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Transforming Conventional Switching Systems to Cost-Effective, Adaptable, Energy-Efficient Smart Switching Systems

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Abstract

Reducing energy consumption in the household and commercial sectors is a major global concern. Our objective is to develop a low-cost automation solution that will help improve adoption and reduce energy consumption. Proposed system has functionality that will help typical Indian households reduce electricity consumption in areas of infrequent usage such as stairs, and parking areas where manual switching of the electricity is difficult. In our proposed model, a manual switching system is replaced with a low-cost and adaptable smart automated switching system. Our design is based on the Passive/Pyroelectric Infrared Rays (PIR) motion-sensing mechanism where motion is used as a trigger to turn on/off electrical appliances. Detailed comparative analysis of daily energy usage of traditional switching with intelligent switching showed reduced electricity consumption by 33 %. Lower cost of equipment will increase the adoption of automated systems, leading to a reduction in electricity consumption. Further, a drop in energy consumption means reduced energy costs and less burden on the grid which leads to a clean environment.

Keywords: Automation; Cost-Effective; Energy-Efficient; Intelligent Switch; Sensor.

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1. Introduction

In today's fast-paced culture, there is an urgent need to conserve basic resources like water, fuel, and electricity and harness renewable energy sources [1-3]. Further, carbon dioxide (CO_2) emissions are strongly related to energy usage, derived from the combustion of hydrocarbons used for electricity generation in power plants [4,5]. As stated in the Global Energy and CO_2 status report, coal-generated electricity is a cause of 30 % of global CO_2 emissions [6,7]. The level of electrical energy consumed in Europe in lighting buildings is significant, accounting for approximately 40 % and leading to approximately 35 % CO_2 emissions [8,9]. Adoption of suitable measures to reduce CO_2

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emissions and conserve our non-renewable resources is the need of the hour. In particular, power shortage is one of the most common problems globally [10]. Hence, for a third-world country like India, it is essential to limit the wastage of fossil fuels and in turn help to reduce CO_2 emissions [11]. Energy consumption minimization in the residential and commercial sectors is a key global concern.

In our residential complexes, we should be conscious about wastage of electric power, such that when electric appliances are not in use, they should be turned off [4,6]. However, it is difficult to carry out simple tasks such as turning on/off lights manually.With the help of new emerging technologies, such as Artificial Intelligence and Smart house (IoT), the wastage of electrical power can be minimized by turning off the devices when not in use [8,12] .The major concerns about manual lighting controls are based on occupancy patterns, energy-saving awareness and occupancy behavior [13]. Different types of switching systems are available for a user to control the lighting installations.The most basic traditional switching system offers ON/OFF options only. To control power consumption, various researchers have proposed alternate solutions. Decreasing the intensity of the lamp, when not in use, is an option but the lamp's intensity must be controlled by dimmable ballasts [14]. Various forms of lighting control mechanisms have been shown to save cost such as S. Srivastava proposed the control of power consumption in street lights using LDR, Sensors and microcontrollers [10]. With automation, more than 40 % of electrical energy can be saved on the Highways [10]. Rizman *et al*. elaborated on a temperature-controlled automatic fan using a microcontroller and temperature sensor [15]. Siddika *et al.* proposed an Arduino-based automatic fan that is turned on/off on human detection. The speed of the fan varies with the temperature of the room **[**16**]**. An automatic lighting and security system using motion sensors and microcontrollers was presented by Mouri *et al.* [17]. Badgelwar *et al.* proposed a technology to detect vehicles or humans on Highways which turn on/off-street lights, using Raspberry pi and sensors [18]. Riyanto *et al*. proposed motion sensors for saving electricity and Greenhouse gas (GHG) emission reduction [19]. Novak [20] proposed an automated system based on traffic flow, using Traffic sensors that monitor the volume of the traffic continuously and the Zigbee module is used for communication with lights. Yavuz *et al.* [21] proposed a remote-controlled device for home appliances automation using a telephone and PIC (programmable interface). The solar panel-based, intelligent wireless street light was proposed by Subramanyam *et al*. Street lights are regulated by creating a Graphical User Interface (GUI) using a Zigbee module [22]. The street lights were turned on at night time due to the application of Light Dependent Resistor (LDR) [23]. Pratibha *et al.* [24] developed an automatic corridor lighting system for the institution using motion sensors.Various sophisticated and innovative home automation systems [25-28] have also been proposed. However, consumers are reluctant to use these technologies because of cost, performance, security and privacy concerns [29]. High maintenance and installation costs of these advanced systems are out of reach for an average middle-class person in developing countries including India [30].

The present study proposes a cost-effective yet feasible solution for automating switch operations. It is an easy-to-install and adaptable smart switch that turns on the appliances on detecting motion and turns them off when not in use. The cost of designing the prototype came out to be around ₹200 which is easily affordable for a typical Indian household. A detailed comparative study of daily energy consumption, with conventional switching and intelligent switching, has also been carried out to validate our concept. The proposed smart switching system is successful in reducing total power consumption by 33 %. Furthermore, lower energy use implies lower energy prices and less strain on the power system, resulting in a sustainable future.

2. Methodology

The present study suggests employing a PIR sensor, to construct an integrated home automation system. The flowchart of the proposed design is depicted in Fig. 1.

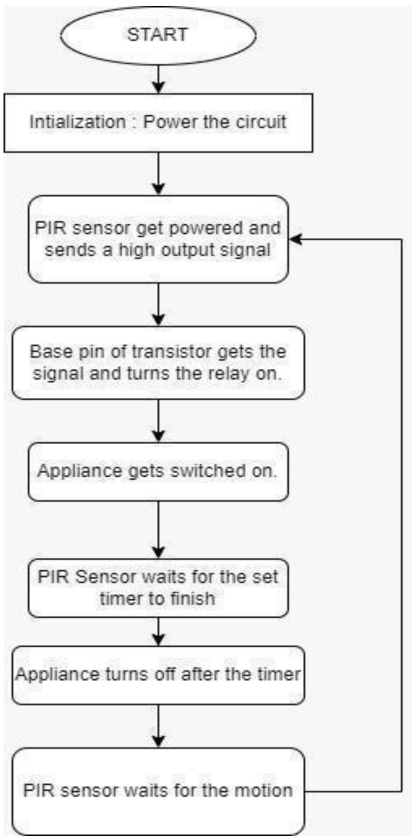

Fig. 1. Flowchart of the proposed intelligent switching system.

2.1. *Specifications of the components used*

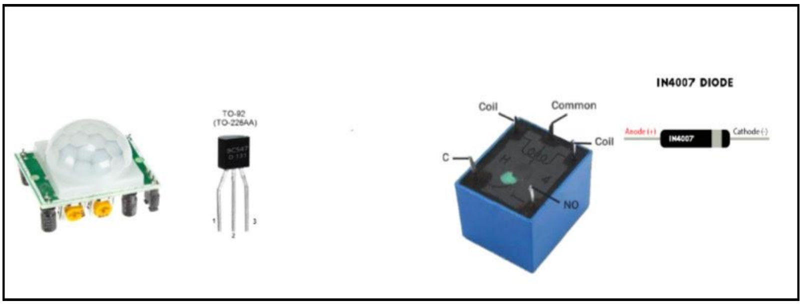

Fig. 2. Actual components used for the design of the prototype.

For the design of the prototype of an intelligent switching system, we have used: PIR Motion Sensor (HC-SR501), NPN transistor (BC547) with maximum gain- 800, Diode (IN4007) and 5V Relay (SPDT). The components used are shown in Fig. 2.

PIR Sensor: PIR sensors are electronic sensors, capable of sensing infrared radiations emitted from an object coming into its field of view, consisting of a pyroelectric sensor and a Fresnel lens which focuses the infrared signals onto the pyroelectric sensor **[**17**]**. The sensitivity of the PIR sensor lies in the wavelength range of 8-12 μm and is therefore used to sense the motion of human beings (~wavelength 9-10 μm) **[**17**]**. PIR sensor generates zero output signal under idle (no movement around the sensor) conditions and on the detection of motion of an object, a high output signal is generated. The schematic diagram showing the working of PIR is shown in Fig. 3.

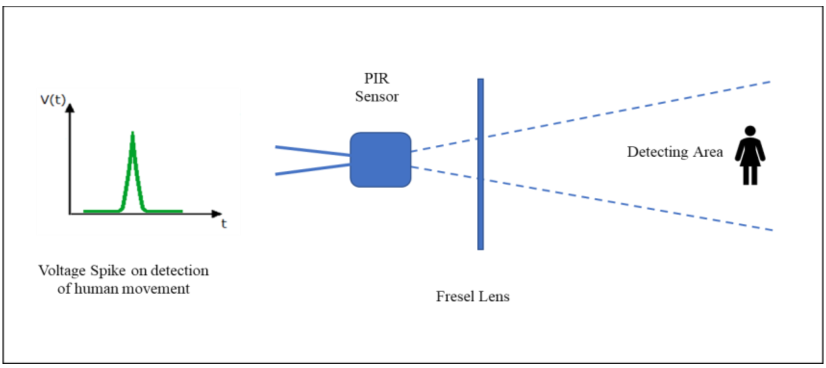

Fig. 3. Schematic describing the working of PIR [4].

PIR (HC-SR501) sensor used in design is having operating voltage (5 V to 20 V with TTL output voltage as high (3.3 V) and low (0 V). It has an adjustable -delay time as well as sensing range < 120° (0 - 7 m). It's temperature range is from – 15 to + 70 °C [31].

Transistor: The transistor (BJT) used in our design was an NPN Transistor (BC547) with 800 as DC current gain: (h_{FE}) maximum value, [31]. 5 mA (maximum) and 100mA as base current (I_B) and continuous collector current (I_C) respectively, with 6V as emitter-base voltage (V_{BEO}) [32].

Diode: The diode used in our design was an IN4007 diode having 1000V as maximum repetitive reverse voltage (VRRM), 1A (at TA = 75 °C) average rectified forward current (I_O) and 30A as peak surge forward current, IFSM [33].

Relay: Relay used has a 5-pin compact configuration, having 5 ms and 10 ms as release and operating time and maximum mechanical switching. It has 5 V DC and 70 mA as trigger values for voltage and current with 7 A @ 250 V to 125 V AC as maximum ac load current and 10 A @ 30/28 V DC as maximum DC load voltage [34].

3. Design of the Prototype

The circuit diagram of the motion-based switch using PIR Motion Sensor, NPN Transistor, Diode and Relay is depictedin Fig. 4.

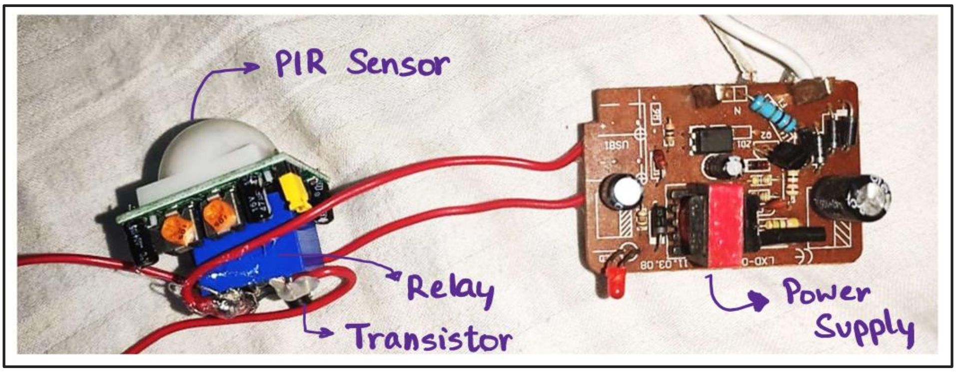

Fig. 4. Circuit diagram of the proposed motion based switch.

The PIR sensor uses passive infrared rays (IRs) to detect human movement and outputs a high signal on the Digital Output Pin which in turn is connected to the transistor for further processing. The transistor acts as a switch for the relay. The relay is connected to the AC appliances (LED bulb in our case) as shown in Fig. 4. PIR sensor uses the motion of IRs as a trigger whose sensitivity can be adjusted. There are two different trigger modes as Repeatable (H) mode and non-Repeatable (L) mode. It can be turned off after a set delay time. The sensing distance and delay can be varied with the help of a distance and delay successfully as shown in Fig. 5.

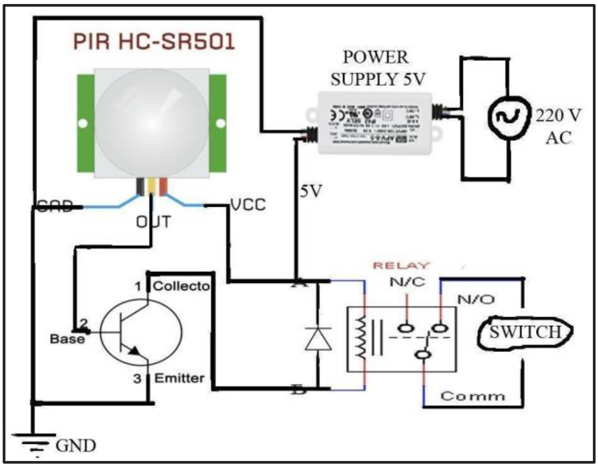

Fig. 5. Prototype of the prepared-designed circuit.

The designed switch can detect motion and turns on the appliances as needed and turns them off when not in use, as depicted in Fig. 6a and Fig. 6b. This will not only minimize energy consumption but will also extend the life of electrical appliances. Tthe proposed home automation system was practically tested.

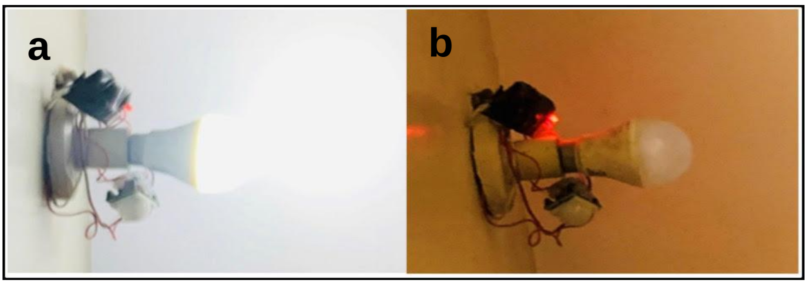

Fig. 6. (a) Bulb on as soon as motion is detected. (b) Bulb Off during no movement.

A comparative study of daily energy consumption using traditional and intelligent switching, performed over a period of one month, is reported here. The daily energy consumption of an LED bulb,installed on the staircase of a residential complex, with and without the sensor was noted. For this, we used a smart plug with the feature of recording and plotting daily consumption data on the mobile app.The data was first recorded for real-time energy consumption of a simple LED bulb with a manual switch. The total energy consumed throughout a day for one month was recorded. After a month, the manual switch was replaced with our sensor-based switch to handle the switching of the LED bulb during the time of need. The comparative weekly average consumption is shown in Table 1 below.

Table 1. Comparative study of one-week consumption with traditional and intelligent switch.

Day after installation	Consumption (traditional switch) (Wh)	Consumption (intelligent switch) (Wh)	Energy Saved (Wh)
1	160	50	110
2	120	40	80
3	140	60	80
4	160	40	120
5	90	50	40
6	180	40	140
7	190	30	160
Total	1040	310	730
Average daily consumption	**148.57**	**44.29**	**104.28**

A

The plot of the above data is depicted in Fig. 7.

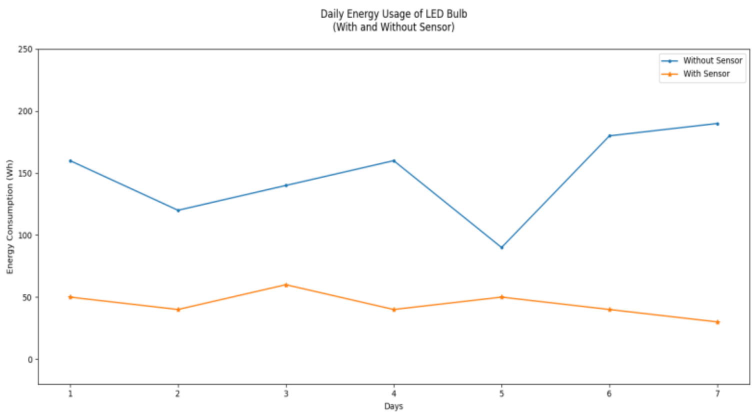

Fig. 7. Energy consumption data with and without motion-based switch.

Fig. 7 indicates that with the usage of an intelligent motion-based designed switch, the energy consumption is almost reduced by three folds. The consumption is almost uniform in the case of the intelligent switch indicating the success of our design to provide a cost-effective and energy-efficient solution for handling power shortage challenges. Further, a reduction in electricity consumption using an intelligent switch also has a positive environmental impact due to reduced carbon footprint.

5. Conclusion

One of humanity's greatest blessings has been the invention of electricity. In particular, electricity accounts for a significant portion of total energy usage. As a result, considerable efforts are required to decrease energy usage in our daily activities. Our proposed design focused on essential features required for an Indian household which lowered the cost of automation. The solution prototype was designed and tested to validate the feasibility and compare the savings and costs with traditional switches. An energy-efficient and cost-effective switch, designed using motion sensors and basic components, led to a decrease in energy consumption as compared to a traditional switch. With the installation of an intelligent switch, the monthly electricity energy consumption is reduced by almost 33 %, compared to the one without the usage of sensors. Further, this design will also extend the life of electrical appliances and ensure user satisfaction. We intend to extend the design of our prototype with the incorporation of more features and also ensure competitive costing to keep it affordable for an average Indian household. Our prototype was prepared for less than ₹200. In the future, we can accommodate more appliances like ceiling fans, air coolers etc. Further, the design can be applied to large-scale settings such as factories and offices to modernise our working conditions at a reasonable price. We can also add more features to this system like light and temperature sensing. There is also scope for the development of better human sensing devices. Heat mapping or using camera modules can be useful for specific types of switching requirements for better energy management.

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