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A Novel Demand Side Management Scheme for Residential Buildings Using Smart System

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Abstract- Energy Management System (EMS) is emphasized as the main area of research in this modern world. Smart techniques are deployed to reduce the cost of energy and energy consumption. Smart energy socket (SES) implicated system is a measure taken to enhance energy usage standards for residential appliances. SES can operate as a central unit of the load management system in residential area, empowering Demand Side Load Management (DSLM) by orderly scheduling the loads. The proposed work concentrates on obtaining energy management for residential buildings, by implementing Smart Energy Socket (SES) designed for both DC and AC systems. The SES proposed is designed with three sockets, namely low, mid and high priority application sockets. The priority depends on customer power usage and requirement. The proposed SES model consists of three different DC outlets for three prioritized DC loads connected and three sockets with AC single-phase supply for different power rated home appliances. The proposed system is capable of controlling and monitoring the load connected to SES using a microcontroller and the Internet of Things (IoT). The work is further extended to implement a fire and gas level detector security system along with SES with three prioritized loads. The proposed hardware schedules the loads based on priority using IoT environment along with fire and gas leak detection.

Keywords Energy management, Smart energy socket, Internet of Things, Sensor, Demand Response.

1. Introduction

The energy management system plays a major role in the smart building to manage the power consumed by the consumers. This EMS incorporates SES, DSLM, Current sensors, Aurdino and relay switches. There are two distribution systems, namely Direct Current (DC) and Alternative Current (AC) system. Due to the compatibility of major electrical equipment, a preferred system of distribution is the AC distribution system. The power distribution scenario is slowly changing with the emerge of photovoltaic cells, wind turbines and fuel cells etc. used in generating the power. The DC system has remained to exhibit numerous preferences over the AC system, which has coordinated to move from regular AC to DC source. Most of the equipment used in the residential area depends on DC power as their internal source of energy for its operation. There is a new trend of research towards DC and AC distribution and power consumption systems. Hiroaki Kakigano et al. analysed the basic characteristics of the DC system and inferred that the total losses in the DC system are approximately 15% lower than the AC system [1]. Analysis of AC/DC and DC/AC distribution systems along with energy efficiency calculations discloses that energy efficiency was found higher in the DC distribution system than the AC distribution system [2] [3]. The plan and usage of EMS were to manage the loads which are plugged within the smart buildings. So, the researcher in [4] proved that the DC system can be more adaptable over AC systems, due to the harmful effects on consumers that may seriously alter the health of the consumers. Cermal Keles et al. proposed an energy management system for the imminent smart buildings in [5].

The author proposed a smart DC socket with an automated power management system which created the possibility of achieving energy efficiency in the smart buildings. Qiansheng Fang et al. proposed a remote control braced smart socket in [6]. Time synchronization in the congregated sockets was accomplished using the network time protocol server. H. Morsali et al. experimented with the influence of deploying the smart sockets for reducing the energy consumed, particularly during heavily loaded duration [7]. A momentary load-changing plan to successfully convince the consumers to change their peak time utilization and to decently charge the electricity bill of the user for their power utilization was proposed by the authors in [8]. Loss calculation and comparison of DC and AC distribution systems were explained in [9]. The performance analysis of a 230 V AC system and a scaled downed version of the DC system with the mitigation of parameters such as wiring losses, device internal loss and energy utilization cost was proposed by authors in [10]. The standards used in smart grids for residential areas, office buildings and automation of buildings were reviewed in [11]. Jihong Zhu et al. [12] examined and reviewed the issues of energy utilization for large residential sectors and put forward a control measure to solve the problem of high-energy consumption in those sectors. The adapted control strategies were based on the technical and management level. Aryuanto soetedjo et al. [13] proposed a fuzzy logic controller-based home energy management system to reduce energy consumption in the residential arena. Joao C. Ferreria et al. proposed a wireless sensor-based energy management system that would monitor and control the warming or cooling, power utilization and lighting level of the equipment, in [14]. An exhaustive survey of permissive technologies, protocols and planning for an urban IoT was elaborated in [15]. Potential information on the communication system using IoT was proposed in [16]. Shedding of loads in a power system is primarily adapted to overthrow the imbalance made in the power generation and power consumed by the load, succeeding with the arise of contingency in the distribution network [17].

Load shedding on the smart grid was classified into three major groups; which are conventional methodologies-based algorithm [18], modern optimization-based algorithms [19] and adaptive load shedding algorithms [20]. Load management, control and monitoring of smart devices using Computational Intelligent Techniques (CIT) like the Internet Of Things (IoT) and Big Data (BD) was proposed in [21],[22],[23]. Non-interrupting load control and monitoring of residential loads using the Deep Learning Technique (DLT) were proposed by Christos Athanasiadis et.al., in [24]. Further, the advanced technologies adapted in smart grid along with detailed summary of automation in measurement and control of smart grid was reviewed by authors in [25]. Also, the challenges that exists on usage of these technologies were elaborated by author Ilhami Colak et.al. in [26].

The review expounds that smart building experiences a crucial move toward CIT like IoT, BD, DLT etc. based control and monitoring of EMS from the microcontroller and wireless technology-based EMS. Also smart sockets that works for only for load connection, monitoring and control using modern technology is focused. A lag in hardware implementation for the smart metering techniques is observed.

- Thereby, this work focuses on the implementation of both DC and AC SES to obtain energy management for smart buildings based on three prioritized loads connected namely low, medium and high.

- A DSLM algorithm that can connect the load based on threshold setting is initiated.

- Microcontroller along with IoT-based control and monitoring of load connected to SES is proposed with a downsized version of the prototype.

- Also, an initiative is taken for including an IoT-based home security system with flame and gas level detector along with SES using handheld mobile and laptop.

The content of this paper is organized as follows: Section 2 elaborating on the proposed SES system, Section 3 focuses on the hardware implementation for DC and AC SES in Section 4. Finally the results obtained are discussed in Section 5 continued by conclusion in section 6.

The main contribution of this paper is to outline the effectiveness of reliability assessment in power systems, classification of reliability assessment techniques and various reliability indices used in reliability evaluation of power systems, and gives a lead to the future perspective in reliability. The highlights of the work is given below.

1. The assessment of reliability indices is carried out to support in identifying the interruptions. In addition, suggestions are provided for a proper reliability initiative to uphold the continuity of power supply.

2. The reliability assessment techniques based on deterministic, probabilistic, intelligent and simulation methods are discussed.

3. This study supports the identification of proper reliability assessment techniques for performance enhancement of electrical distribution networks.
4. The present review work has been explored with various reliability assessment methods in detail to fulfill power system requirements in reliable manner and most of the reviews emphasis on historical assessment and analytical approach.

The paper has been organized as follows: The reliability indices of various hierarchical levels of power systems are presented in section 2. The classification of various reliability assessment techniques and their significances are explained in section 3. Section 4 and 5 presents the summary and conclusions.

2. Proposed Method And Simulation

The DC distribution system competes equally to the AC distribution network, owing to various applications with different voltage and power ratings. The current work introduces an SES which can be adapted to the power distribution system to provide a drastic improvement in load side management. Implementation of the load-scheduling algorithm via SES would also increase the efficiency of DSLM. A domestic distribution system operation based on SES is designed in this work. This approach gives load adaptability using load tripping and loads connecting algorithm, by controlling the load directly with the power threshold set for each SES based on the priority. Figure 1 delineates the functional block diagram of the SES, which communicates with the SES through the power line communication module and also sends a command to the Aurdino microcontroller from the sockets.

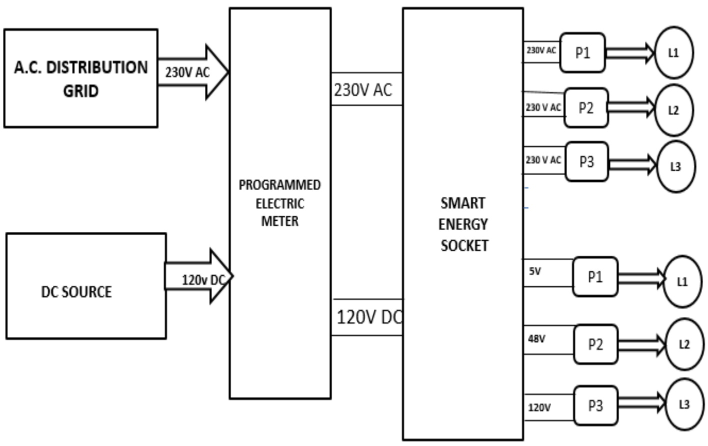

Fig.1. The Functional block diagram of the proposed SES

The function of the microcontroller is to accomplish the commands from SES like measurement, control and monitoring of the power modification module. The proposed SES can schedule the load using the inbuilt microcontroller programming. Owing to modernization, the inter-networking control over the load connected is made with IoT. IoT is preferred to collect and exchange data potentially, across the formed framework. Nowadays, so many technological developments have been made in the arena of the power distribution system. The flexibility in customer demand extensively encourages the infiltration of alternative RES into the grid. The proposed SES is designed to operate for both AC and DC voltage.

The proposed SES consists of three DC power sockets and three AC sockets. Since low-power appliances such as cell phones require 5V DC as input voltage, a DC socket for low voltage applications is provided in SES. Computer and laptop operate on medium DC voltage, hence a 48V DC outlet is used to serve the medium power appliances. As the International Electro-technical Commission has allowed 120V as a safe operating voltage limit for humans, a high power DC voltage socket is provided for the operation of household appliances such as a mixer grinder, washing machine, etc. SES is also designed for 220V AC lines for the conventional AC loads with three different power ratings.

To make the availability of DC supply, 220V AC supply is being converted into DC using an AC/DC converter block. To design the socket for different operating DC voltage, the DC/DC chopper system is used. This chopper circuit is designed using a Pulse Generator as a controller to drive pulse width modulation (PWM) block to generate a gate signal to the ideal switch. So, the switch will control the supply according to the input signal. The AC/DC converter converts the input AC voltage to DC voltage. Three DC/DC converter block is used to transform the obtained DC output to 5 V, 48 V, 120 V range. Three different DC voltage is obtained across the socket. The allowable load to 5 V socket is 5W, 48 V socket is 200W and 120 V socket is 1000 W. The simulated DC SES is shown in Figure 2 with the different range of operating voltages as output as shown in Figure 3. The load scheduling with L2 & L3 tripped and L1 switched on is depicted in Figure 4. The control and monitoring of loads connected in SES are performed in the simulated model using a coded function block. The control of switching operations in SES is performed based on the load connected to each socket. Power consumed by 5V socket is indicated as L1, which is stated as the highest priority level; where switching off is prohibited. The power consumed by 48 V is designated as L2 medium priority level, where the preference of switching this socket depends on the total power consumed. The socket with 120V is of less priority which is shed first during the abnormal condition. The function block act as the control signal for switching the SES and a DSLM algorithm is programmed in the block to perform the switching operation of SES. The power calculated at each socket is given as input to the functional block. The maximum allowable peak power limit is given as Pm. The aggregate of power consumed in the home is given as Pho.

3. Demand Side Load Scheduling Based On the Priority Listing

The aim of introducing the DSLM algorithm is to limit the power consumed by controllable equipment at home. There is a periodical check of power consumed by each load connected in the socket. The ON/OFF signal sent to the socket depends on whether the power calculated exceeds P_m or lesser than P_m. When $P_{ho} \leq P_m$ then power supplied from the grid is sufficient to meet the customer demand and the function block sends a HIGH (1) signal to all the three sockets so that all the sockets are in ON mode. When $L_1+L_2 \leq P_m$ and $P_m < P_{ho}$, , the power generation plunges with the demand which remains the same as the previous case; the function block isolates the L3 socket having the lowest priority and sends HIGH (1) signal to L1 and L2.

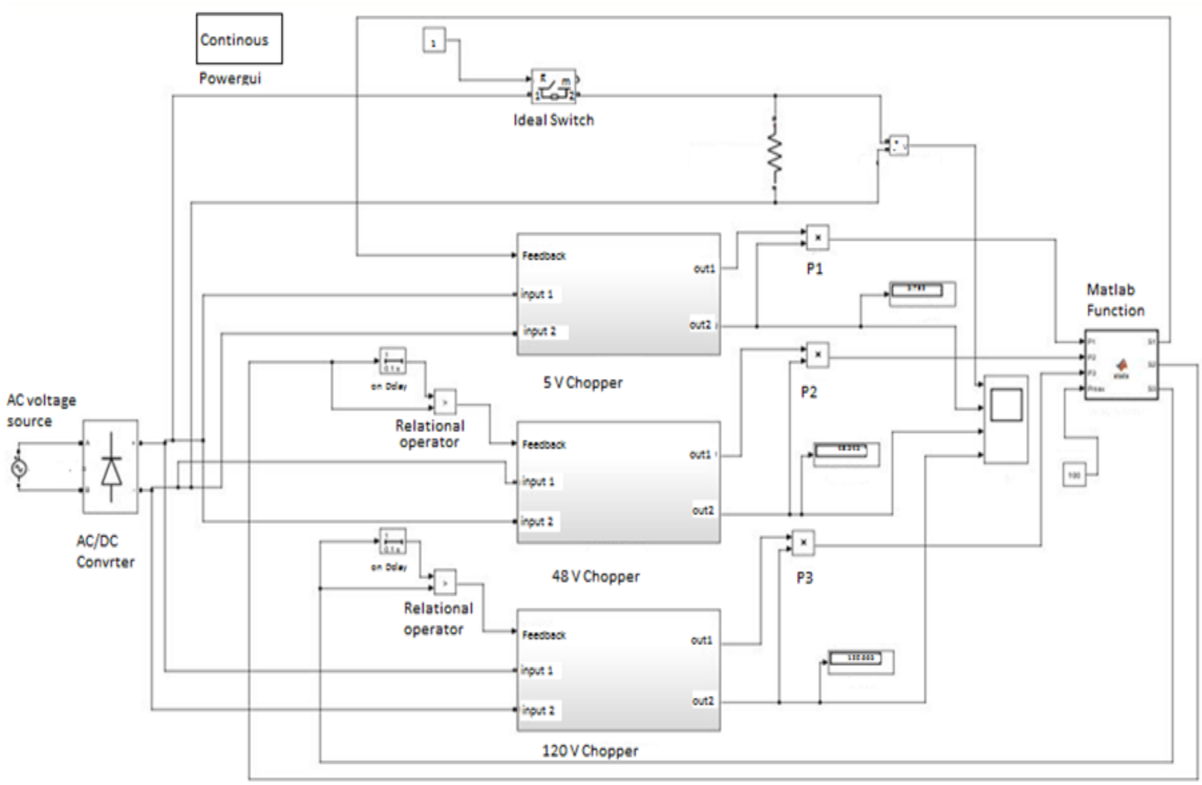

Fig 2. Simulated model for Smart Energy Socket

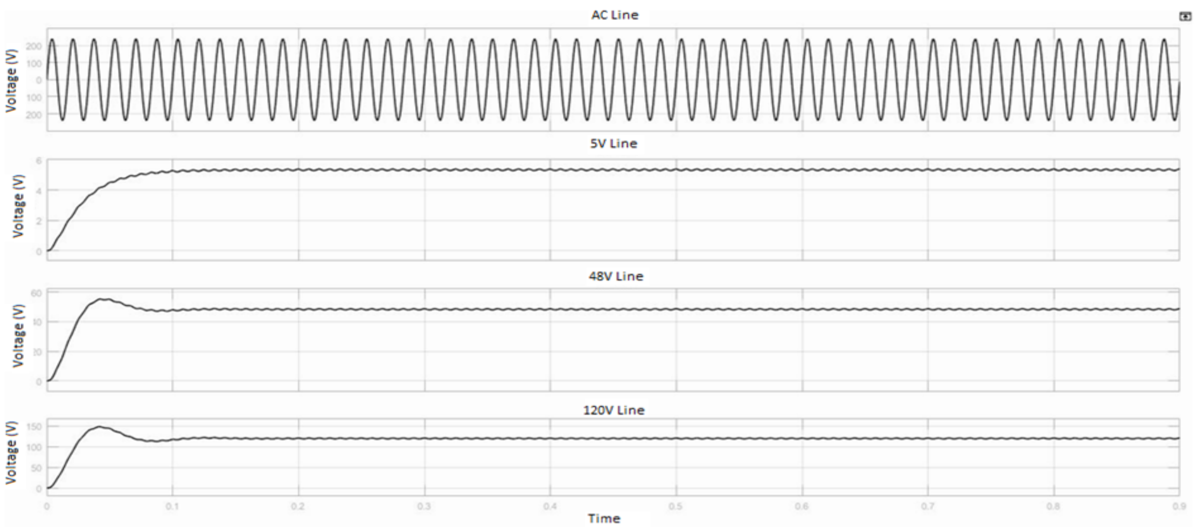

Fig. 3. Simulation Output of DC socket

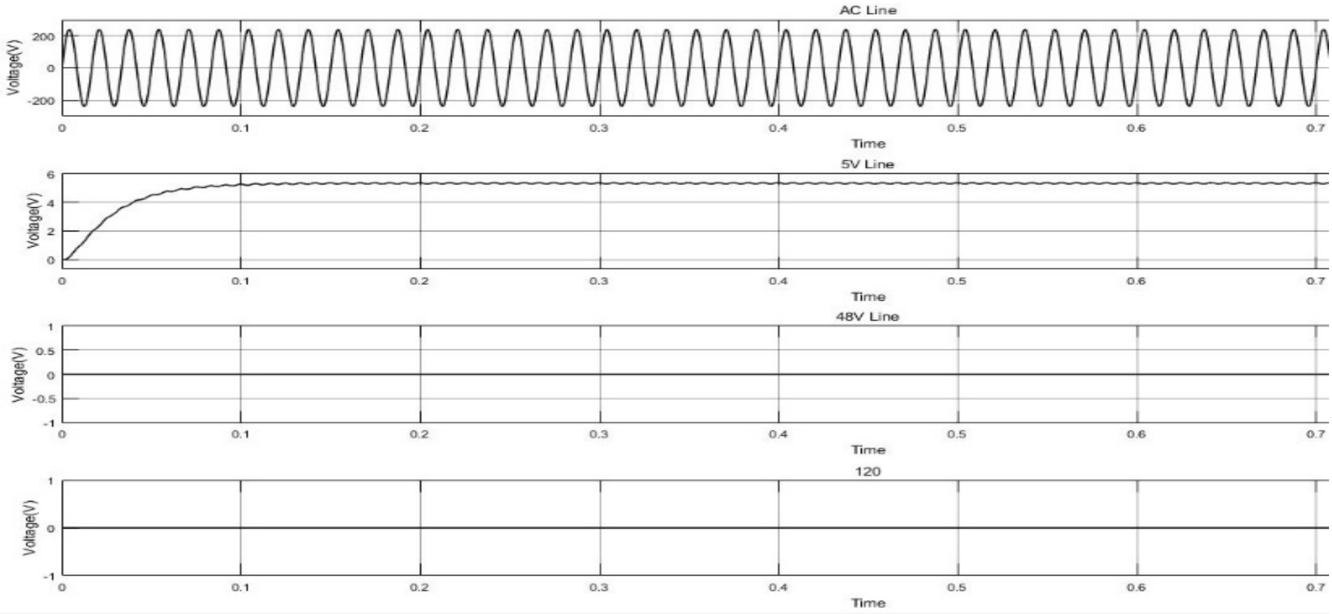

Fig .4. Simulation of DC socket with L2 and L3 rescheduled

When there is a further decrease in power available, the lowest priority switches L2 and L3 are switched off by sending a LOW (0) signal and only the L1 switch having the highest priority is in ON condition. The tripped loads are rescheduled to low grid power pricing duration with load limitation for the particular duration. The DSLM algorithm is fed to the microcontroller to actuate the SES and it is given as:

Step 1: Calculate the total power of priority groups P1, P2 and P3.

$$L = \sum_{i=1}^{n} P_i \quad (1)$$

where Pi is the measured power of each socket.

Calculate Pm based on user cost preference Cmaximum and user cost at that instant is Cpresent

P_m=C_maximum/C_present +Pho+P_GRID (2)

Step 2: The value Pm is the forecasted allowable power of the particular hour.

Step 3: Calculate the total power consumption which is considered as Pho

Step 4: If Pm ≥ Pho; then all sockets are in working condition. If yes continue operating all the load connected to all sockets, else go to step 5.

Step 5: If step four is violated in such a way that Pm is greater than the summation of SES priority P1 & P2 but Pm is less than Pho i.e., P1+P2≤ Pm ≤ Pho; then turn off L3 load connected to P3 socket until the condition Pho ≤ Pm and P1& P2 are serving the loads L2 and L1. If yes perform the tripping of P3 socket and calculate the total power as in step 1 else Step 6.

Step 6: If P1 ≤ Pm < P1 + P2, then turn off L2 loads connected to P2 socket one after the other after switching all the L3 loads, until the summation of all the loads is lesser than Pm. However, keep working all L1 loads connected to P1 socket. If Pho ≤ Pm , continue calculating total power till any violation.

Since the loads connected to the P1 sockets are considered as the mandatory loads, the power consumed is well within the base load forecasted. In addition, the tripped loads are postponed using the load scheduling strategy. Since the loads connected to the P1 sockets are considered as the mandatory loads, the power consumed is well within the base load forecasted. In addition, the tripped loads are postponed using the load scheduling strategy.

Similarly for the AC SES, the design in Matlab Simulink is made using a finite AC source with 230 V, 50 Hz as the output rating, for serving three loads of low, medium and high priority. The corresponding output wattage and current consumption for AC SES with the DSLM algorithm is obtained using Matlab. The simulation of AC socket is made for three different power rated loads such as 375W as highest priority P1, 40W as medium priority P2 and 1000W rated load as low priority P3. Figure 5 depicts the AC socket design for three prioritized loads.

The lighting loads are considered as highest priority loads, fan and other motor loads are considered as medium and low priority loads. The current and power consumed by the three loads considered in the design of AC SES is obtained concerning its priority as output. The current consumed by each load and its connecting and disconnecting duration according to the DSLM procedure is shown in Figure 6.

Also, the real power absorbed concerning the load's priority of getting connected is depicted in Figure 7(a). Figure 7(b),(c),(d) shows the simulation of the AC socket based on the DSLM algorithm which trips the P3 and P2 priority load based on the amount of power consumption level for a particular time.

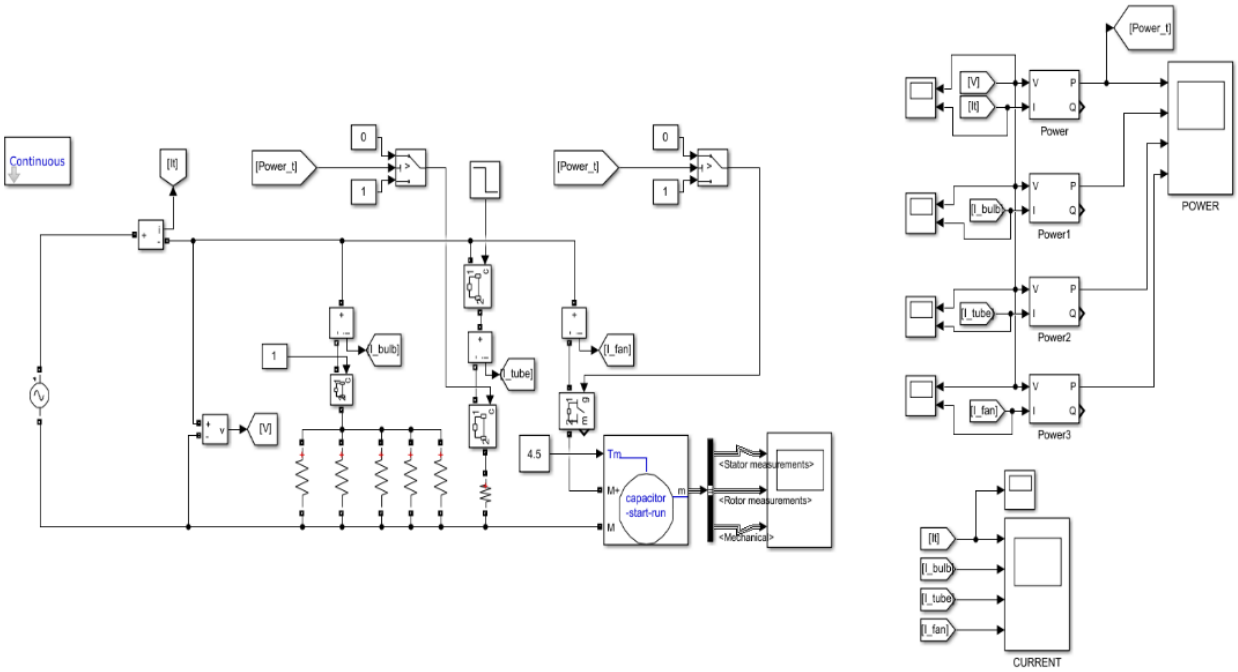

Fig. 5. Simulink design for AC socket

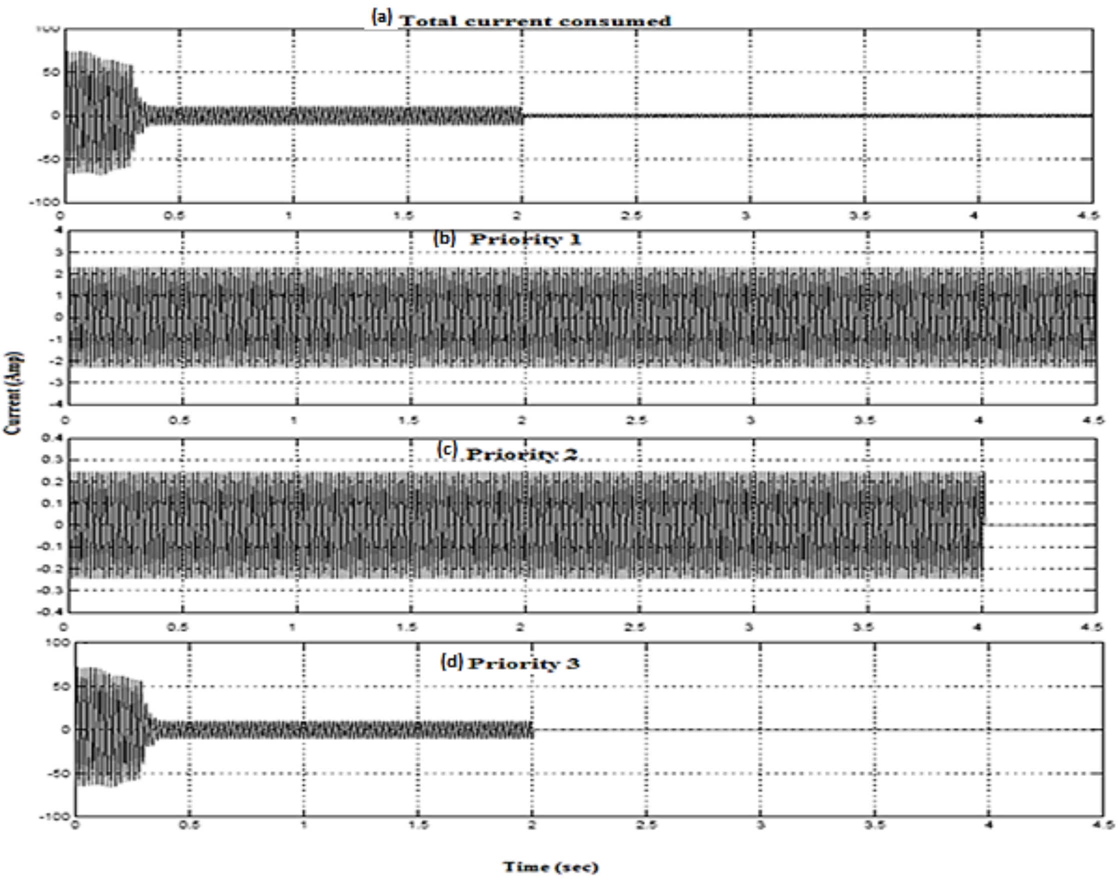

Fig.6. (a) Current waveform of total loads connected to AC socket **Fig. 6.** (b),(c),(d) Current waveform of simulated AC socket based on its priority

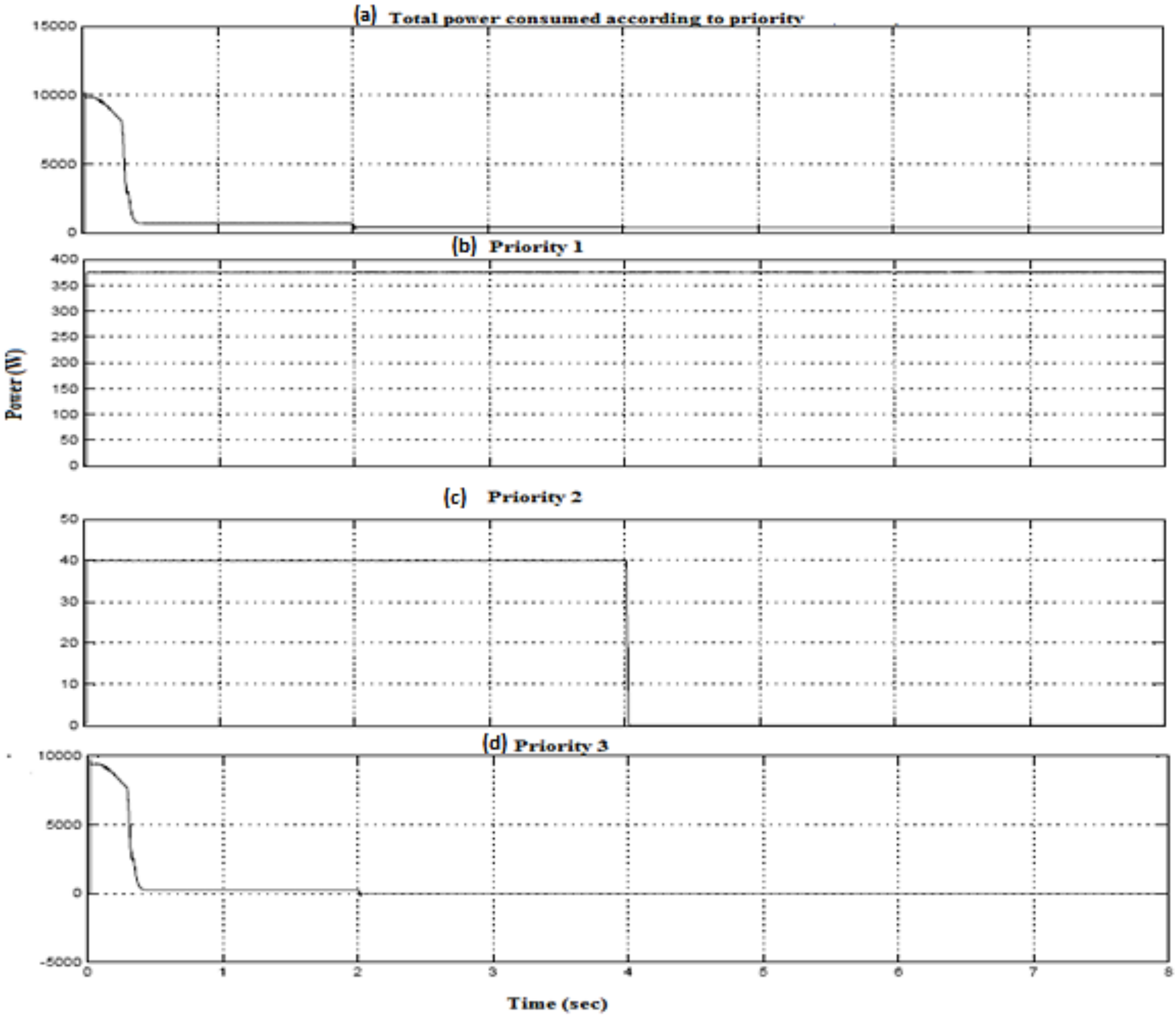

Fig. 7. (a) Real power consumption by the total loads connected to AC socket. **Fig. 7.** (b), (c),(d) Real power consumption by the loads connected to AC socket based on its priority

4. Design Components and Data for Hardware

A scaled-down version of hardware; demonstrating the systematic load scheduling depending on the amount of power allowed to be drawn for a particular period is modelled. The model from the simulation has been taken one step forward to realize the hardware prototype both for DC and AC-SES. The list of components used for hardware implementation includes the Microcontroller that forms the functional block of SES. The control and monitoring unit for SES is provided using the Arduino Nano a user-friendly board based on the ATmega328 (Arduino Nano 3.x). Current Sensors (CS) are used for estimating the power consumption of the connected load. The Allegro ACS712 provides economical and precise solutions for AC or DC sensing. The TA12-100 CS is designed such that it can be used with microcontrollers like the Arduino. These sensors are based on the Allegro ACS712ELC chip. These current sensors are available with full-scale values of 5A, 20A and 30A. The 30A sensor is used for the design of SES in this work. CS gives the measured current as of the input to the Arduino. These current measurements are the controlling parameter for the relay board for connecting or tripping a load from the socket. A relay breakout board can be switched with a 12V low-voltage low current control signal. The control signal is fed directly to a BSS138 N-channel MOSFET, which in turn actuates the relay coil when the signal voltage exceeds the set threshold voltage. The programmable electric meter for performing the control action of SES is picturized in Figure 8. To supply conventional AC loads AC-SES is modelled. The scaled-down version of the prototype has a UNO Arduino Series 2 microcontroller for monitoring and controlling the loads connected to the SES. A 9V DC battery is used for supplying the Arduino board. Lamp loads of different power ratings are connected in the sockets to serve as three loads of different priorities.

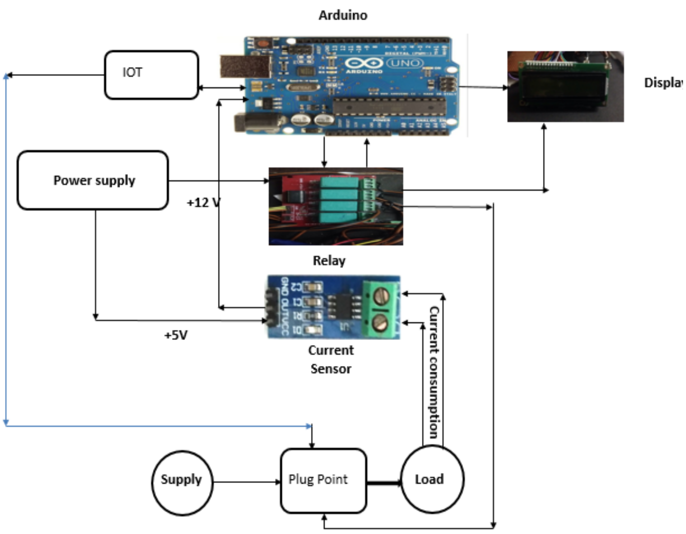

Fig. 8. Programmed Electric Smart socket meter for load scheduling

The current drawn by loads connected in each socket is sensed by TA12-100 AC sensors which are designed to be easily used with microcontrollers like the Arduino. The current sensors are programmed through Arduino to measure the AC consumed by the load. The Sensors sense the current signal and it is given as the input to the Arduino. These values are the controlling parameter for the relay board. A 12 V relay breakout board is used for scheduling the load. The breakout board has a single-pole double-throw (SPDT) relay switch. It makes it easy to switch 12V high current signals using low-voltage, low-current control signals from a microcontroller. The control signal is fed directly to a BSS138 N-channel MOSFET, which in turn actuates the relay coil when the signal voltage exceeds the specified maximum.

4.1 IoT monitoring based Smart energy socket

An improvised and potentially enriched conventional AC socket can be made available by using modern technology prevailing in today's environment. This paved way for the implementation of IoT-based SES with priority load tripping. The proposed system has three load sockets which can also admit additional loads to be connected parallel with the sockets. This load consumption is realized using a microcontroller, which in turn is interfaced with a relay setup. Activation and deactivation of loads in the socket can be controlled by the relay through the current sensors that sense the current at each socket using Raspberry Pi. Node MCU (Microcontroller Unit) is an open accessed window for IoT forum. It consists of firmware that operates on the ESP8566 Wi-Fi Soc (System on Chip). Arduino microcontroller interfaced node MCU is used to transmit and receive the control signals from and to the loads. The switching operation of the loads are controlled by node MCU. If the power consumed by the load exceeds the threshold value then the scheduling of the load is done on the socket by the DSLM algorithm at that time instant.

5. Result and Discussion

The hardware setup for the DC and AC SES system for priority based load connection and disconnection using DSLM algorithm with IoT monitoring and control is implemented. Figure 9 depicts the working model of DC SES system that controls and monitors the load connection using the programmed microcontroller unit. Figure 10 represents the IoT-based AC SES with three prioritized power socket and Figure 11 depicts the load scheduling, load controlling and monitoring using IoT platform for loads 1, 2 to be connected and load 3 to be disconnected due to the power constraint $P1+P2 \leq Pm \leq Pho$. The voltage and current measured along with the load power-tripping indication-using IoT is picturized in Figure 12. The proposed system is relevant due to its automotive way of controlling, monitoring and display of load data, thereby making the system to be efficient and reliable.

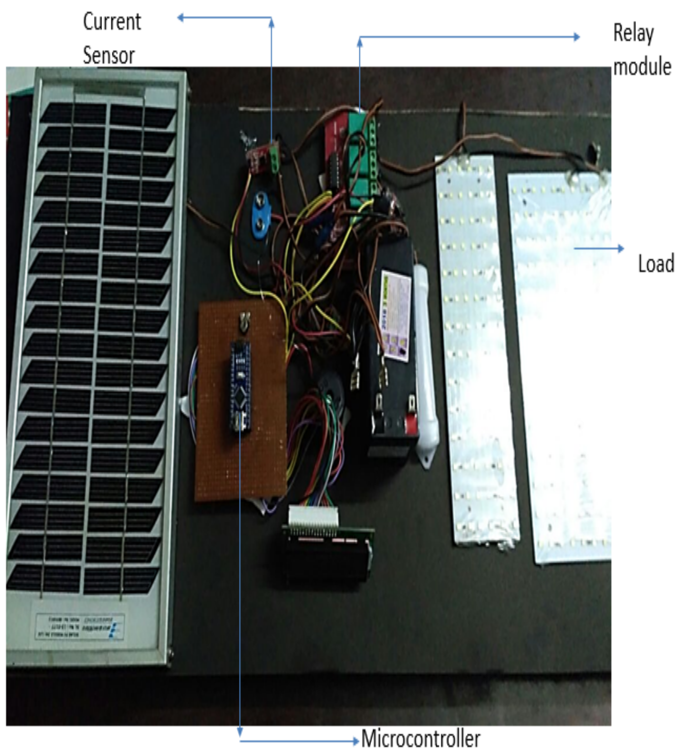

Fig. 9. Working model of DC Smart socket

Furthermore, the proposed system is enhanced with the advantage of IoT technology to monitor fire detection and gas level detection along with SES with three different prioritized home loads. The flame detector detects the temperature change of the area and sends its signal to the management unit. An UVIR flame sensor that works for 100cm distance and above 760nm wavelength is used. Robotly MQ gas sensor is used for detection of five different gases that works well with microcontroller unit. Also, the gas detector unit is used for indicating the gas level. The microcontroller unit in turn sends the response to the user and system to take necessary action. IoT is employed to update the sensors standing to the cloud. Figure 13 picturizes the SES with a flame security system and gas detector using IoT.

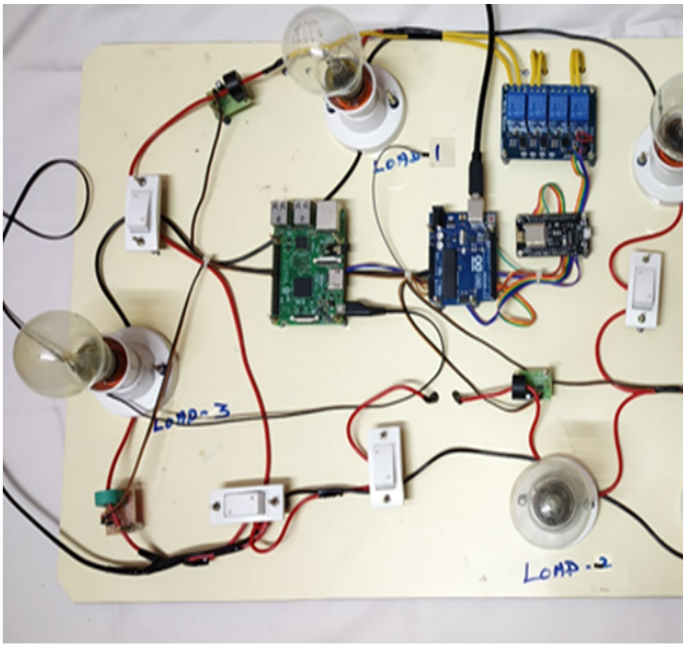

Fig. 10. AC Smart socket interfaced with IoT

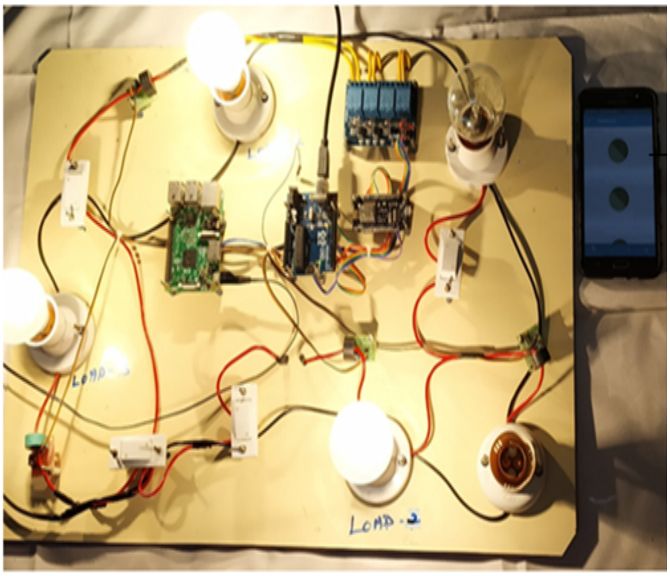

Fig. 1. (a) AC Smart socket with all loads and IoT display

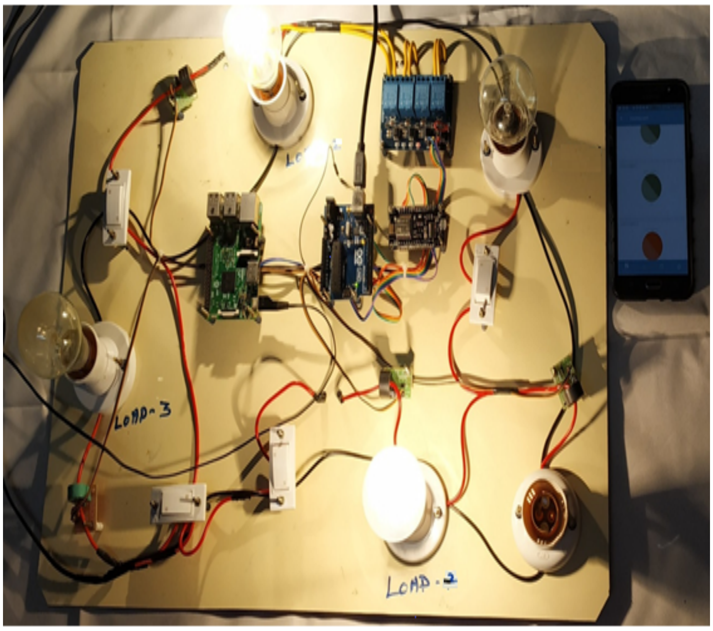

Fig. 11. (b) AC Smart socket with load 3 disconnection with IoT display

Fig. 12. IoT indication Voltage and current graph during the load1 connected period

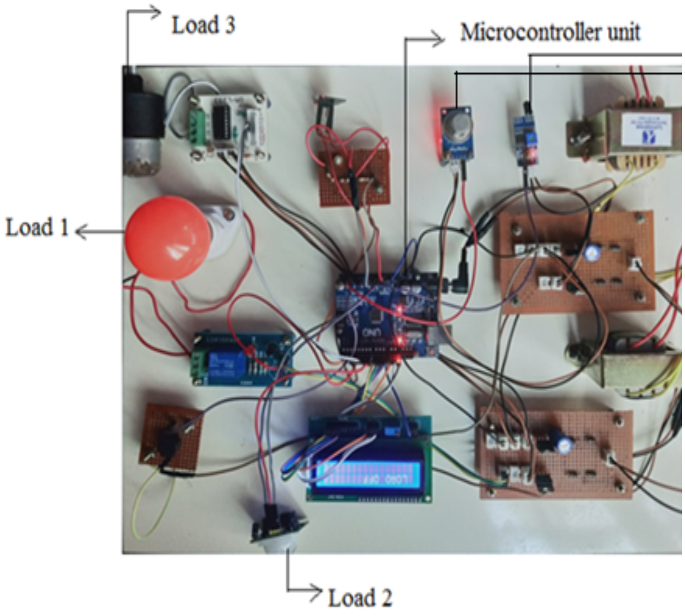

Fig. 13. SES with bulb and motor load along with security system

5. Conclusion

This work presents a smart energy socket for smart buildings. To provide an efficient, reliable load scheduling of the consumers the concept of SES was proposed. The work manifests the result of DSLM in the DC and AC distribution system. The simulation and prototype model proposed in this work proves that deployment of the SES can decrease the power consumption during peak hours along with cost minimization without decreasing the total load on the system. A DC and AC SES are proposed to connect and disconnect the loads according to the low, medium and high priority. The DSLM algorithm and the microcontroller achieve this. In addition, node MCU interfaced with Arduino can control and monitor the load connected using the IoT platform. In addition, the SES is implemented to operate the loads based on priority during peak hours so that the utility can be stress-free without overloading. Furthermore, an upgraded version of SES hardware setup is attempted with priority scheduling of AC loads along with flame and gas level detector using IoT platform. Thereby it is realized that due to the implementation of SES the peak to average ratio of the load during 24 hours decreases which would be a better solution for meeting the exponential increase in the load. SES would benefit the consumer with a reduction in the electricity bill.

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