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A Microcontroller Based Efficient Scheduling System for Air Conditioner Focusing on Maximum Electricity Savings Using PWM Concept

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ABSTRACT

With the development and uses of various electrical and electronic devices, energy consumption in our daily-life is rapidly increasing. Since Air Conditioner (AC) itself is responsible for about half of the energy consumption in home and office environment, several contributions have been proposed to reduce costs. However, almost all of them require internal modification of the AC. As a result, the existing techniques hardly focus the user satisfaction during troublesome situations. To address existing limitations, in this paper, a microcontroller based smart scheduling system using Pulse Width Modulation (PWM) concept has been proposed for efficiently managing the AC operational time. The PWM concept provides complete power switching control rather than traditional sensor control without user intervention. The PWM concept has been applied to dynamically operate the AC using user-defined 'On_time', 'Off_time', and 'Cycle_number'. Each Cycle_number is comprised of one On_time and one Off_time period that drives running and mode-switching operation of the AC automatically for the defined Cycle_number, which reduces greater energy consumption during sleep-time. Over traditional sensor control in AC, the proposed PWM based scheduling process controls power switching by automatically managing full-power "cut-off" and "activation" phases which is expedient for power saving and safety. The proposed application enables controlling the AC more dynamically than our traditional thermal sensor control by changing its mode of operation. The tested results reveal that the proposed technique can reduce 50%-75% unnecessary energy consumption by the users in-home or office environment.

Key words: Air Conditioner (AC), Embedded System, Microcontroller, PWM, Solid State Relay.

1. INTRODUCTION

Electric energy consumption and electricity misuse have become a major concern now a day. The energy crisis is increasing mainly due to the rapid growth of the population and their demand. As a result, the establishment of more and more power plants is required which is very expensive and time-consuming. So the energy-saving strategy or efficient energy consumption technology is essential to reduce energy consumption and loss. By ensuring the appropriate utilization of electric devices at home, 40%-50% electric energy loss can be minimized. The air-conditioner (AC) which is one of the most energy-consuming devices (up to 50% of the total power) can be smartly and automatically scheduled to achieve such sort of savings [1]. Although AC provides a comfortable working environment, the power-saving strategy of it is a promising research area that deserves further concentration. Researchers have proposed a number of technologies for reducing energy consumption in different aspects. For example, a novel implementation of a building energy management system to meet-up the residential demand response is presented in [2]. In the electrical engineering field, an electric device based on an energy manipulation technique is developed that involves an adaptive monitoring and controlling an operation to reduce an average 20% electricity. The limitation of this work is that the electricity-saving has been confined to a specific environment such as in a telecommunication equipment room [3]. Instead of using the traditional proportional-integral-derivative (PID), the authors exploit the Fuzzy-PID controlling system in the air conditioner [4]. However, once the fuzzy system becomes erroneous, its correction operation becomes expensive (more detail about the fuzzy logic controller is found in [5]. Authors have presented a work entitled by-a wireless home energy management system with a smart rule-based controller, in which battery usage has been completely eliminated.The authors have added that the used rule-based scheduling algorithm can be further enhanced [6]. Ensuring a high indoor temperature by a smaller temperature lift through a separate dehumidification system, a maximum of 70% energy savings can be achieved according to the literature presented in [7]. However, this technology has two limitations: firstly, its installation process is costly due to the dehumidification system and the configuration of system components is complex and time-consuming. The second restriction is that it is mostly suitable for an automotive AC in which the indoor thermal condition must ensure comfort level [8]. The work presented in the report that the energy-saving potential can be obtained by the use of a higher standard air conditioner which maintains a minimum seasonal energy efficiency ratio (SEER) of 10.0 [9].The result of this helps to cut the associated pollution emissions and unnecessary electricity use by a higher efficiency air conditioner. However, a large investment is required to purchase such high standard AC. Another technique to reduce energy use and cost by a multi-objective evolutionary algorithm where the temperature is checked by a thermostat and AC is controlled within a higher and lower threshold [10]. Work has been carried out a smart heating and air conditioning method for home energy management system [11].This study emphasizes the importance of customer's conveniences and problems relating to scheduling method. The technique used the On-Off technique based on the temperature value from the sensor. Here the obvious problem is that the power of AC is not fully disconnected and it requires interior adjustment also. Another work has been established as a technique to improve split-air conditioner performance by using a variable thickness of evaporation cooling pads [12]. They have also modified the AC by a different evaporative cooling pad and a relative comparison of Coefficient of Performance (COP) which shows the corresponding efficiency of an AC. A self-energy saving device to improve the performance of a split-type air conditioner which is fabricated using a complex moisture-transferring and quick-drying textile (MTQDT) has been proposed [13]. An evaporation pressure control approach which is based on evaporator pressure and relative humidity reading method which is compared with relative humidity reading (EPCR) and evaporator outlet pressure reading (EPCP) has been introduced [14]. The development of the EPCR system improves indoor thermal comfort and energy efficiency than the EPCP. A nonlinear system using adaptive fuzzy for variable-air-volume (VAV) air conditioning system where they attempt to control the temperature of supply air and return air close to their predefined target has been presented [15]. However, the implementation requires further modification since it requires more than 40 minutes to achieve the desired result. All these methods which have been presented in the literature require internal modification of the AC and cannot always be used with an existing air conditioner. To the best of our knowledge, almost no method is reported in literature where an external device has been developed for a smart AC scheduling system focusing on electricity saving. To address the limitation of existing techniques, the proposed system is designed for external use of the control device which is portable to use with all types of AC those are in service already. The system operation principle is developed based on the pulse width modulation (PWM) concept [16]. In the case of PWM, each complete cycle consists of an on_duty and an off_duty time stamp. In the proposed system we have similarly designed an adjustable on_duty and off_duty pulse setter using our smart scheduling algorithm but the main difference is that its cycle duration(in minutes) is much greater than the conventional PWM cycle duration(typically in μs) [17]. Moreover, the scheduling time is user friendly and arbitrarily manageable by the scheduling algorithm. Thus, the adjustment parameter's unit is calculated in minutes instead of micro-seconds in the proposed technique. The Cycle_number which integrates both On_time and Off_time can be initially adjusted from 0 to 9 cycles. Within each cycle, the On_ time and Off_time can be individually fixed between 11 to 99 minutes according to the user's desire. It is experimentally tested that the strategic fixation of On_time, Off_time, and Cycle_number parameters according to the users' comfort level, 50% to 75% energy consumption can be reduced. Moreover, the traditional AC comes up with sleep-mode for which it goes only at off state after a certain period of time and never comes back at on state until restarted. However, the proposed automation controller can repeatedly execute the sleep-wake function with full power cut off function not only to reduce redundant energy consumption but also to preserve user comfort level [18]. In addition, the newly introduced controller is extremely cheap and externally installable. Moreover, unlike the existing energy-saving methods reported in the literature, the proposed device fully helps avoid damaging the AC from external interference such as high voltage variation.

2. PROPOSED METHODOLOGY

The system block diagram is shown in Figure1. It takes Alternating Current as an input of the entire system at the left. The typical input rating is 220 volt 50Hz. At the associate position of the power unit, the current and voltage protection circuit block are depicted. This unit takes Alternating Current and provides necessary protection in case of very large voltage and high current for Air conditioner and control device. The block shows an alternating current to direct current conversion unit. The core system including microcontroller, button module, and displays need 5 volt DC to operate. Hence a DC power conversion unit is employed which provides 5volt 1000mA current. The core system is directly correlated to user interaction. In the core system, the microcontroller reads and executes all instructions sequentially which have already written in its memory. Moreover, one of the outputs of the microcontroller is directly interlinked with Solid State Relay (SSR) which helps to switch the Air Conditioning mode directly. The user interacts with the button module to adjust 'On_time', 'Off_time', 'Cycle_number'. At the right of the microcontroller, two display units are used to show the current timestamp and current cycle count sequentially from top to bottom position. Timestamp display shows On_time and Off_time sequentially for the corresponding Cycle_number that is shown at the same time in cycle count display. The cycle count display shows the current cycle number and provides information about the remaining cycle number to the user. The SSR takes operating current from "Current and Voltage Protection Circuit" and takes required action for Air conditioning operation. The switching operation of SSR is performed by the microcontroller while, at the right-end, the air conditioner performance is observed. The key steps including the software implementation are explained in the next subsections. Thus, an embedded architecture that combines the hardware and software components in a single platform is experienced for smart AC scheduling operation [19]-[20].

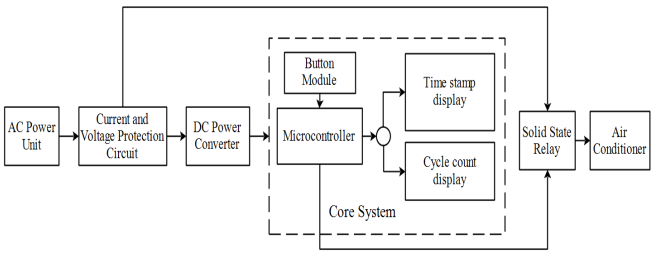

Figure 1: Block diagram of the proposed system

2.1 Hardware Architecture

The hardware architecture part is comprised of the surge protector, microcontroller, button module, and solid-state relay. The detailed description of the individual phases is illustrated below.

2.1.1 Surge Protector

For safety and longevity, the surge protector has been incorporated and exploited in the protection circuitry part of the system. This protection circuit is depicted in Figure 2 as the 'Current and Voltage Protection Circuit' block. Surge is a sudden increment of voltage or current from a normal or standard value. This voltage spike lasts about 1 to 30 microseconds and may reach over 1000 volts to instantaneously destroy any electrical equipment [21]. To protect the system and AC from thunder, a voltage and current surge protector is required. Several protection techniques have been proposed by researchers such as resistive coupling, capacitive coupling, inductive coupling, and many more [22]. These methods are most suitable for telecom purposes with vast applications. To serve our purpose an electronic-based surge protection circuit has been integrated into the system which is shown in Figure 2. In this figure, we have just used a fuse of 40A which ensures proper current to the output section. This provides enough current to drive 1 ton to the 2-ton air conditioner. To protect the air conditioner from high voltage, a metal oxide varistor (MOV) is used in parallel with alternating current input line. Because of being highly sensitive, the MOV of metal oxide type is much popular. Moreover, it is cheaper than any other type and costs only $0.10. If high voltage is imposed on this circuit, the two terminals of the MOV become short and burns out to protect the air conditioner. Thus, a cost of only $0.10 MOV saves an air conditioner of $600 to $1500.

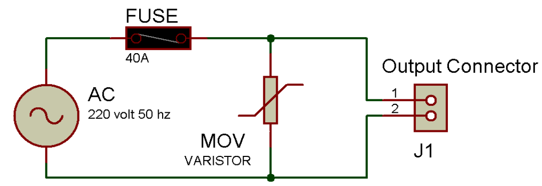

Figure 2: Surge protector circuit used in the proposed system as a safeguard to the abrupt higher current and voltage variation.

2.1.2 Microcontroller

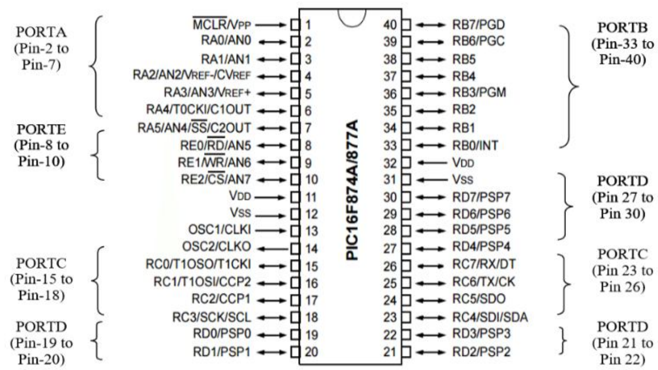

Figure 3: The pin configuration of PIC16F877A microcontroller

From Figure 3, the PORT(s) can be controlled as input or output by configuring the TRIS register (for the pins and associated port control) through coding. Here we have used PORT-B and PORT-C to display the left digit and right digit of On_time. After a certain time period, the same PORT-B and PORT-C displays left digit and right digit of OFF_Time. These PORT pins have configured through the TRIS register of the corresponding PORTs, while the Cycle_number is configured through to PORT-D pins. PORT-A pins are configured to take input by using the TRIS-A register. PORT-E pins are used to control SSR and provide the necessary power to time stamp indicator LEDs. The ports and associative functions are shown in Figure 8 which has been further discussed in the circuit explanation section. This powerful chip (i.e. PIC16F877A) also comes with built-in 256 bytes Electrically Erasable Programmable Read-Only Memory (EEPROM). It has been exploited in our implementation to save the information of On_time, Off_time, and Cycle_number since this counting has been used again and again by the device program. Compared to the PROM which can be programmed once only, the rationale of using the EEPROM is that it can be rewritten, modified, or updated by the user several times. Moreover, the limitation of EPROM is that once programmed, it can be erased by exposing a strong ultraviolet (UV) light source which may create a hazard for an AC user. In contrast, an EEPROM that can be rewritten or reprogrammed electrically can resolve the problems of PROM and EPROM. Moreover, the EEPROM comes as a build-in package with the microcontroller PIC16F877A which helps to elude the additional device cost.

2.1.3 Button Module

The system parameters (i.e. On_time, Off_time, andCycle_number as stated earlier) can be adjusted by using the Button Module which performs parameter adjustment operation. In the case of parameter adjustment, two types of operations are related to the Button Module. One type of operation is push which has been designed for increment and decrement function. The other type is press and holds operation through which a user can switch from one parameter to another. The parameters increment (INC) and decrement (DEC) operations can be performed by two white buttons sequentially from left shown in Figure 4 with push operation. Parameter switching adjustment i.e. from On_time to Off_time switching or Off_time to Cycle_number switching can be carried out using the yellow button by the press and hold operation. In Figure 4 the press and hold option of the green button is used to select either Run Mode or Set Mode. In Set Mode, the 7 segment display led blinks rapidly to indicate that the programming has been entered in Set Mode. If the 7 segment display led do not blink or constantly glows it indicates that the system operates in Run Mode. Figure 4 presents the button module for the proposed device.

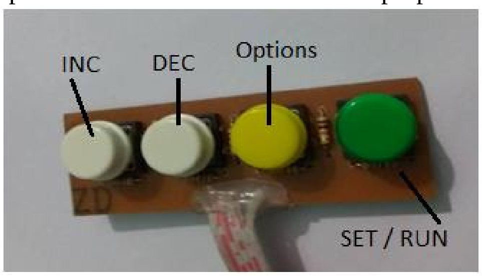

Figure 4: The button module for On_time, Off_time, and Cycle_number parameter adjustment.

2.1.4 Solid State Relay

In the proposed method, the AC driving switching component is a relay. As we already know the microcontroller cannot drive current more than 25mA-5volt and it is operated by direct current. Therefore, to drive the Air conditioner using alternating current, interfacing between microcontroller and relay is essential. There are several types of relays such as reed relay, mechanical relay, and solid-state relay. The first two types are not convenient for our system because of their low current driving capacity and operational noise. The customized solid state relay that is used in this experiment is based on TRIAC BTA-40 which performs switching operation of AC current. The TRIAC is a very popular switching element for the alternating current which is controlled by an Optocoupler-MOC3021. In an optocoupler principle, the signal is shifted between two circuits but the circuits are isolated electrically. This is performed by an optical signal provided by a built-in LED in MOC3021. The SSR circuit diagram shown in Figure 5 is simulated in the Proteus ISIS design suite which is a well-accepted simulation tool used by engineers and researchers and mostly used for electronics simulation.

Here, we have designed a customized SSR in order to achieve the exact amount of current and voltage capacity rating. This time the circuit is capable of providing a maximum of 40A-800volt current rating thereby transferring more voltage and current than an ordinary relay available in the market. Traditionally AC consumes a high power at the starting than the running condition. So the design of the supply switch (Solid State Relay) must be highly rated. Hence we have used BTA-40 TRIAC which is capable of providing 40A current continuously and that is quite enough for a 1 or 2 Ton AC.

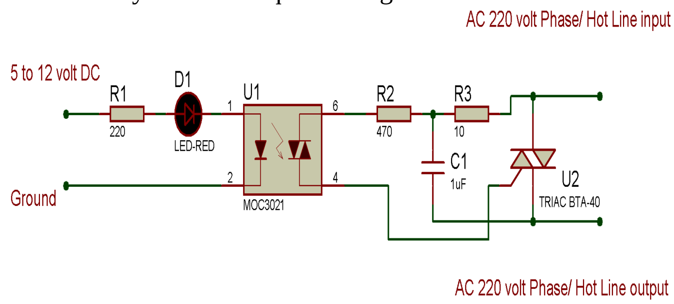

Figure 5: Customized Solid State Relay for our device.

Another small advantage of the SSR that it does not create any noise at the state-changing time (i.e. on_state to off_state or off state to on state) like any mechanical relay. Another advantage of this circuit is that it has a built-in snubber circuit (in Figure 5 R3 and C1 components are collectively working as the snubber circuit) which is usually used to suppress the voltage spikes (more detail about the spike detector circuit could be found in produced by the circuit's inductance [23]. Among various types of snubber circuit configuration such as Resistor-Capacitor (RC) and Resistor-Capacitor-Diode (RCD) snubber [24], we have used the RC configuration for its simplicity and better performance.

2.2 Software Architecture

System software architecture has been written in the MikroC platform. MikroC firmware development tools are user friendly in terms of developing complex problems [25]. After successful compilation, the generated machine code can be simulated through Proteus ISIS design suite and virtual-PIC16F877A microcontroller. After several modifications during the simulation, the successfully generated desired output files have been installed in real-PIC16F877A microcontroller with other peripheral devices. Figure 6 describes the functioning flow chart of the proposed implementation. The flow chart in Figure 6 explains device software architecture. At the very beginning, the mode selection option comes into operation. The system may run in either Set Mode or in Run Mode and this can be set by the press and hold operation of the green button shown in Figure 4. From Figure 6 in Set mode users can modify the On_time, Off_time, and Cycle_number and store in Microcontroller's EEPROM. In Run Mode, the program flow will be rightward. The microcontroller reads from the EEPROM and checks whether the Cycle_number is greater than 0 or not. If the Cycle_number is greater than 0 then each cycle number carries out an On_time and an Off_time sequentially. By completing an On_time and an Off_time, it will complete a full cycle. The Cycle_number will be decremented by 1 automatically and new Cycle_number will be updated in internal EEPROM. Once the Cycle_number equals to 0, then the air conditioner will be active only for the On_time. This is shown from the right side of Figure 6 and once the On_time count will be completed, the system will shut down the AC until Restarted or further Set Mode selected.

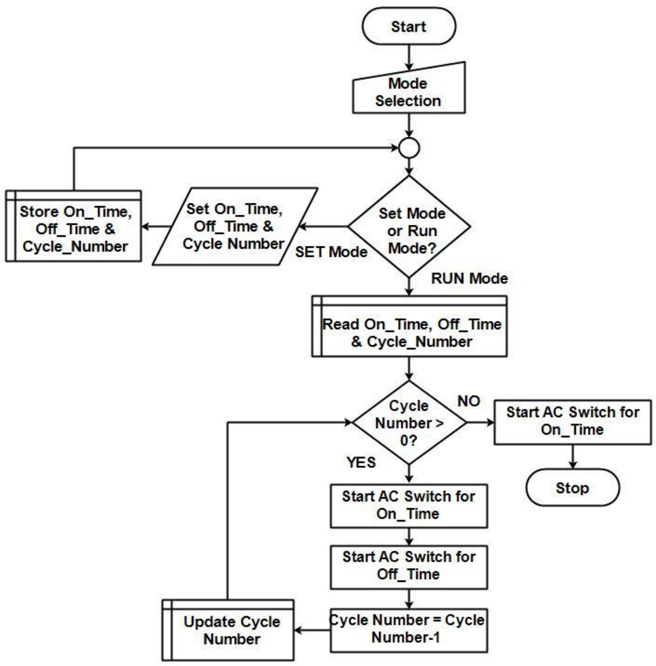

Figure 6: Flow chart of the proposed system.

2.3 PWM methodology used as Cycle Control

Sometimes the PWM is called PDM (pulse duration modulation). Typically, PWM is used to effectively control DC motors [26]. In addition, this control strategy can be used for torque ripple reduction in brushless DC motor [27]. The technique can also control the actual consumption of electricity and this characteristic is the basics of implementing the concept of controlling air conditioner through the PWM mechanism. In PWM, every cycle comprises an on-duty and an off-duty period which becomes very smaller. For example; a single cycle comprises one or a few millisecond time duration. In the case of our device, the duty has extended on a larger scale as the traditional duty is not applicable to the air conditioner. Hence in our modified PWM signal, we have given the luxury of choosing a minute unit to hour unit for a complete cycle instead of a millisecond unit. Moreover, through other peripherals, this duty cycle can be adjusted like a typical PWM signal adjustment, and thus, a typical PWM concept has become a useful technique for an air conditioner. The mathematical presentation of the duty cycle can be explained as:

$$\text{₠} = \frac{\text{ঌ}}{\text{ꝏ}} \times 100\% = \frac{\text{ঌ}}{\text{ঌ}+\Theta} \times 100\% \quad (1)$$

Where ₠, ꝏ, ঌ, and Θ indicate the duty cycle, total time period, the time period when the device is On, and the time period when the device is Off respectively. Here, $\text{ꝏ} = \text{ঌ} + \Theta$ = counting of a single time cycle [28]. Figure 7 shows the air conditioner operational timing diagram of the proposed implementation. Here, AC remains On/Off within the duration of the AC_start_point and AC_end_point of a timeline. Hence, we can calculate the savings from an AC depending upon its On_time ঌ, Off_time Θ and the complete cycle number $\aleph$ as follows. For each cycle, the On_time ঌ willremain the same (which will be adjusted by the user), as well as the Off_time Θ, will remain the same also for every cycle (will be adjusted again by the user). The On_time ঌ and Off_time Θ may or may not be equal. It completely depends on the user's selection.

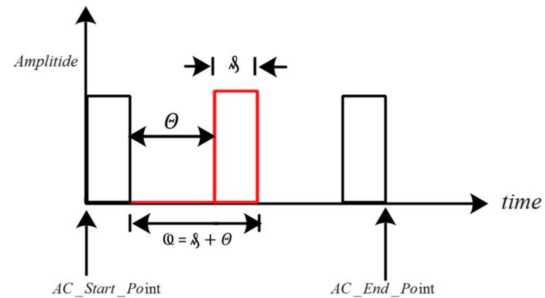

Figure 7: The proposed AC operational timing diagram.

$$\text{Ѫ} = \frac{(\aleph+1)\times\text{ঌ}}{(\aleph\times\text{ꝏ})+\text{ঌ}} \times 100\% \quad (2)$$

$$\text{¥} = \left(100 - \frac{(\aleph+1)\times\text{ঌ}}{(\aleph\times(\text{ঌ}+\Theta))+\text{ঌ}} \times 100\right)\% \quad (3)$$

Where Ѫ and ¥ indicate the amount of consumed electricity and saved electricity respectively. Using equation (2) and (3) users can calculate both consumed electricity and saved electricity. The equation outcomes justification can be achieved without using the scheduling system and using the scheduling system for a fixed time interval with the user's air conditioner. How much electricity a user can save is absolutely depending on the user-defined On_time, Off_time, and the complete Cycle_number parameters.

2.4 System Configuration

The major parts of the device such as surge protector, microcontroller, button module, and solid-state relay have been described in Section 2.1. The software architecture and the duty cycle are detailed in Section-2.2 and Section-2.3 respectively. The overall system configuration has now been explained which is comprised of two steps (i) circuit explanation and (ii) main device implementation. Eventually, the overall hardware and software parts have been combined for simulation purposes.

2.4.1 Circuit Explanation

Figure 8 implies the entire circuit configuration of the device. At the center, PIC16F877A works as the main controller. Both PORT-B pins (pin-33 to pin-40 as previously detailed in section 3.1.2) and PORT-C pins (pin-15 to pin-18 and pin-23 to pin-26) of microcontroller show either On_time or Off_time at the same time. Which one is displaying can be realized from the corresponding LED. For example, the simulation in the following Figure 8 displays On_time=26 minutes. This is realized from the corresponding LED, D1 is on and it belongs to On_time shown in Figure 8 The left 7 segment displays the left digit and the right 7 segment displays the right digit. Here we have used 7 segments, as it is clear, cheaper display, and having better visualization than liquid crystal display (LCD). As we are working in a minute unit and 2 seven segment displays, the device can work with 99minutes maximum for each half cycle. The LEFT_DIGIT and RIGHT_DIGIT both are displaying On_time or Off_time at the same time, while PORT-E pins (pin-8 to pin-10) actives corresponding LED to indicate about current timing state. The other single digit 7 segment display shows Cycle_number through PORT-D pins (i.e. pin-19 to pin-22 and pin-27 to pin-30) of microcontroller continuously. Here D1 and D2 LEDs represent On_time and Off_time respectively which is shown at the left bottom of Figure 8. D3 indicates Set Mode LED. The corresponding button of the button module is shown in the simulation respectively. Button OPT is used for selecting On_time, Off_time, and Cycle_number. To select an option user needs to press and hold the OPT (OPTION) button for a 1.5 second and these options will appear sequentially one after another. Button SET/RUN is used to switch either Set Mode or Run Mode.In the Set Mode, a user can set the parameters while in Run Mode a user can operate air conditioner according to his/her own desire.

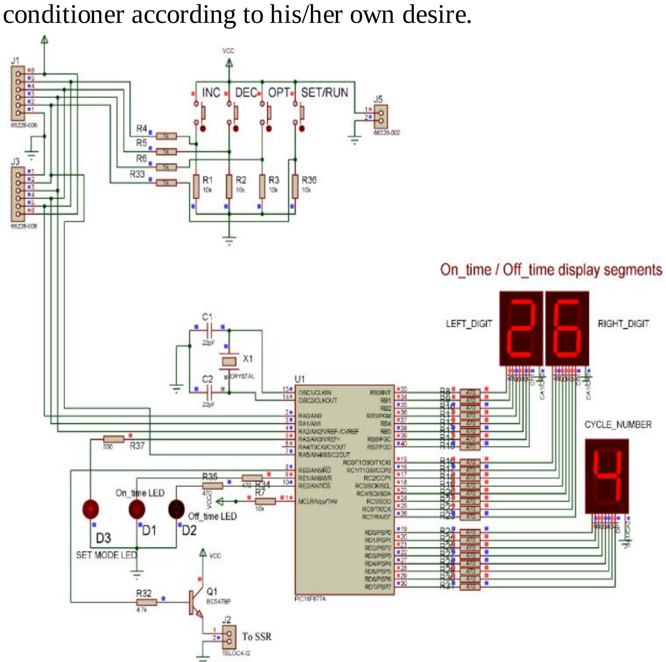

Figure 8: The complete circuit simulation in Proteus ISIS design suite.

2.4.2 Main Device Implementation

Figure 9 shows the circuit operation, according to the previous simulation. Here all the circuit components are working in real-time. The On state of the left top LED indicates the device is in Set Mode and the user can set up the corresponding parameter in this mode. This Set Mode LED also confirms the operational mode of the AC, which may be either On-time or Off-time. To be specific, the top-right LED of the core system indicates that the left and the right digit 7 segments both are displaying On_time which is 26 minutes. Hence, the On-time LED is currently turned. A black DC power supply jack provides DC input power for the entire core system. The green connector would be connected to the SSR circuit. The Green connector has two pins, one is for ground and another is connected to microcontroller pin-8 according to the circuit shown in Figure 8. These 2 pins would be connected to left 2pins of SSR circuit shown in Figure 5 earlier. At the top-left position, 6 wires go to the button module as shown in Figure 4. It should be mentioned that the main printed circuit board shown below is completely a discrete device that only controls the customized SSR and the SSR controls the AC. If the PCB burns out in any rare condition it will not create any minimum effect on the user's air conditioner.

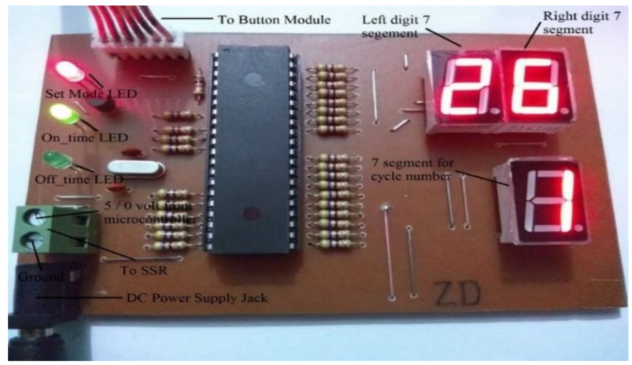

Figure 9: The internal configuration of the main circuit board which is currently in operation.

3. RESULT AND DISCUSSION

The experimental outcomes analysis is comprised of three parts: (i) The proposed AC automation controller installation, (ii) MOS calculation, and (iii) device performance calculation. These phases are explained in detail in the following sub-sections.

3.1 Controlling System Installation

Different power saving methods introduced in the literature require internal modification of AC which directly affects the internal circuitry. Thus, the AC remains at high risk and the compensation for a user is approximately $1500 to buy a new air conditioner. On the contrary, an external controller has been developed using the proposed technology which saves the AC by burning a simple varistor or fuse integrated with the protection circuit. Thus, at best it costs a maximum of $10 in the worst case. To test the performance of the proposed implementation, we have installed 7 ACs at home and 5 ACs in the office environment. The Air Conditioners are purchased by users from different vendors and the size varied from 1 to 2 tons. An automation controller for each of the AC was installed dedicatedly. These Air Conditioners were operated mostly in the summer season during day and night time. The control mechanism was the use of buttons as stated earlier. The performance of these Air Conditioners has been rated by evaluating both the energy-saving and comfort level features using an assessment of mean opinion score (MOS) level from 0 to 10. Higher the score the more improved the energy-saving and satisfaction level is. Figure 10 illustrates that an AC is currently in operation in the home environment by exploiting the proposed AC scheduling or automation controller.

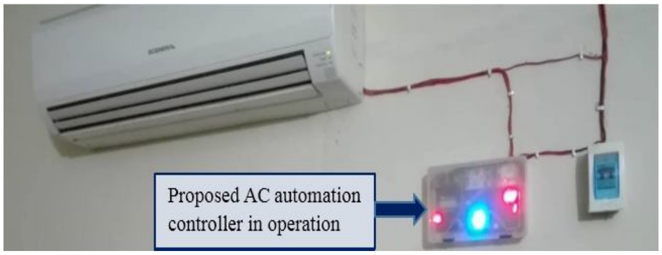

Figure 10: Real-time operation of the air conditioner by exploiting the proposed automation controller.

3.2 MOS Calculation

The MOS which is a well-established quality measurement tool in telecommunication engineering has been used for evaluating the quality of experience of the users [29]-[31]. In our experiment, we have also used the MOS to evaluate the user experience in accessing the proposed device. From Table 1. It is observed that twelve users have rated the energy-saving and comfort level upon their satisfaction by continuously using the proposed AC automation controller for one month. It is reported in Table 1. that User-2 scores 7 in terms of comfort level, however, this user is highly satisfied in terms of electricity savings and scores the highest (i.e. 10 out of 10). The inverse scenario is observed for User-4 and comments that the controlling device reduces unnecessary use of AC by ensuring maximum comfort level. User-6 also complements comments that the controller is a user-friendly device for reducing the electricity cost significantly by maximizing the comfort level. A similar perception is also reported by the User-12 who states that the device is a suitable comfort controller in the home environment which can confirm 70% electricity misuse minimization for AC purpose. The overall average comfort level score of 8.85, while the energy-saving score is 9.0 as reported in Table 1. The visual interpretation of Table 1. is presented in Figure 11. It is also obvious from the overall data representation in Table 1. that the comfort level has an inversely proportional correlation with the electricity savings [32] which can be mathematically expressed by:

$$\Omega \propto \frac{1}{\omega} \qquad (4)$$

Where, Ω and ω indicate the comfort level and the energy-saving respectively. The equation of MOS can be obtained as arithmetic mean [33]-[35] over the population which is mathematically equated as:

$$\vartheta = \frac{\sum_{i=1}^{N} SC_i}{N} \qquad (5)$$

Here, ϑ indicates the MOS, N=total number of users, S=individual rating for a particular interest. According to equation (5) if SC_i becomes the score of comfort level (where C stands for the comfort level) for i^{th} element and SE_i becomes Score of energy-saving level (where E stands for the electric energy saving) for i^{th} element, the MOS of two cases can be sequentially calculated as:

$$\vartheta_c = \frac{\sum_{i=1}^{N}(SC)_i}{N} = \frac{105.5}{12} = 8.79 \qquad (6)$$

$$\vartheta_e = \frac{\sum_{i=1}^{N}(SE)_i}{N} = \frac{108.5}{12} = 9.04 \qquad (7)$$

Table 1: Electricity saving and comfort level based mean score calculation of 12 users and their remarks.

User	Enviro-nment	Comfort Level Score (Out of 10)	Electricity Saving Score (Out of 10)	Outcomes with remarks (after using the proposed AC automation controller)
User -1	Home	9	8.5	Assures safety and minimizes monthly electric consumption
User -2	Home	7	10	Up to 75% electric savings by air conditioner with moderated comfort level
User -3	Office	10	8	Reduces energy consumption by air conditioner while highly increasing the comfort level
User -4	Home	10	7.5	Reduces unnecessary use of AC by ensuring maximum comfort level
User -5	Office	8.5	10	The best device for the office use.
User -6	Office	10	10	A user friendly device for significantly saving the electricity by maximizing the comfort level.
User -7	Office	9.5	8.5	Enhances comfort level.
User -8	Office	8.5	8.5	50-60% electricity saving is obtained.
User -9	Home	7.5	10	Reduces monthly electricity bill dramatically
User -10	Home	9	7.5	Minimizes electricity loss by ensuring the comfort level.
User -11	Office	8.5	9.5	Satisfactory device to save 65% electricity
User -12	Home	9.5	10	Confirms 75% electricity misuse minimization and a suitable comfort controller in the home environment.

Where ϑ_c and ϑ_e indicate the MOS value in terms of comfort level and electricity savings respectively.

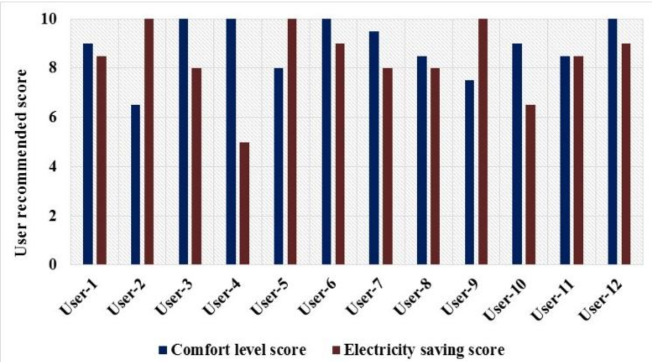

Figure 11: The recommended comfort level and electricity saving score of the users who have used the proposed AC automation controller in home and office environment.

Figure 12 is a graphical representation of the individual user comfort rating after using the proposed AC automation controller. The MOS value 8.79 which is obtained from equation (6) is incorporated in the graph for a fair comparison. The current standard deviation values for each user are also presented where the obtained average value is 0.76, while this average before using the controller was 2.59. Thus, a more consistent satisfaction level is precisely obtained once they have used the proposed controller.

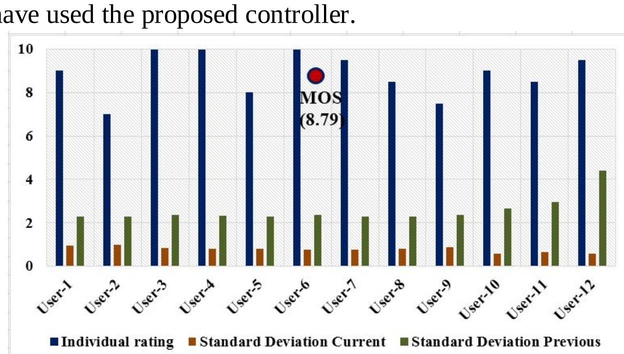

Fig 12: Graphical representation of individual user comfort rating after using the proposed AC automation controller where the MOS value is 8.79 as equated in (6). The current standard deviation values (average 0.76) are more consistent compared to the previous values (average 2.59) which more precisely indicate user satisfaction once they have used the proposed controller.

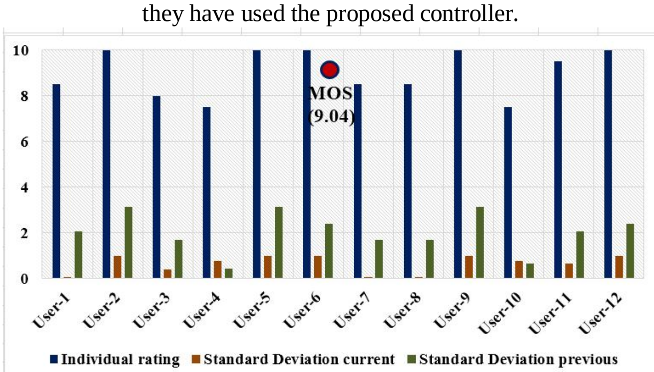

Figure 13: Graphical representation of individual user satisfaction score in terms of electricity saving after using the proposed AC automation controller where the MOS value is 9.04 as equated in (7). The current standard deviation values (average 0.64) are more consistent compared to the previous values (average 2.11) which more precisely indicate the user satisfaction once they have used the proposed controller.

Similarly, Figure 13 graphical represents the individual user satisfaction score in terms of electricity saving after using the proposed AC automation controller where the MOS value is 9.04. The current standard deviation values (average 0.64) are more consistent compared to the previous values (i.e. average 2.11 prior to suing the automation controller) which more precisely indicate the user satisfaction once they have used the proposed controller focusing on the electricity saving.

3.3 Device Performance Calculation

Let us now move on to the efficiency of an AC. The effectiveness of an AC can be measured through Coefficient of Performance (COP), Energy Efficiency Ratio (EER), Seasonal Energy Efficiency Ratio (SEER), and the Heating Seasonal Performance Factor (HSPF). These factors are related to consumed power or energy. So, these factors are related to each other. An equation can be formed which shows how all these factors are related to each other as:

$$\text{Ϛ} = \Psi \times 0.293 = \frac{\delta}{3.41} = \frac{1.2544-(1.12-(0.04\times\vartheta))^2}{0.2728} \quad (8)$$

Where Ϛ, Ψ, δ, and ϑ indicate the COP, HSPF, EER, and SEER respectively. We shall emphasize COP and the other factors can be calculated from the above equation. The COP can be calculated in terms of temperature by the following equation:

$$\text{Щ} = \frac{T_C}{T_H - T_C} \quad (9)$$

Here, T_C is the cold temperature and T_H is the hot temperature. Thus, the COP is dimensionless. Figure 14 represents different value for T_H and T_C that was collected during the user's feedback or score collection focusing on calculating the efficiency of an AC.

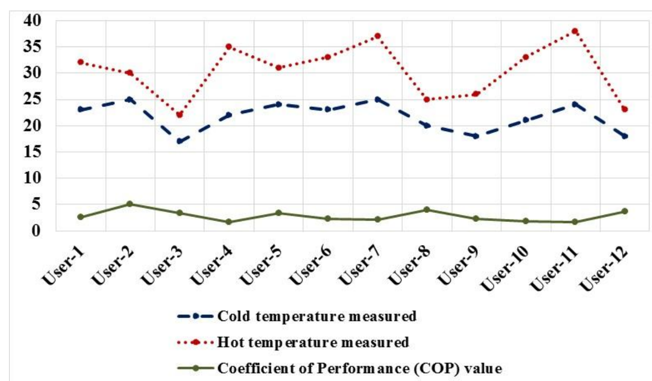

Figure 14: The Coefficient of Performance (COP) measurement of an AC from the recorded hot and cold temperature experienced by each user.

From Figure 14 it is noticed that the COP values have a wide range from 1.69 to 5.00. It is recommended in [36] that the typical value of COP may be from 2 to 4 but our experiment shows that it is not strictly true for all countries. Although higher COP value represents better performance and lowers energy consumption, it varies hour by hour. Moreover, different vendor's air conditioners have different energy consumption capacity. For example, user-2 has higher COP value than user-1 which indicates that user-2 enjoys better energy efficiency than user-1. COP values 2 to 4 may be considered as a standard range but it actually depends on the use and environmental temperature in which it is used which is also proved in our experiment. Due to using the proposed controlling device, AC is used for a particular time slot, and for the remaining time slot, it remains in the off state. It may be considered as an additional advantage for an air conditioner. This is because long time AC operation causes the generation of heat and the continuing operation may shorter AC's lifetime.

4. CONCLUSION

In this research, the problem of the recent energy-saving complexity of an air conditioner (AC) has been resolved. Most of the technologies proposed require a major internal modification of an AC. Some of the existing technologies may turn off the AC after a certain quantum or switch it on again but the supply power is not completely cut off. Also, the supply power is applied directly to the AC without filtering and all the proposed technologies cannot solve the problem of AC power consumption already in service. To address these drawbacks, a microcontroller-based smart scheduling system using the PWM concept has been proposed for efficiently managing the AC operational time. The experiment is carried out in the local city by exploiting 12 users. In most cases, they have shown their satisfaction level of both comfort and energy saving at home and office environment. Although the electricity-saving measurement is not uniform for all the users for arbitrary parameters (Cycle_Number, On_time&Off_time), users claim that the proposed technology saves around 50-75% electricity without sacrificing comfort level. Moreover, the proposed controller is externally configurable which also includes surge protector. This can help avoid damaging the AC directly from external high voltage or surge. Although AC is a high power electronic equipment, the controller device using the above mentioned customized circuitry, efficient scheduling firmware, and customized Solid State Relay, provides a completely safe scheduling operation for AC.

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