP) is considered as tariff for bill generation. However, it does not considered the shortages in the electricity supply.

The problem of electrical task scheduling is introduced in [19]. The objectives are to minimize the daily cost or the consumer dissatisfaction. The results show that a saving on the daily cost is achieved. In [20], demand response model is applied to residential users. Specific loads are considered such as television, air conditioner, and lamps. The load usage is optimized to reduce the daily cost. However, the above approaches consider only specific types of electrical load. In addition, the objectives are considered separately, and optimizing using Pareto optimizing.

In [21], Demand Side Management (DSM) approach is proposed for DC microgrid. Photovoltaic (PV) solar system with batteries bank is used in [21] as the DC source. The electric loads are classified into controlled and deferrable loads. The operation of the deferrable loads can be delayed. Therefore, the proposed algorithm in [21] aims to shift the operation of deferrable loads from the low DC power generation to sunny time at which the DC power generation is high. The results in [21] shows that the energy efficiency is improved, and the power loss in battery is reduced because of the reduction in charge/discharge times of batteries. However, the proposed scheme in [21] assumes only DC microgrid. In addition, user comfort is not considered.

In [22], Real-Time Electricity Price based Energy Management (RTEPEM) system is introduced for DC microgrid. RTEPEM manages the electrical source selection and load scheduling so that the electricity cost is optimized. The electrical sources used in RTEPEM are PU, PV, and storage devices (BB and Hybrid Car (HC)). RTEPEM selects the source with the cheapest cost to supply the load. RTEPEM shifts the deferrable load to hours with lowest energy cost. However, the objective function in [22] do not consider the user comfort.

In [23], electric source selection in the microgrid is introduced. The load is connected to the nearest source to improve system efficiency in terms of power loss, voltage drop, and reliability. However, the system proposed in [23] does not consider the electric load scheduling and user comfort. In [24], a prototype of HAN-based load measuring and monitoring device is presented for Advanced Metering System (AMS). The device can measure the electrical load through utilizing voltage and current sensors and microcontrollers. However, the scheduling of electrical loads is not considered in [24]. In addition, the limitation of electrical energy is also not considered in [24].

In this paper, Automated Home Management (AHM) system is proposed to smartly manage, control, count and schedule the consumer loads. AHM consists of hardware, software, and algorithm parts. The hardware is developed to remotely control, monitor and manage the electrical loads. The software is implemented to manage the hardware and collect the information via Internet. The proposed AHM contains two algorithms. The first algorithm is the Power Limit Management (PLM), and aims to contribute on solving the problem of electricity shortage. PLM aims to ensure that the overall load does not exceed the available supplied power. Smart Electrical Task Scheduling (SETS) is the second algorithm which aims to schedule the loads so that the daily cost and user dissatisfaction are minimized. Unlike other related work, the proposed SETS algorithm is a heuristic approach that schedules the electrical loads to improve the user comfort and electricity cost. In addition, PLM algorithm solves the problem of electricity scarcity in area with crises, such as Gaza Strip.

AHM Framework

As shown in Fig. 1, Automated Home Management (AHM) system consists of three major parts: smart metering, load management, automation control. Firstly, smart metering is the main component in SG for collecting information about power consumption from the end users, and controlling the SG. Automatic Meter Reading (AMR) [25] is the technology that automatically collects smart metering information and redirects it to a central database for billing and troubleshooting. AMR supports two-way communication with meters. Thus, information which is available on-line at the right time and location enhances the grid control, operation and management. The smart meter is a physical measurement device that allows two-way communication from the meter and the central control system at operator side. Smart meters read the

Fig. 1 AHM framework

power consumption and other electrical measurement points and send them automatically to a central control system [26]. Therefore, billing system is performed automatically from gathering meters readings. Furthermore, control commands and triggers can be sent from the central control system to the smart meters.

Secondly, the load management aims to distribute electrical power according to its availability and demands. In rush hours, electrical power can be focused in working and manufacturing areas, while during afternoon and night it can be focused to homes. Furthermore, the amount of electrical power can be controlled for individual users according to user needs. For instance, low electrical power can delivered for the users who do not pay their bills. Another example, countries that have shortage of electrical power can manage the delivered power so that it can guarantee the continuity of electricity delivery to homes.

Finally, the automation control aims to remotely control the user appliances and devices so that the optimal electrical power is delivered to the home. The amount of electrical power may vary according to predefined policies adopted by the operator. Therefore, the automation control capability ensures operating the needed user appliances and devices according to the amount of delivered electrical power. As shown in Fig. 1, light, air conditioner, entertainment and security systems are remotely managed and controlled by the proposed AHM according to the user needs and delivered electrical power demands and availability. For instant, the operator or the user can remotely connect and disconnect the devices.

Figure 1 also shows the communication infrastructure adopted in this paper. The Internet of Things (IoT) platform using Message Queuing Telemetry Transport (MQTT) protocol [27] is adopted to connect the AHM system at homes with the data center at electrical operator. Furthermore, the users can control their homes using their smart phones through Internet.

Detailed Description of the Proposed AHM System

AHM Architecture

The AHM architecture is shown in Fig. 2. The Micro Controller (MC) is the heart of AHM. It receives the sensed electrical parameters, such as current and voltage from sensors. MC also computes electrical power using electrical power relations [28]. The sensed and calculated parameters are sent via the Ethernet port to be viewed in the customer, and operator sides so that electrical bills can be generated. Furthermore, MC triggers the suitable actions using actuators according to the received commands from customers or operators and sensed readings. For instant, electrical loads

Fig. 2 AHM architecture

connected to controllable Alternative Current (AC) output can be connected and disconnected accordingly. The power supply delivers Direct Current (DC) power to the MC, sensors and actuators.

AHM Hardware Circuit Design

Figure 3 demonstrates the hardware design for the proposed AHM system. Arduino Uno is used as a MC [29, 30]. Arduino Uno has ATmega32S-based microcontroller with fourteen digital input/output pins, and six analog inputs. It powers with 5 V DC by using the PC directly via USB port, external AC to DC power supply powered via jack, or external batteries powered via jack. Arduino Uno can be programmed using Arduino software (IDE) via USB port. The current and voltage sensors are used to measure the electrical current and voltage respectively. ZMPT101b single-phase AC voltage sensor module [30] is used in this paper. The voltage sensor is connected in parallel with the load via its line and neutral port. It also has output, ground and DC power ports. The Allegro ACS758 current sensor [31] is used to sense the electrical current. It consists of two terminals for current being samples, and output, ground and power supply terminals. The current sensor is connected in series with the load. The actuators are activated using relays. The relay is an electro-mechanical switch that allows controlling the conduction of a high voltage/current connection using a low voltage/current connection. Therefore, the alarm and controllable loads are connected as an output via relays. HanRun HR911105A Ethernet shield module [32] with single port RJ45 connector is used to connect the AHM system with the operator or customers via Internet. A main contactor is connected to the input terminals of delivered electricity source to remotely control

Fig. 3 AHM hardware design

the connectivity of the electrical power. The power supply converts AC power to DC power to supply the DC power to MC and sensors.

AHM Software Development

Figure 4 shows the software development for the AHM system. In Fig. 4a, the electric parameters are monitored. The electric current, voltage and power are measured and displayed. The limited power for power management is controlled using Fig. 4b. The low and high delivered power for homes can be adjusted according to available power in the distribution network. This selection of low and high load limited power is adjusted by the operator. Furthermore, the time

period for low and high power consumption is controlled. All these settings are remotely achieved using IoT via MQTT. However, the configuration settings are locally saved inside the AHM system. As shown in Fig. 4c, the AHM system is able to count the electricity usage and generate monthly bills.

The MQTT component includes MQTT broker and MQTT clients. MQTT broker is available online via Internet. It is used as a proxy server between AHM system and data center at electrical operator. All the messages of AHM system are forward to the data center (web server) through the MQTT broker. On the other hand, the commands are sent from the application to the AHM system through MQTT broker. The Arduino microcontroller in AHM system and the web server at the operator side works as clients for MQTT broker. The

Fig. 4 AHM software development

clients can publish or subscribe messages to the MQTT broker. When the client publishes a message (i.e. topic), it means that the client will send the message through MQTT broker. On the other hand, when the client subscribes a message (i.e. topic), it means that the client will receive the message from MQTT broker. Therefore, electricity operators can publish a command message, for example, to close/open the main contactor. The message is forward to AHM system through MQTT broker.

Power Limit Management (PLM) Algorithm

In regions that suffer from a shortage of electrical power like Gaza Strip [33, 34], electrical power management inside homes is a critical issue. Gaza Strip has only one plant for electrical power generation [35]. Gaza strip needs at least 500 MW of electrical energy. The sources of this electrical energy are Egypt (17 MW), Israel (120 MW) and electrical plant inside Gaza Strip (80 MW). This means that these sources cover only about 50% of electricity needs for Gaza Strip. In addition, Gaza Strip suffers from difficulties to get the fuel for electrical plant operation. Furthermore, the transmission lines and distribution networks of electricity in Gaza Strip are old and continuously degrading without any improvements, due to the unstable political situation in Palestine.

Thus, electrical power consumed inside properties can be managed to be within a predefined range. To achieve these goals, power management algorithm named Power Limit Management (PLM) algorithm is developed in this paper. The flowchart of the PLM is shown in Fig. 5. P_D is the maximum delivered power or the predefined available power of the property. P_{c_i} is the consumed power for the AC output i where $1 \leq i \leq n$ and n is the number of AC output ports. Each

AC output port is assumed to have a priority (Z_i) that indicates the operation importance of the AC output port. The importance of AC output increases when the priority of the AC output port increases. The consumed power of all AC output ports is calculated and stored in the parameter (P_c).

```

1: define sampling interval,  $\Delta t$ ;
2: get the current  $P_D$ ;
3: set  $P_c = 0$ ;
4: for ( $1 \leq i \leq n$ ) do:
5:   sense the consumed power  $P_{c_i}$ ;
6:    $P_c = P_c + P_{c_i}$ ;
7: end for;
8: set  $j = 1$ ;
9: while ( $P_c > P_D$  &  $j \leq n$ ) do:
10:  activate alarm "Overloaded";
11:  disconnect AC with priority  $Z_j$ ;
12:  update  $P_c$ :  $P_c = P_c - P_{c_j}$ ;
13:  increment  $j$ :  $j = j + 1$ ;
14: end while;
15: if ( $P_c == P_D$ ) do:
16:  exit;
17: else if do:
18:  set  $j = n$ ;
19:  while ( $P_c < P_D$  &  $j \geq 1$ ) do:
20:    connect AC with priority  $Z_j$ ;
21:    update  $P_c$ :  $P_c = P_c + P_{c_j}$ ;
22:    decrement  $j$ :  $j = j - 1$ ;
23:  end while;
24:  go to Line 8;
25: end else if;
26: delay  $\Delta t$ ;
27: go to Line 2;
```

Fig. 5 Flowchart of PLM algorithm

Algorithm 1 shows the PLM algorithm that manages power distribution to the AC output of AHM system. When the total consumed power exceeds the predefined available power, the AC output loads with lower priority are disconnected. On the other hand, if the total consumed power is less than the predefined available power, the AC output loads with higher priority is connected. Therefore, the PLM algorithm aims to provide fair distribution for the available power according to load priority strategy.

Smart Electrical Task Scheduling (SETS) Algorithm

Problem Formalization

Electrical task (T_j) is modelled as a tuple of the form:

$$T_j \equiv \{N(T_j), t_{ps}(T_j), t_{pf}(T_j), t_{rs}(T_j), t_{rf}(T_j), t_e(T_j), P(T_j), PC(T_j)\} \quad (1)$$

where j is the task identification, $N(T_j)$ is the task name, $t_{ps}(T_j)$ is the preferred task start time in hours, $t_{pf}(T_j)$ is the preferred task finish time in hours, $t_{rs}(T_j)$ is the real task start time in hours, $t_{rf}(T_j)$ is the real task finish time in hours, $t_e(T_j)$ is the task execution time in hours, $P(T_j)$ is the task power consumption in KW, and $PC(T_j)$ is the task power count in KWh. The task is preferred to be executed in the interval $[t_{ps}(T_j), t_{pf}(T_j)]$. Therefore, the real task start time should be bounded as follows:

$$t_{ps}(T_j) \leq t_{rs}(T_j) \leq t_{pf}(T_j) \quad (2)$$

It is obvious that task execution time and task power count are calculated as follows:

$$t_e(T_j) = t_{rf}(T_j) - t_{rs}(T_j) \quad (3)$$

$$PC(T_j) = t_e(T_j) * P(T_j) = [t_{rf}(T_j) - t_{rs}(T_j)] * P(T_j) \quad (4)$$

Real Time Pricing (RTP) is considered as tariff for bill generation. Thus, the total price of electrical power during the billing period (n) is the cost of the electrical usage during the billing period and can be computed as follows:

$$TP = \sum_{i=1}^n RPC(i) * RPP(i) \quad (5)$$

where n is the billing period which is defined as the number of hours in the billing period (n), TP is the total price of electrical power during the billing period (n) in price unit, $RPC(i)$ is real power count at hour i in KWh, and $RPP(i)$ is real power price at hour i in price unit per KWh.

Objective Function

For billing period of one day ($n = 24$ hours), the daily price (DP) in price unit can be computed as follows:

$$DP = \sum_{i=1}^{24} \sum_{j=1}^m [PC(T_j) * RPP(i)] \quad (6)$$

where, m is the number of daily tasks. The user dissatisfaction (UD) is defined as the total number of hours that tasks are postponed to be started, compared with the user preferred start times. Thus, user dissatisfaction for a task T_j is computed according to the following formula:

$$UD(T_j) = t_{rs}(T_j) - t_{ps}(T_j) \quad (7)$$

Therefore, the overall user dissatisfaction (UD) is calculated as follows:

$$UD = \sum_{j=1}^m UD(T_j) = \sum_{j=1}^m [t_{rs}(T_j) - t_{ps}(T_j)] \quad (8)$$

In this research, the main purpose of the proposed Smart Electrical Task Scheduling (SETS) algorithm is to get the task scheduling solution that minimizes the daily price (DP) and the user dissatisfaction (UD). Therefore, the objective function is defined as follows:

$$F_{obj} = \alpha * DP + (1 - \alpha) * UD \quad (9)$$

The electrical tasks are scheduled by determining the real start and the finish time of tasks. The scheduled tasks are stored in the data structure referred as P . Therefore, the best scheduling of the electrical tasks is determined as follows:

$$P^* = \operatorname{argmin}_P \{F_{obj}\} \quad (10)$$

Subject to:

$$P_T(i) \leq P_{av}(i) \quad (11)$$

where, $P_T(i)$ is the total consumed power in W at hour i and $P_{av}(i)$ is the total available power in W at hour i .

SETS Heuristic Algorithm

The Smart Electrical Task Scheduling (SETS) algorithm is explained in Fig. 6 and Algorithm 2. Firstly, data structure (P) that is used to store the scheduled tasks is declared. A variable T is also declared to store tasks. The weighting parameter (α) in Eq. (9) is selected in Line (3). After that, the tasks are scheduled so that the objective function is minimized. For each task, the objective function is computed for different real starting time of the task, where real starting time is increased in step of one hour in the range between the preferred starting time and preferred finish time. The real starting time with the smallest objective function is selected to schedule the task. In Line (5), the real starting time is set to the preferred starting time. Then, the current task is stored in variable T . The data structure (P) is cloned to a temporary data structure (P_{temp}) in Line (7). In Line (8), The task stored in T is inserted into P_{temp} . The objective function of P_{temp} is calculated and stored in F_{obj} . For each new increment of $t_{rs}(T_j)$, the objective function of P_{temp} is calculated and stored in $F_{temp_{obj}}$. The real starting time of the task with smaller objective function is replacing the old one. The task starting time with smallest objective function is scheduled and stored in P .

Fig. 6 Flowchart of SETS algorithm

Results and Analysis

In this section, the performance of the proposed SETS algorithm is evaluated using event-driven simulation. C++ is used to build the simulation environment using an Intel Core i5 2.5 GHz processor and 4GB memory. The billing period is set to ($n = 24$ hours). Unless it is specifically stated, the power consumption of tasks ($P(T_j)$) is selected to be uniformly distributed in the range of $0 < P(T_j) < 7$ KW. In fact, the preferred start time, and finish time of tasks are selected by the user according to its needs. Therefore, to evaluate the proposed algorithm, a random selection of preferred start time, and finish time of tasks is achieved. Thus, the preferred start time of tasks ($t_{ps}(T_j)$) is randomly selected the range of [1, 23]. The preferred finish time of tasks ($t_{pf}(T_j)$) is randomly selected the range of $t_{ps}(T_j) \leq t_{pf}(T_j) \leq 24$ using uniform distribution. The execution time of tasks ($t_e(T_j)$) is selected to be uniformly distributed in the range of $0 < t_e(T_j) < 5$ hours. The electricity price at hour i is randomly selected in the range of $0 < RPP(i) < \maxPrice$, where $\maxPrice$ is the largest hourly price during the day. In RTP approach, twenty-four hourly prices of electricity for the next day is assumed to be announced in advanced by the electricity operator to the users. The announcement of the next day hourly prices should be done in sufficient

```

1: define data structures,  $P$ ;
2: define variable  $T$ ;
3: select  $\alpha \in [0 \ 1]$ ;
4: for each task  $T_j$  do:
5:   set  $t_{rs}(T_j) = t_{ps}(T_j)$ ;
6:   set  $T = T_j$ ;
7:   define  $Ptemp = P$ ;
8:   insert  $T$  into  $Ptemp$ ;
9:   calculate  $DP$ , and  $UD$  of tasks stored in  $Ptemp$ 
   according to Equation (6) and (8);
10:  compute  $F_{obj}$  according to Equation (9);
11:  define  $Shift = t_{rs}(T_j) + 1$ ;
12:  while ( $Shift \leq t_{pf}(T_j)$ ) do :
13:    set  $t_{rs}(T_j) = Shift$ ;
14:    define  $Ttemp = T_j$ ;
15:    replace last element of  $Ptemp$  by  $Ttemp$ ;
16:    calculate  $DP$ , and  $UD$  of tasks stored in  $Ptemp$ 
    according to Equation (6) and (8);
17:    compute  $Ftemp_{obj}$  according to Equation (9);
18:    if ( $Ftemp_{obj} < F_{obj}$ ) do:
19:       $F_{obj} = Ftemp_{obj}$ ;
20:       $T = Ttemp$ ;
21:    end if;
22:    increment  $Shift$ :  $Shift = Shift + 1$ ;
23:  end while;
24:  schedule  $T$  and store it in  $P$ ;
25: end for

```

Fig. 7 Daily price (DP) with tasks size for different α

time so that the users can manage the load using the proposed algorithms.

SETS Evaluation

Random Tasks Generation

In this section, tasks are randomly generated to evaluate the proposed SETS algorithm. In Figs. 7, 8 and 9, the number of tasks varies from 10 to 50 tasks by step of 10. The Daily Price (DP), User Dissatisfaction (UD), and Objective Function (F_{obj}) for different values of α versus the number of tasks are plotted. It is noted that, with increasing the number of tasks, DP and UD are increased because more electrical power is required to execute the tasks. For $\alpha = 0$, UD is minimized to zero according to Eq. (9). Since DP is not considered for $\alpha = 0$, it takes high values compared with $\alpha = 1$. On the other hand, DP is minimized and UD is increased for $\alpha = 1$. The selection of $\alpha = 0.5$ aims to schedule the tasks with best UD

Fig. 8 User dissatisfaction (UD) with tasks size for different α

Fig. 9 Objective function (F_{obj}) with tasks size for different α

and DP . Thus, as seen in Fig. 7, DP in case of $\alpha = 0.5$ is small compared with the case of $\alpha = 0$, and is close to its value when $\alpha = 1$. Moreover, UD is improved compared with the case of $\alpha = 1$. Therefore, the weight parameter α is selected as needed. When the user wants a low price and low user satisfaction, α is selected as a high value, and vice versa.

In this section, tasks are randomly generated to evaluate the proposed SETS algorithm. In Figs. 10, 11 and 12, the maximum electricity price ($maxPrice$) varies from 2 to 10 price unit by step of 2. The Daily Price (DP), User Dissatisfaction (UD), and Objective Function (F_{obj}) for different number of tasks versus the maximum electricity price are plotted. In Fig. 10, DP is increased with increasing of number of tasks because more electrical energy is required to execute the tasks. Furthermore, DP is increased with the increase of the $maxPrice$ as the hourly electricity prices could take higher values. Figure 11 shows that the UD is increased with the increase of number of tasks because more tasks are involved

Fig. 10 Daily price (DP) with maximum price for different task sizes

Fig. 11 User dissatisfaction (UD) with maximum price for different task sizes

to the SETS algorithm. However, the UD slightly changes with the increase of $maxPrice$.

Case Study: Specific Daily Tasks, and Electricity Price

In this section, specific daily tasks for a normal user with a given electricity price during one day are considered. Thus, simulation uses a specific electrical price during one day which is shown in Fig. 13. As it is clear, the hourly prices are high in the rush hours between 12 pm to 17 pm, medium in normal times between 7 am to 11 am and 18 pm to 24 am, and low after mid night until 6 am.

Table 1 shows specified daily tasks for normal user. Task properties are also stated in Table 1. The user is assumed to perform cooking and dish washing twice a day. Clothes washing using washing machine is assumed to be performed once a day. After operation of washing machine, clothes are dried

Fig. 12 Objective function (F_{obj}) with maximum price for different task sizes

Fig. 13 Hourly prices in a daily period

and ironed once a day. Electrical Vehicle (EV) is also charged once a day.

The scheduling times for the tasks are explained in Figs. 14, 15 and 16 for different values of weighting parameter α . The x-axis represents the task ID, and the y-axis represents the times (i.e. preferred start time, preferred finish time, real start time, and real finish time). For $\alpha = 0$ in Fig. 14, according to Eq. (9) the objective function considers only the user dissatisfaction, and eliminates the daily price. Therefore, the SETS algorithm gives a solution with $t_{rs}(T_j) = t_{ps}(T_j)$ for all tasks. On the other hand, as shown in Fig. 15, for $\alpha = 1$, the SETS algorithm considers only the daily prices. Thus, user dissatisfaction is not considered and the tasks start at a time with the cheapest electricity cost, between preferred start and preferred finish times. Figure 16 shows the case of $\alpha = 0.5$. In this case, the SETS algorithm considers both user dissatisfaction and daily price. Therefore, the tasks start at times that minimize the user dissatisfaction and daily price together.

Table 2 shows the User Dissatisfaction (UD), Daily Price (DP), and Objective Function (F_{obj}) for different values of α . The UD is minimized to zero when $\alpha = 0$. In this case, all tasks are started at the preferred start time. Therefore, according to

Fig. 14 Electrical tasks scheduling for $\alpha = 0$

Eq. (8), the UD is equal to zero. However, the DP is not considered. On the other hand, the DP is minimized when $\alpha = 1$. However, the UD is not taken into account in this case. Therefore, the DP is reduced in case of $\alpha = 1$, compared with DP in case of $\alpha = 0$. However, UD is increased in case of $\alpha = 1$. Similarly, the UD is reduced in case of $\alpha = 0$, compared with UD in case of $\alpha = 1$. However, DP is increased in case of $\alpha = 0$. To get the advantages of both cases, the weighting parameter α is chosen in the range between zero and one. For $\alpha = 0.5$, UD is improved by 91.5% compared by the case of $\alpha = 1$. Furthermore, DP is improved by 11.4% compared by the case of $\alpha = 0$. Moreover, the increased values of UD (compared with $\alpha = 0$) and DP (compared with $\alpha = 1$) are not significant

Comparison with Other Approaches

Specifically, the main two objectives for task and load management are reducing the daily price and increasing the user satisfaction. However, there is a conflict between these objectives. It means that increasing the consumer satisfaction is achieved by operating the electrical load any time during the day. Consequently, the daily cost increases due to operating

Table 1 Tasks information for a daily period

Identification $ID(T_j)$	Task name	Power consumption (KW) $P(T_j)$	Operation time (Hours) $t_e(T_j)$	Preferred start time (Hour) $t_{ps}(T_j)$	Preferred finish time (Hour) $t_{pf}(T_j)$
1	Cooking 1	2.5	2	10	14
2	Cooking 2	2.5	2	18	21
3	Dish Washing 1	0.5	1	16	18
4	Dish Washing 2	0.5	1	22	24
5	Washing Machine	0.5	1	8	20
6	Dryer	2	0.25	21	24
7	Iron	1	0.5	17	21
8	EV Charging	3.3	3	1	8

Fig. 15 Electrical tasks scheduling for $\alpha = 1$

the tasks any time without avoiding the times with high cost of electricity. On the other hand, reducing the daily price is achieved by operating the electrical load only at the times during the day with low electricity price. Consequently, the user satisfaction decreases due to operating the tasks at specific time based on the electricity cost without taking into the account the times that are preferred to the user.

Planning of tasks using a multi-objective evolutionary algorithm is introduced in [19], and optimum load management strategy is developed in [20]. In [20], demand response model is applied to residential users. Specific loads are considered such as television, air conditioner, and lamps. The load usage is optimized to reduce the daily cost. In [19, 20], one objective is only improved without considering the other.

Unlike other approaches introduced in [19, 20], it is worth mentioning that the proposed SETS algorithm aims to reduce the daily price and user dissatisfaction with a level of

Fig. 16 Electrical tasks scheduling for $\alpha = 0.5$

improvement that is based on the value of a weighting parameter. The proposed SETS uses a weighting parameter (α) that can tune the level of comfort and daily price. According to Table 2, considering the weighting parameter, α , aims to improve both objective functions. In addition, the approaches in [19, 20] considers only specific types of electrical load. As discussed in Section 5.1.1, the proposed SETS overcomes this limitation by considering any type of electrical tasks.

Practical Implementation

Figure 17 shows the practical implementation of AHM system. The electronic schematic of AHM system is shown in Fig. 3. Arduino Uno is the heart of the system. Ethernet shield module is connected to Arduino. The Ethernet module is connected to a router via Foil Twisted Pair (FTP) cable for Internet access. Four relays are fabricated in a PCB. These relays are used to connect/disconnect the four controllable AC load outputs. The loads are represented by four lamps. Another relay is installed to connect the alarm output with Arduino. 12 V 20 Ah battery with voltage regulators is used to deliver DC power for Arduino and Internet Router. Heat sink is used as a cooling medium for the regulator. The Arduino is powered by DC using jack.

A main relay is used to control the connection of AC power source. If the loads exceed the maximum limit without disconnecting any devices, the electricity is cut off using the main relay. The current sensor is connected with AC source in series after the main relay. It measures the electrical current and send the measurement to the Arduino. The voltage sensor is connected with AC source in parallel. It measures the electrical voltage difference and sends the readings to the Arduino. The current and voltage sensors are supplied with DC power after the regulators. The step size to retrieve the data from the sensors is set to five seconds, and the results are updated to the user every three minutes.

The operation of current sensors, voltage sensor, and Arduino MC require stable and reliable uninterruptable Power Supply (UPS) or Float Cum Boost Charger (FCBC) [36]. Therefore, the source of DC can be either from the full wave rectifier that convert AC to DC, or from the battery bank during the failure of AC supply. The current circuit design in this paper considers only battery bank with charger. In future work, stable DCBC will be used to ensure the reliability of DC supply.

Conclusion

The main objective of this research is to develop an energy management system that smartly manage the electric loads in homes, according to the available electrical power so that the electricity cost and user satisfaction are reduced. Thus,

Table 2 UD , DP and F_{obj} for different weighting parameter (α)

Weighting parameter (α)	User dissatisfaction (UD)	Daily price (DP)	Objective function (F_{obj})
$\alpha = 0$	0	13.64	0
$\alpha = 0.5$	2	12.09	0.51
$\alpha = 1$	23.75	10.03	0.78

Automated Home Management (AHM) system is developed for Home Energy Management Systems (HEMS). The proposed system consists of hardware, algorithms, and software parts.

The purpose of hardware part is to develop a smart meter that can measure, control and monitor the electrical loads. The heart of the hardware part is the microcontroller. It receives the sensed information, processes the algorithms, and sends the calculated parameters and possible actions locally and via IoT environment. Smart meter which is the main component of smart grid, is fabricated to remotely control and manage the electric loads of smart homes based on the available electrical energy in countries with shortage of electrical power.

In the algorithms part, Power Limit Management (PLM) and Smart Electrical Task Scheduling (SETS) algorithms are developed. PLM algorithm automatically connects/disconnects the loads based on the available electric energy. When the total consumed power exceeds the predefined available power, the AC output loads with lower priority are disconnected. On the other hand, if the total consumed power is less than the predefined available power, the AC output loads with higher priority is connected. SETS algorithm schedules the electric loads of smart homes so that the electricity cost and user comfort are improved. RTP in hourly basis is considered as tariff for bill generation. The electric tasks, and electricity prices are firstly modelled. After that, the objective function is defined as a weighted sum of user dissatisfaction and daily price. Finally, SETS algorithm is introduced as heuristic method to get the near-optimal tasks scheduling.

In the software part, software application is implemented to remotely monitor electric current, voltage and power, and control the limited power for power management. All these settings are remotely achieved using IoT via MQTT. On the

other hand, the configuration settings are locally saved inside the AHM system. The electric current, voltage and power are measured and displayed.

Simulation is performed to get and analysed the results for random electric task, and hourly price generation, and specific daily tasks, and electricity price. Simulation results show that the weight parameter α controls the main objective of the users. When the user wants a low price and a low user satisfaction, α is selected as a high value, and vice versa. The SETS algorithm works with different scenarios, such as price changes and tasks size variations. The SETS algorithm is also evaluated for specific daily tasks and the results show that SETS algorithm gives a schedule of tasks operation that improves electricity price and user comfort. For $\alpha = 0.5$, UD is improved by 91.5% compared by the case of $\alpha = 1$. Furthermore, DP is improved by 11.4% compared by the case of $\alpha = 0$.

Future works consider controlling the source selection in DC micro-grid. Other micro-grid electrical sources, such as PV, EV, and BB should be studied. Mechanism to charge and discharge the electrical EV should be also discussed. Other methodologies such as GA for obtaining function optimization should be also considered.

Compliance with Ethical Standards

Declarations of Interest none.

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Fig. 17 Hardware implementation of AHM system

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