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Design and Development of a Smart Home Appliance Controlling System for Energy Conservation

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Abstract **Review Article**

Background**:** The rising demand for electricity and increasing costs during peak hours require affordable and practical solutions to manage household energy consumption efficiently. ***Purpose*****:** This study focuses on reducing electricity consumption and lowering utility bills during peak hours. The study developed a system that can detect daily peak and off-peak hours to control the zero-crossing points of the AC supply voltage. The intelligence of the developed device is an algorithm written for the Microcontroller Arduino Uno, which can prolong the zero voltage levels by sensing time. For this instance, a control parameter called “w” was created. We have discussed how SCR and opto-diac circuitry, also known as the control unit, can save energy by varying “w” from 1ms to 9ms. ***Methods & Results*****:** The performance of the system was tested separately by using a 60W bulb, an AC fan, and a 1000W electric iron as loads, and it was found that the system can save up to 20% energy without bothering the consumers. ***Significance*****:** The proposed low-cost solution is capable of controlling several equipment at a time, and the best part is that we don’t need to change the conventional non-smart home appliances. Thus, this unique work should be welcomed in a smart country.

Keywords: Energy conservation, Peak hours, SCR, Smart controlling, Arduino Uno.

INTRODUCTION

Smartness is intelligence. This research aims to specifically measure our day-to-day energy consumption behavior to assign an intelligent technology in the existing grid to achieve a realistic goal using available resources in real-time operation. Electricity shortages occur when supply cannot meet demand. It is possible to avoid a shortage by offering a high rate during rush hours to minimize usage by properly controlling our devices (e.g., home appliances) intelligently. Reducing the electricity demand in the peak hours will also reduce the price. Though right now in Bangladesh we use a flat electricity rate for residential usage, by analyzing the Bangladesh Power Development Board (BPDB) annual report, 2016-17, and the Electricity Distribution Code of Bangladesh Energy Regulatory Commission (BERC), we believe that in the near future, we are going to adopt a peak/off-peak time-based billing system. Again, the developed countries are using a peak-off-peak-based electricity billing system. According to our current demand curve, the BERC has fixed the peak hours from 5 pm to 11 pm, which is mentioned in the electricity distribution code. So we have developed a smart system connected to the existing grid to run the home appliances at a low energy-consuming state in the peak hours without disturbing the consumers’ comfort.

The research paper [1] the work of Kaniz Fatema Tuly, in which she investigated the worldwide smart home products, was our inspiration for this research. We conceived the idea of developing a combined smart control system for conventional home appliances, rather than purchasing separate smart products. Two Bangladeshi researchers, Jahangir Alam and Meherul Azam [2] have designed and constructed a circuit which is designed to control the speed of an AC fan through any IR remote. Rabisankar, Susmita, and three more Indian researchers [3] have shown a way to control the speed of a single-phase induction motor with variation of ambient temperature, making “n” number of speed ranges from a total of (n-1) window detectors. We have used that concept in our research to divide the half cycles of the AC signal into 10 equal parts. Hongling Xie and four other North Chinese scholars [4] have designed a smart meter that performs wireless communication with the system master station to upload users’ power consumption information and receive real-time price information by an MCU (microcontroller unit) and a real-time clock chip. From this paper, we have learned the use of interrupts, which helped us to develop a system to behave differently in a pick/off-pick time-based billing system. Mustafa Saad and two other Libyan researchers have suggested an automatic control solution to control the fan speed in their work [5] by integrating a microcontroller for automatically controlling a room's temperature. Although we are not dealing with room temperature, the system's software was an important study material. The speed controlling part of this paper was helpful, as we were also interested in speed control. Again, we have learnt to control the current phase of a synchronous motor from S. Morimoto's article [6].

Smart System for Controlling Home Appliances

The key points influenced us in this research are to reduce the consumers' electricity use during the peak hours (17:00 hr to 23:00 hr). The basic sections of our system are:

1) Modified ZCD
2) The Control Unit: It is divided into two sections:
   i. The Logic Section
   ii. The Switching Section

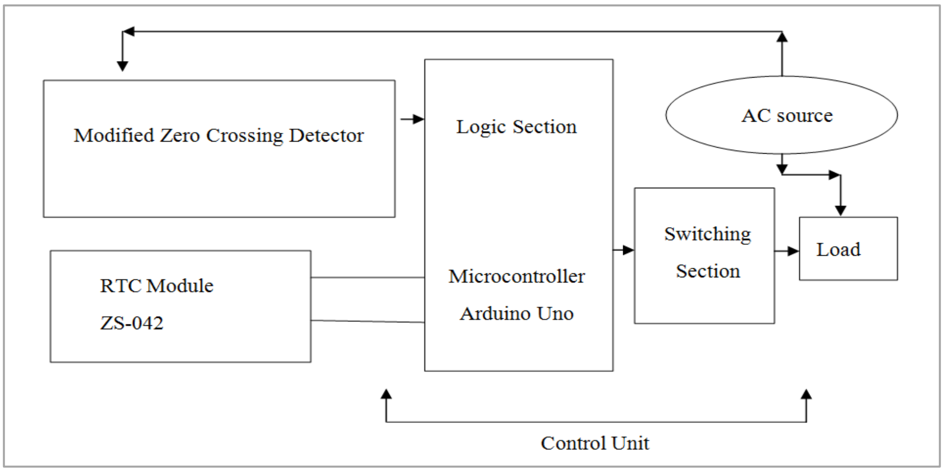

Figure 1: Block Diagram of the Smart System

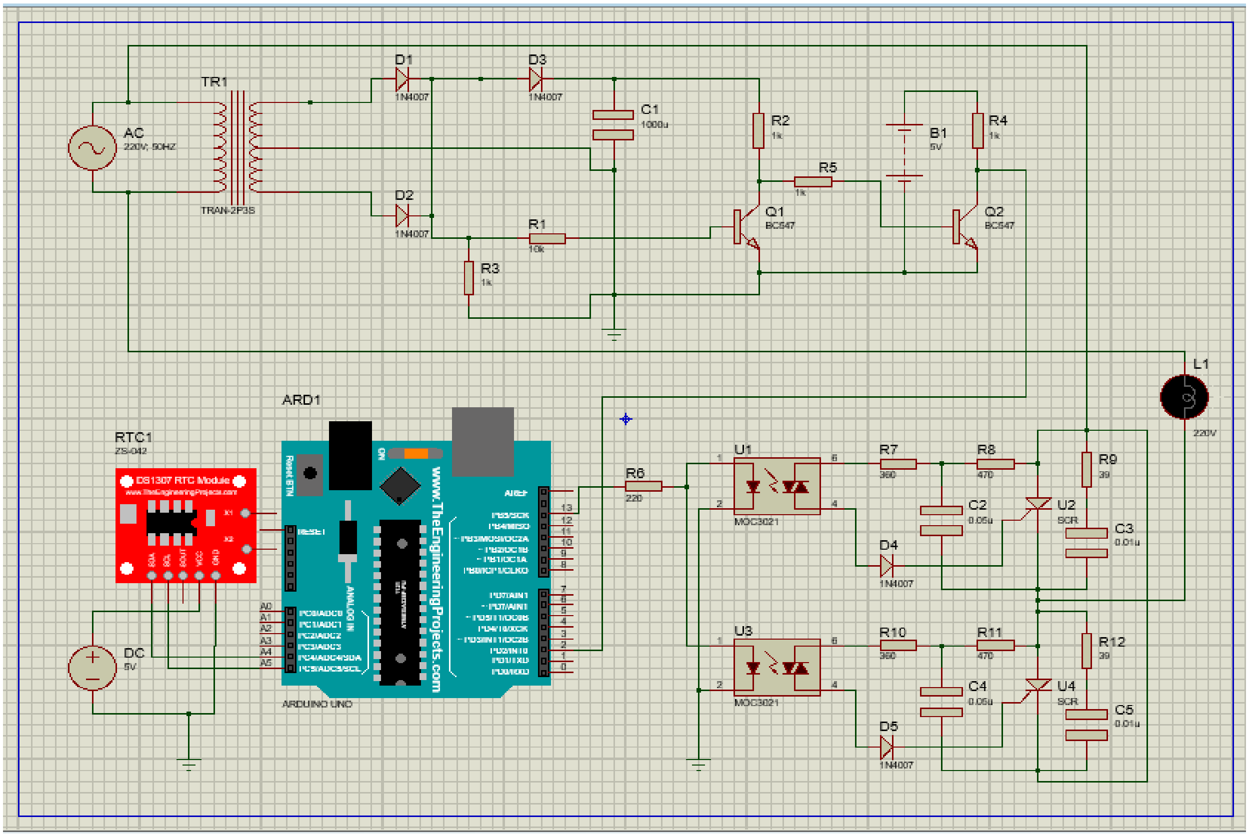

Figure 2: Schematic Diagram of Smart Home Appliance Controlling System

Our designed and developed unique system is capable of sensing a particular time period of a day to conserve energy. The output of the Modified ZCD becomes low when the AC sine wave crosses the 0-voltage level and sends it to the microcontroller of an Arduino Uno interfaced with the ZS-042 RTC (Real Time Clock) module called the Logic Section. The developed algorithm uploaded in the Arduino Uno gives a delayed output, analyzing the peak /off-peak time and the falling edges of the O/P of Modified ZCD. This output controls the zero crossing points of the AC sine wave with the help of the switching section, which is basically a combination of SCRs and Opto diacs. Thus, we can run a load at a controlled power consumption mode. All the schematic diagrams given in this paper were developed and run with Proteus 8 Professional software.

Modified Zero Crossing Detector

As we are going to control the AC 220 volts, we have developed a modified zero-crossing detector [7] by simply adding an extra transistor to the basic one. A ZCD is a type of voltage comparator used to detect the sine waveform transition from positive to negative that coincides with when I/P crosses the zero-voltage condition.

A. Circuit Analysis

Considering VAC=220 V, 50Hz, and transformer TR1of 6-0-6 Volts configuration, let's analyze the following circuit.

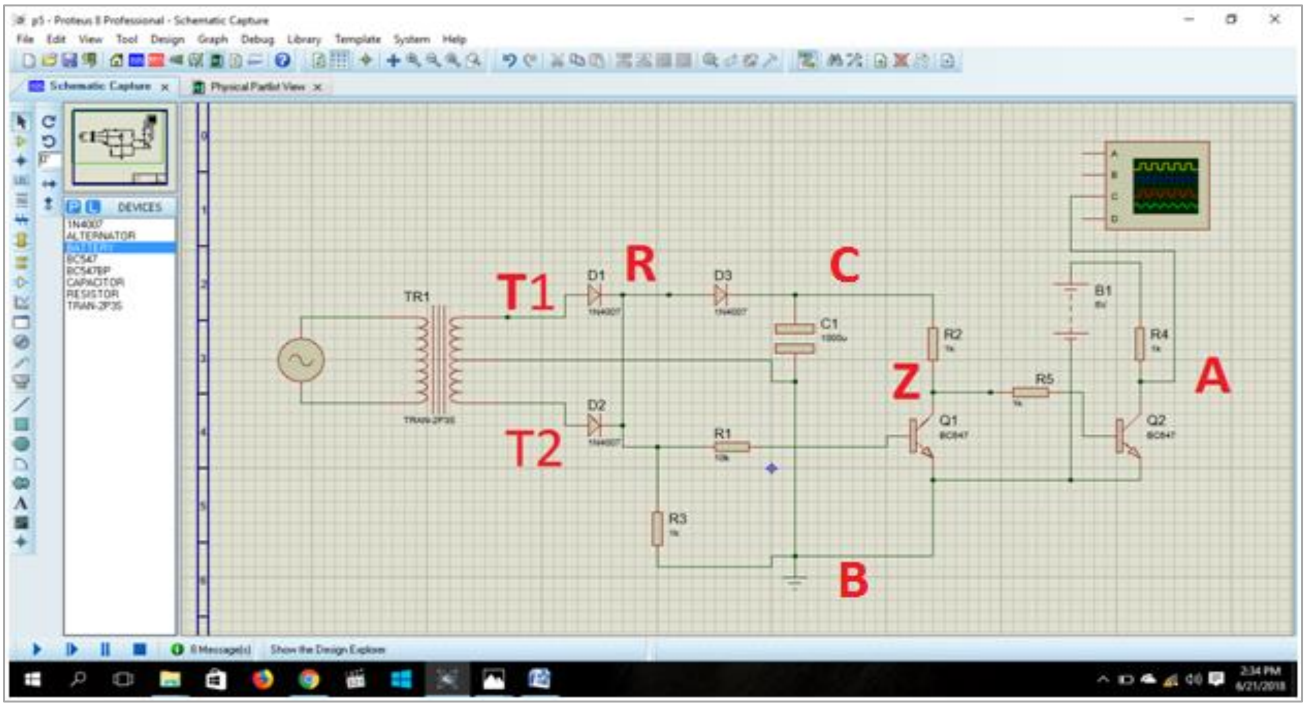

Figure 3: The Modified ZCD

Table 1: Analysis of ZCD (√ = Current Carrying Path)

Equipment/path	+ ve half cycle	0	- ve half cycle
D1	ON	OFF	OFF
Path T1	√		
D2	OFF	OFF	ON
Part T2			√
Path R	√		√
D3	ON	OFF	ON
C1	Charging	Discharging	Charging
Path C	√	√	√
Path B	√		√
Point Z	Low	High	Low
Pint A (o/p)	High	Low	High

R1 is there to ensure that the voltage falls to zero; stray capacitance is sufficient to stop the circuit from working without it. The Capacitor, C1, is a very important component, and its capacitance must be high enough to provide charges to the resistance R2 when the sine wave crosses the 0 voltage level. So we have used a 1000µF Capacitor. T, R, and A are the points from where we can get transformer, rectified, and zero-crossing detector outputs.

B. Significance of Modified ZCD

Since we used a 6-0-6 Step-down Centre Tapped Transformer with an input voltage of 220V, the output RMS voltage will be 6V, which equals 8.485V peak-to-peak. However, the Arduino Uno operates at up to 5V. Therefore, we connected point Z to the base and supplied 5V DC to the collector of the new transistor, each through a 1kΩ resistor.

The Modified ZCD gives an inverted output of the basic ZCD; that means it becomes low when the sine wave crosses zero. So, the falling edges of the Modified ZCD indicate the Zero Crossing points. The following figure shows both the output of the ZCD and Modified ZCD circuits. The top one is the O/P of ZCD at point Z, while the bottom one is for the Modified ZCD at point A, where ↑ and ↓ represent the rising and falling edges, respectively. When the sine wave goes towards zero, we get a falling edge in the O/P of the Modified ZCD at point A.

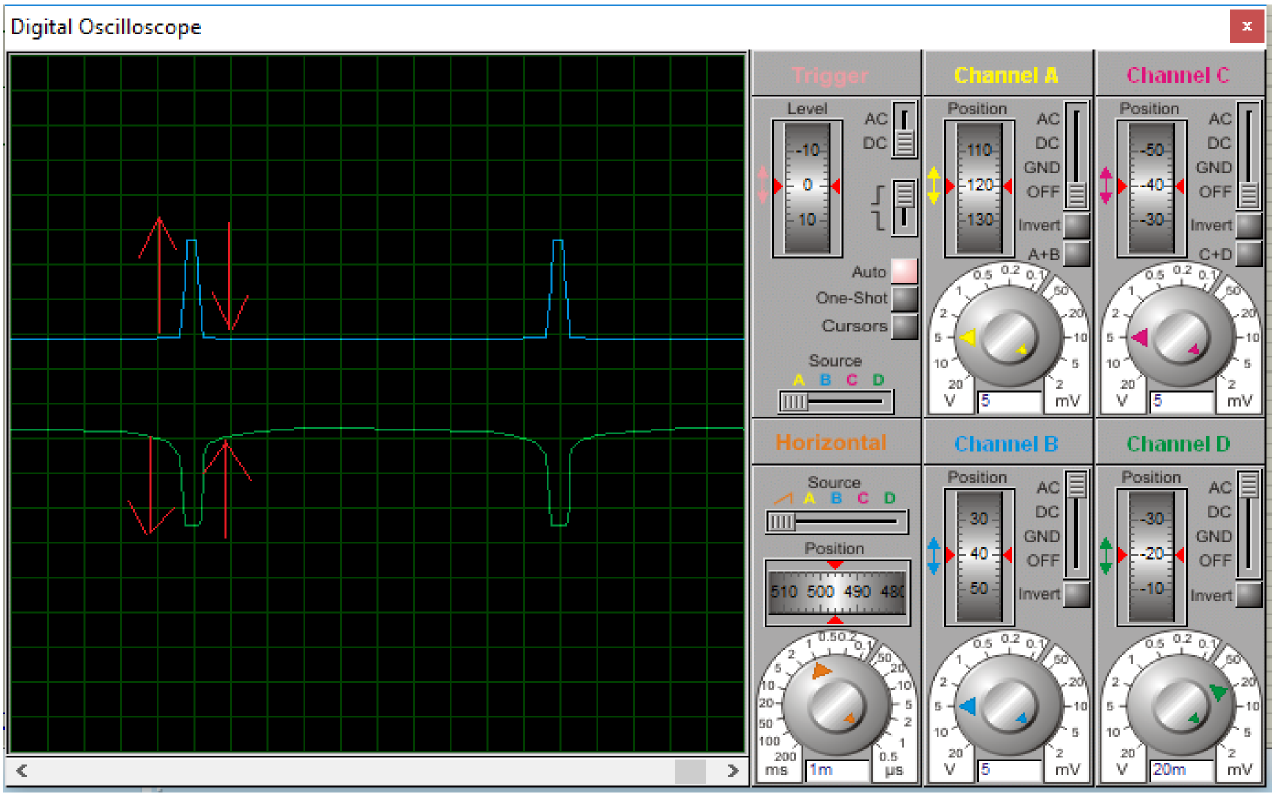

Figure 4: The Rise of ZCD becomes the Fall in Modified ZCD

The Control Unit

The control unit of our intelligent system is divided into the logic section and the switching section, which is able to sense the daily peak and off-peak hours to control the power consumption of a load.

A. The Logic Section

The logic section is composed of the ZS-042 RTC module (which can track time) and Arduino Uno. The SDA, SCL, VCC, and GND ports of the ZS-042 module should be connected to the A4, A5, 3.5/5V, and GND ports of the Arduino Uno, respectively. As we could not find the library for the ZS-042 RTC module in our Proteus 8 Professional software, we have used a similar type of library function called “DS1307 RTC Module” to draw our circuit diagram. So, in the schematic diagram, we will not find any VCC or GND port because the library is developed in that way. Pin 2 of the Arduino Uno is the Input of the Logic Section circuit. We have connected the point A, the output of the Modified ZCD, to the input Pin 2. The Arduino Uno will analyze the output of Modified ZCD to find out the falling edges, where the sine wave crosses the 0-voltage level.

We have used Pin 13 of Arduino Uno for the Output of the Logic Section circuit. The developed programme has been uploaded to the Arduino Uno of the logic section, which can sense the time to detect whether it is peak hour or not, and also the falling edges of the signal coming from the Modified ZCD circuit to control the width of the OFF time. The “width” is defined as “int w” in the programme. Once the connections are done properly, the RTC module will start talking to the microcontroller.

B. The Switching Section

The second part of the Control Unit is called the switching section. In this research, we have used two MOC3021's (opto-diac) and two TYN610s (SCR) for the two half-cycles of the AC sine wave which we are going to control.

The ground of the Modified ZCD is connected to the ground of the Arduino Uno; that means, with the ground of the Logic Section of the Control Unit. But the Switching Section of the Control Unit is powered by an AC signal. The two points of an AC signal are called HOTLINE and NEUTRAL. We cannot connect the ground of the Modified ZCD to the NEUTRAL. For this reason, we needed opto-diac as the ground of opto-diac [9] It is connected to the ground of the Control Unit. Thus, we have solved the common ground problem. The following "Fig. 5" shows the switching section of the Control Unit.

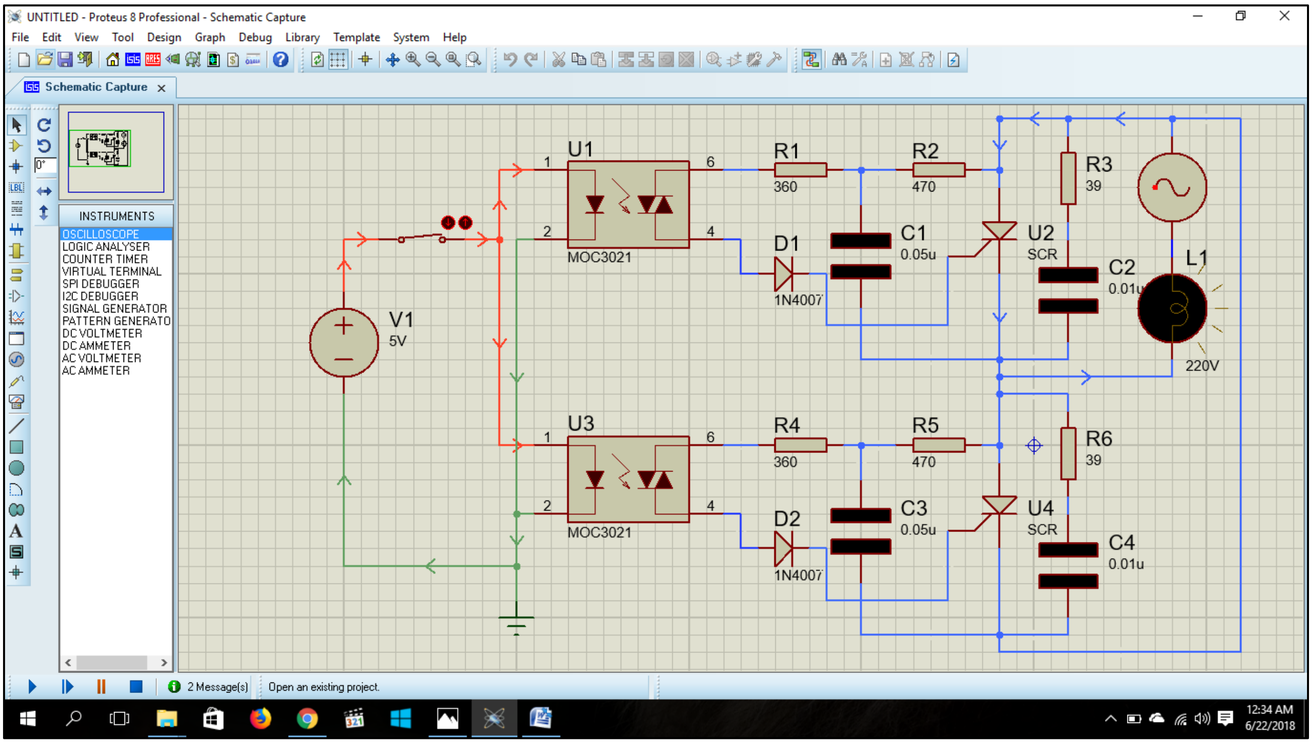

Figure 5: The Schematic Diagram for Testing the Switching Section

Table 2: Analysis of Switching Section of The Control Unit (√ = short circuit, × = open circuit, 1 = 5V)

Equipment's		**AC sine wave (half cycles)**			
		+ ve half cycle		**- ve half cycle**	
		DC (Volt)		***DC (Volt)***	
		0	5	0	5
U1 (opto-diac)	Pin 1-2	×	√	×	√
	Pin 6-4	×	√	×	√
U3 (opto-diac)	Pin 1-2	×	√	×	√
	Pin 6-4	×	√	×	√
U2 (SCR)	Gate signal	0	1	0	1
	Direction of current	×	Anode to Cathode	×	Cathode to Anode
	State	OFF	ON	OFF	OFF
U4 (SCR)	Gate signal	0	1	0	1
	Direction of current	×	Cathode to Anode	×	Anode to Cathode
	State	OFF	OFF	OFF	ON
Load condition		OFF	ON	OFF	ON

While analyzing the switching section, we must keep in mind that the DC=0V and DC=5V represent the O/P of the Arduino Uno, which is the I/P of the Logic Section of the Control Unit. When the switch is OPEN, it means the O/P of Arduino Uno is Low. When the switch is CLOSED, it means the O/P of Arduino Uno is HIGH. LAMP is the Load connected to the supplied AC power. Lamp OFF and ON mean load DISCONNECTED and CONNECTED, respectively.

The features of the switching section of the Control Unit are:

- The one end of the load is connected to the AC power supply, and the other end to the SCR.
- The two SCR's are connected in such a way that the cathode of one is connected to the anode of the other and vice versa. One SCR will work during the positive half-cycle [10] and the other during the negative half-cycle of the AC sine wave.
- We have used a DC voltage source and a switch just to observe the simulation. We wanted to test whether the circuit runs properly or not. Again, we wanted to find out how the circuit behaves with the change in polarity. In the main circuit, we have not used the DC voltage source or switch in the logic section.
- From the datasheet of MOC3021 we can say that the 39Ω resistor and 0.01μF capacitor are for snubbing the SCR and the 360Ω, 470Ω resistors and 0.05μF capacitors are for snubbing [11] The opto-diac for safety issues

C. Resistor Interfacing Logic and Control Units

Combining the logic section and the switching section, we have developed the Control Unit. From the datasheet of MOC3021, we have learnt that all devices are guaranteed to trigger at an IF (forward current) value less than or equal to max IFT (LED Trigger Current, Current Required to Latch Output). The recommended operating IF lies between the max IFT (15 mA for MOC3021) and the absolute max (60 mA).

The input of our switching section is 5V. Considering the current as 15 mA and 60 mA, we calculated the limit of the resistor (R) value.

$R = (5 \div 15) \times 1000\Omega = 333.33\Omega$

Or, $R = (5 \div 60) \times 1000\Omega = 83.33\Omega$

So, $83.33\Omega \leq R \leq 333.33\Omega$

In this research, we have chosen a resistor of 220Ω between the Logic Section and the Switching Section

Intelligence of the System

We have developed a simple and smart programme as the intelligence for our home appliance controlling system, which can:

- Sense the peak (5 pm to 10:59 pm) and off-peak hours (11 pm to 4:59 pm) using the RTC ZS-042 module.
- Turn OFF the main power for a while, sensing the falling state at point A of Modified ZCD.

A. Important Features of The Software

We are using the 50Hz AC signal to be controlled, which takes 20ms to complete a full cycle. So, the time for a half cycle is 10ms. That means we will get a FALLING edge every 10ms. So we can control the width of the output of Modified ZCD mentioned as "w" in "Fig. 6" by using the "delay()" function. We can vary "w" by simply varying "delay(1)" to "delay(9)" as it represents milliseconds. When w=3, that is "delay (3)", it means the load will be disconnected for 3 milliseconds from the falling edge of the signal coming from the point A of the modified ZCD. So "w" will be our controlling parameter. Anyway, this programme cannot sense a particular day or month, but it is possible to make the programme work that way. This might be needed, because in weekends the peak and off-peak hours' format may be different. Again, the timing pattern of winter might be different than the summer season. Anyway, this change is easily possible, which might be further work for our system

We have used "attach Interrupt(digital Pin To Interrupt(2), led_off, FALLING)" interrupt calling function [12] for our system. Here, "digital Pin To Interrupt(2)" denotes the PIN through which the Arduino Uno will check the interrupt. Again, we could also write "0" or "1" for pin 2 or 3 instead of writing "digital Pin To Interrupt (2)". The "led_off" is the ISR (Interrupt Service Routine), which describes what to do. The "FALLING" denotes that we are going to check the falling edge of the signal.

The library functions used here are #include <Wire.h> and #include "RTClib. h". "Date Time now = rtc. now();" is used for time tracking.

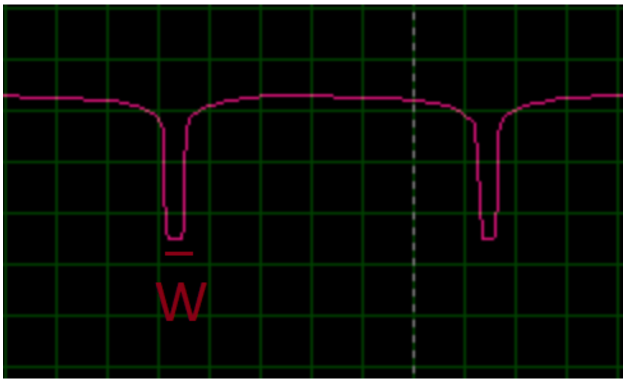

Figure 6: Definition of the Controlling Parameter "W"

B. System Software

We have written the following programme for our system:

```
// ds3231 provides 24 h format time
// Date and time functions using a DS3231 RTC connected via I2C and Wire lib
#include <Wire.h>
#include "RTClib.h"
RTC_DS3231 rtc;
char days of the Week[7, 12]={"Sunday", "Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday"}; // no use until we set day
volatile bool signl=false;
int w=0;
void setup () {
 #ifndef ESP8266
 while (! Serial); // for Leonardo/Micro/Zero
```

```
#endif
  //Serial. begin(9600);
  pinMode(13, OUTPUT);
  attachInterrupt(digitalPinToInterrupt(2), led_off, FALLING);
  if (! rtc.begin()) {
    //Serial.println("Couldn't find RTC");
    while (1);
  }
//the following if condition is of no use unless RTC battery is ok
  //if (rtc.lostPower()) {
    //Serial.println("RTC lost power, let's set the time!");
    // following line sets the RTC to the date & time this sketch was compiled
    //rtc.adjust(DateTime(F(__DATE__), F(__TIME__))); // this line will set the time according to system (Computer) time
    // this line sets the RTC with an explicit date & time, for example to set
    // January 21, 2014 at 3am someone would call:
    // rtc.adjust(DateTime (2014, 1, 21, 3, 0, 0));
  //}}
void loop () {DateTime now = rtc.now();
  If (now.hour() >= 17 && now.hour() <= 22) // 5 pm to 10:59 pm
 {w=2; // delay time 2 msec}
  else if (now.hour() >= 23 && now. hour() <= 23 || now.hour() >= 0 && now. hour() <= 16) // 11 pm to 4:59 pm
   {w=1; // delay time 1 msec}
   if(signl)
   {//digitalWrite (13, LOW);
     delay(w);
    digitalWrite (13, HIGH);
    signl=false;}
    //delay (500); //delay time to start monitor}
  void led_off ()
  {digitalWrite (13, LOW);
  // detects FALLING
   signl=true;}
```

Results Analysis

We have selected 5 pm to 11 pm as peak hours and the parameter “w=2” (2 ms) for the peak hours. That means our designed device will be able to save 20% energy during the peak hours without bothering the consumers’ comfort.

A. Modified ZCD Output

We have used a 6-0-6 output transformer. So the peak voltage value is around 6V. The graph shows that the output voltage of the transformer is 9V. The curves represent the two ends of the used centre-tapped transformer. So if the rms value of transformer O/P = 6V, then the peak value of transformer O/P = (6×√2) V = 8.485V.

The following wave shapes are captured through a DIGITAL OSCILLOSCOPE.

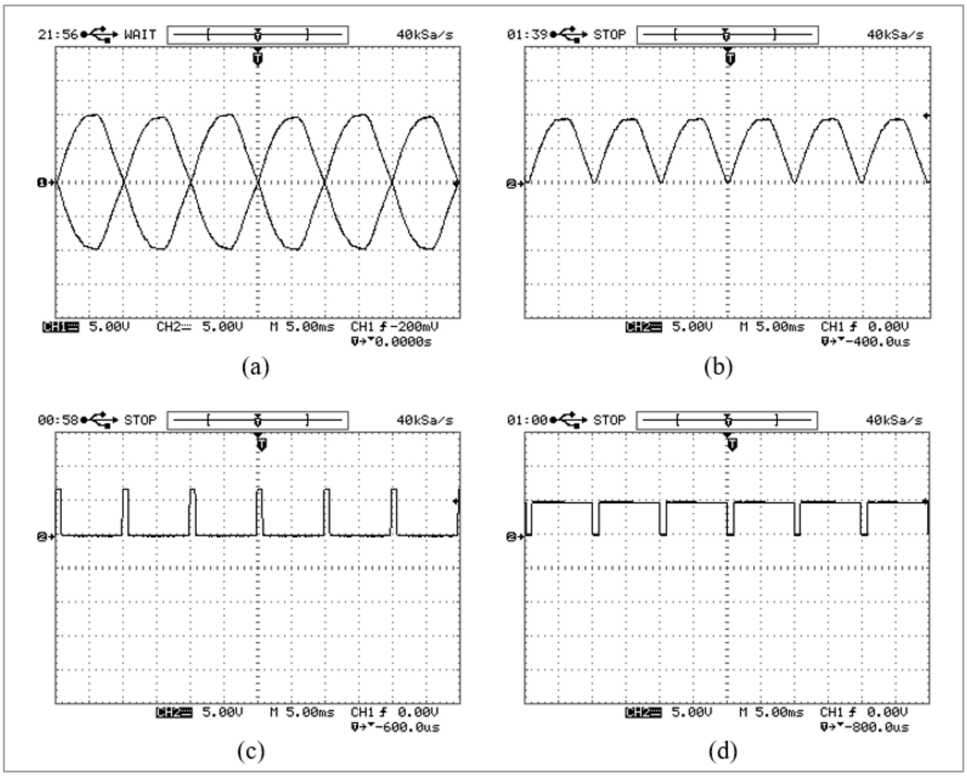

Figure 7: Output taken from Different Points of the Modified ZCD. (A) Transformer Output, (B) Rectified Output, (C) Output at Point “Z” of “Fig. 3”, (D) Modified ZCD Output at Point “A” of “Fig. 3”

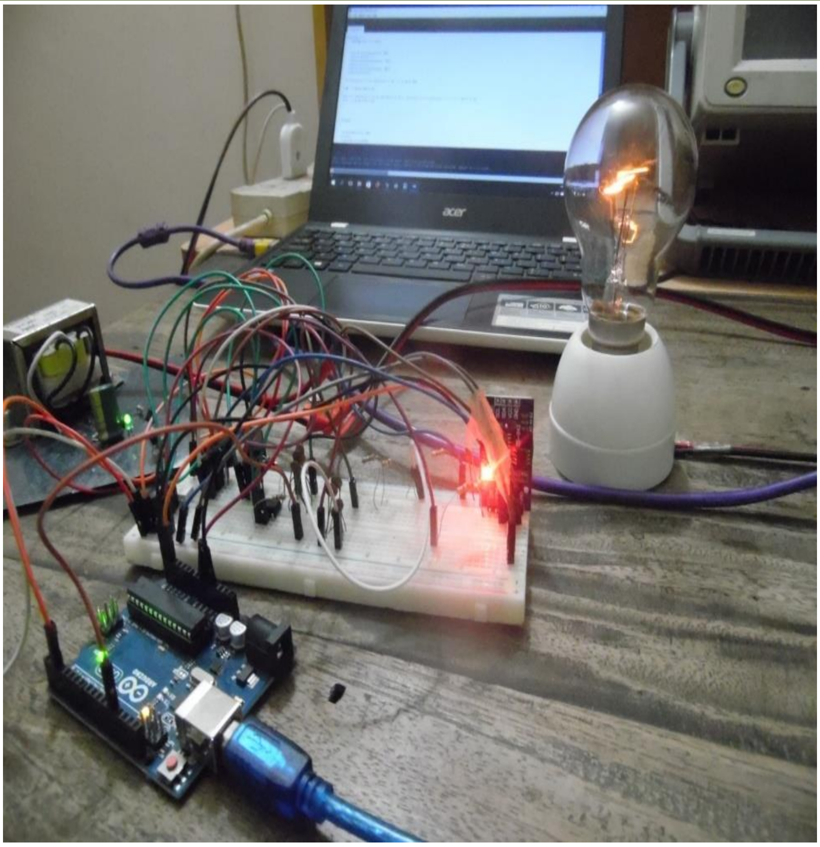

Figure 8: Load Consumes 20% of the Supplied Power when "W=8"

B. Waveform of Load Voltage for a 60W Bulb

The frequency used in our country varies from 49-51Hz. That means the time needed for one half-cycle will be 10.2 ms to 9.8ms. So if the Actual Power Consumption is P_A, then

$\{(9.8\text{-w}) \div 9.8\} \times 100\ \% < P_A < \{(10.2\text{-w}) \div 10.2\} \times 100\ \%$

For w=2; $79.59\% < P_A < 80.39\%$

"Fig. 9" to "Fig. 17" is the observed change in wave shapes varying the controlling parameter "w" from 1 to 9 for a 60W bulb. In every case, 1st and 2nd picture shows the SCR Gate triggering signal and load voltage wave shapes, respectively.

The flickers created by the RTC module create a fluctuation [13] of 95-105% of the desired voltage. The parameter "w" varies ±0.75ms of the given value in a full cycle; that means the fluctuation in one half cycle can create an impact on the next half cycle. Due to "w" fluctuation, we can get "w=10" instead of "w=9". So "w=9" is the worst case to work with, as then the load can remain ON for a whole half-cycle.

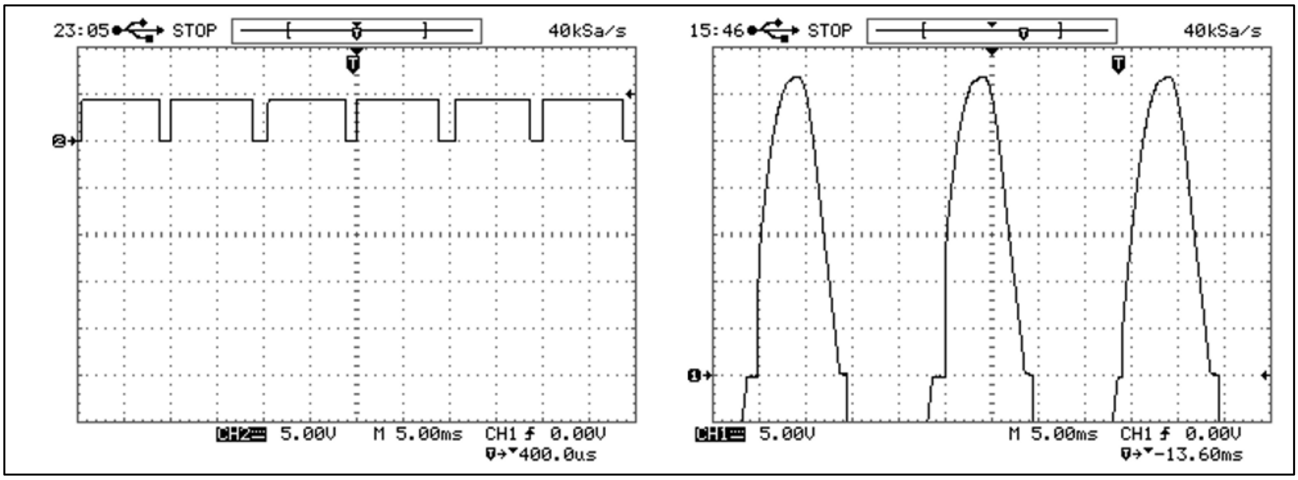

Figure. 9: W=1; 8 - 10% Power Saved by the Smart System

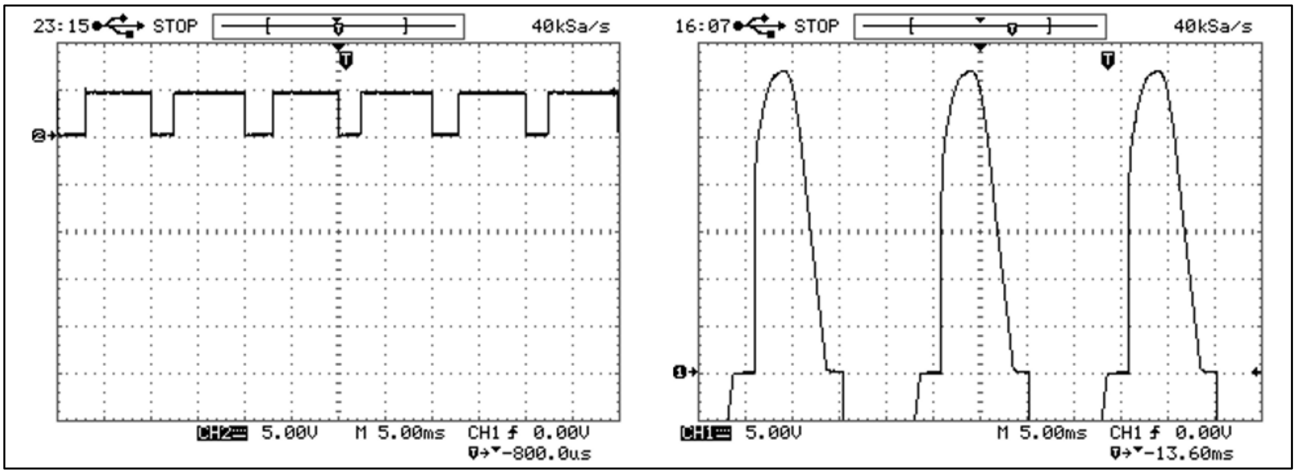

Figure. 10: W=2; 19.6 – 20.4% Power Saved by the Smart System

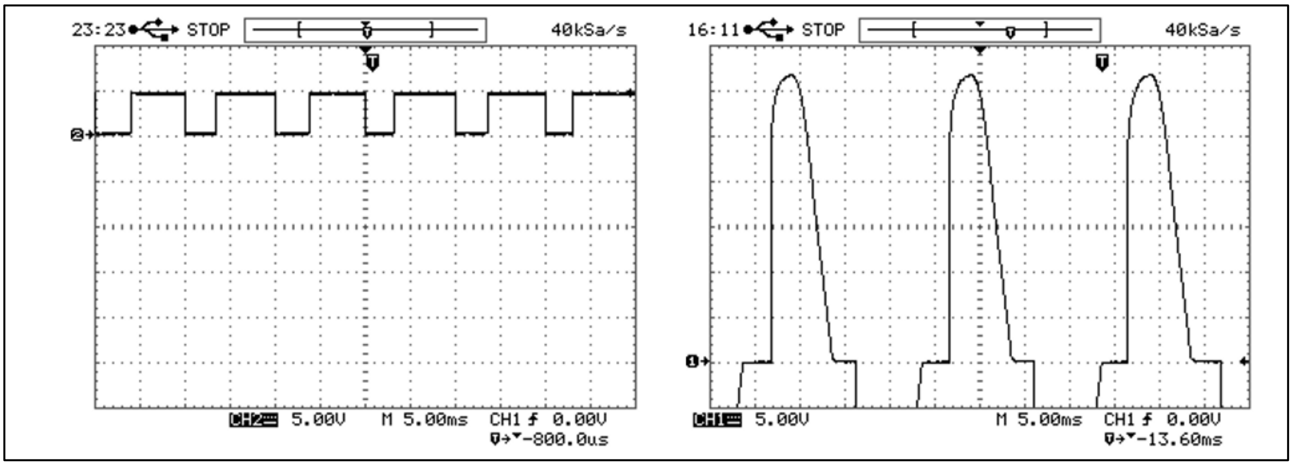

Figure. 11: W=3; 29.4 – 30.6% Power Saved by the Smar

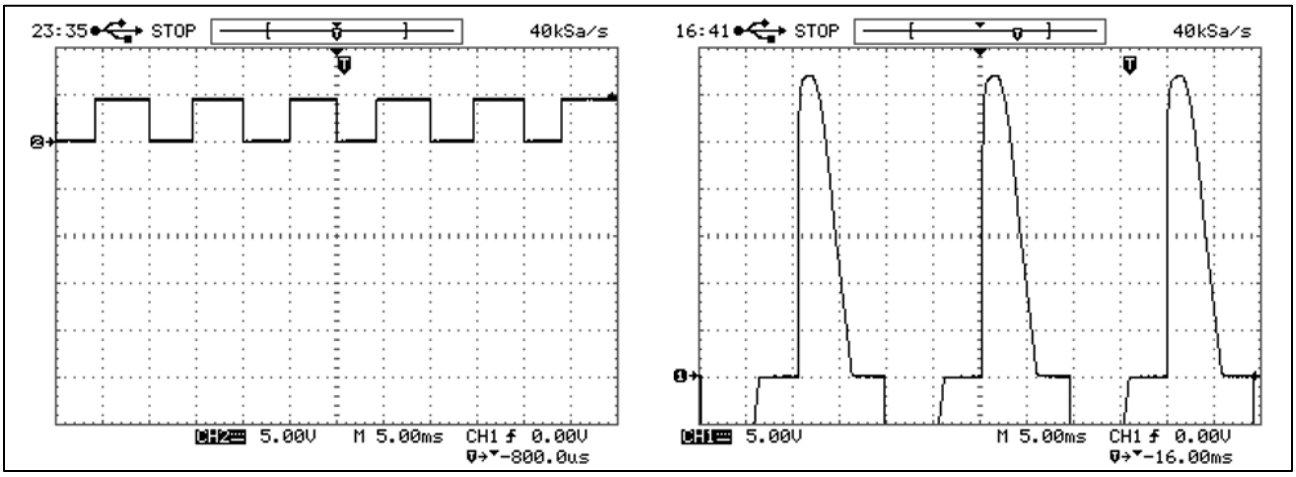

Figure. 12: W=4; 39.2 – 40.8% Power Saved by the Smart System

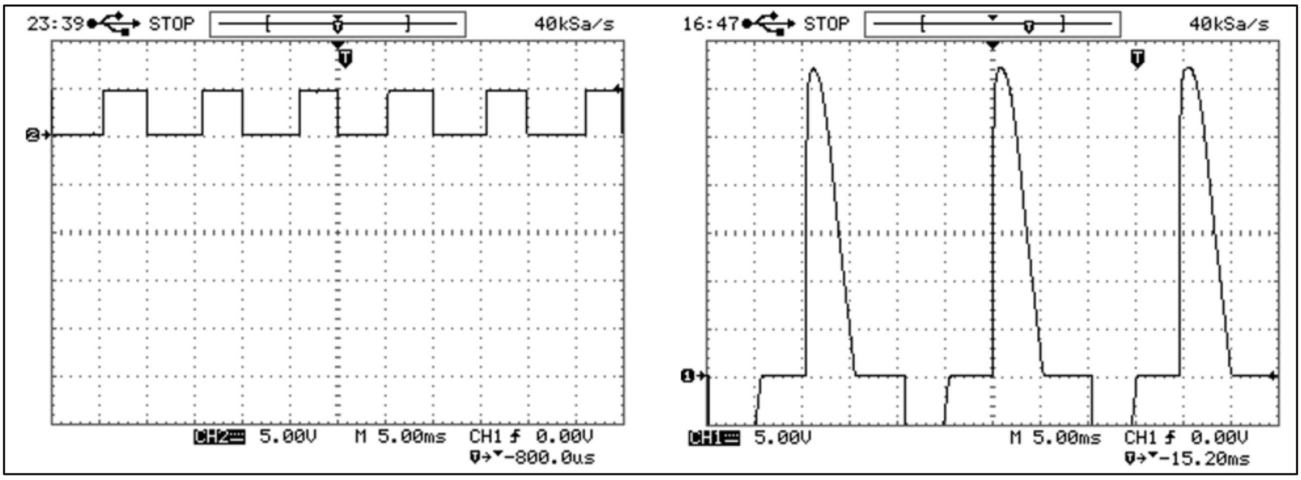

Figure. 13: W=5; 49 – 51% Power Saved by the Smart System

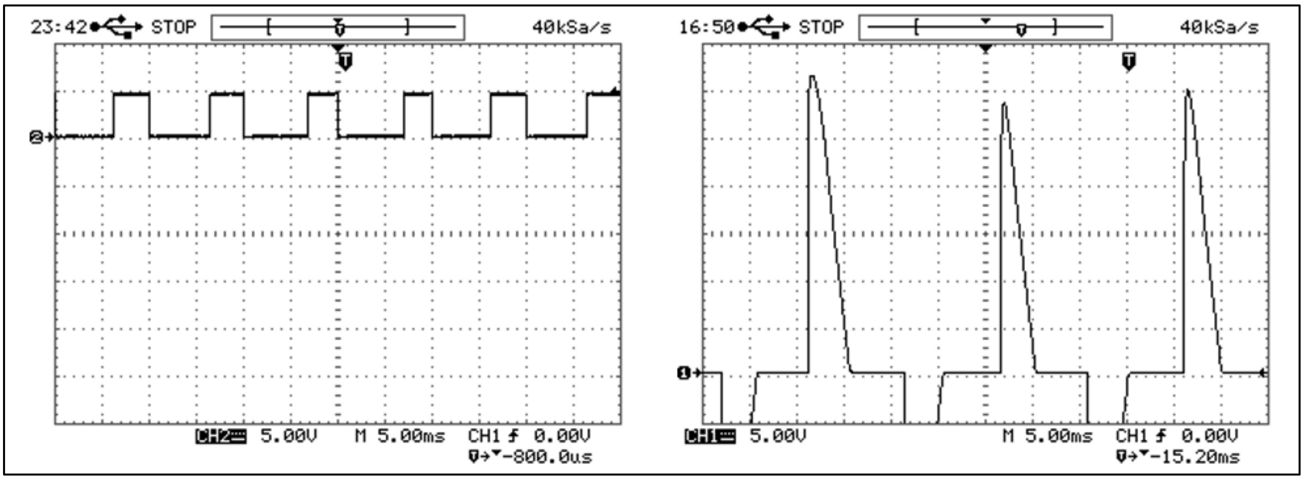

Figure. 14: W=6; 61.2 – 58.8% Power Saved by the Smart System

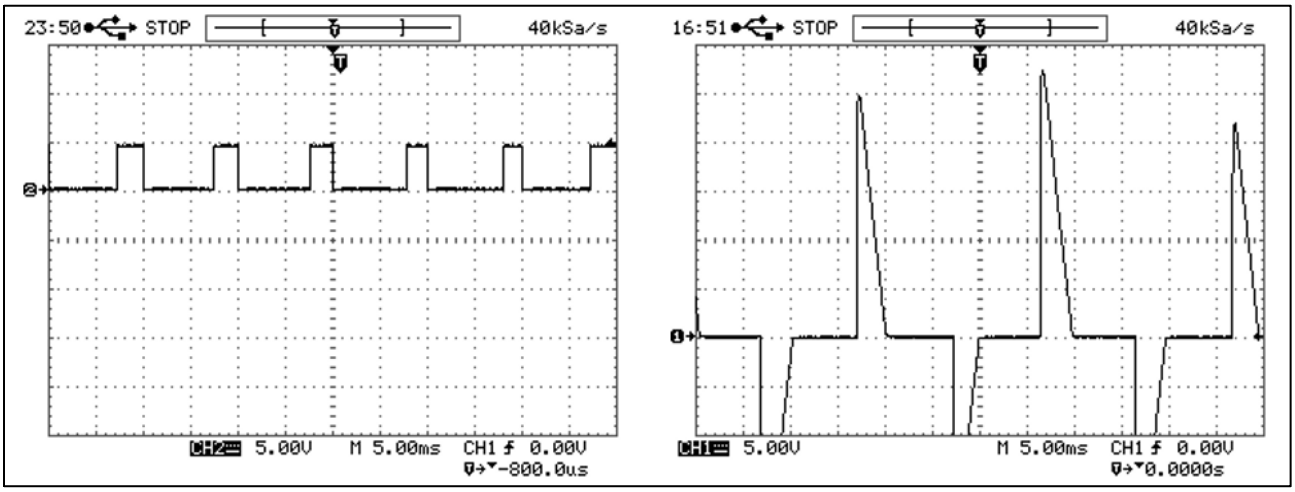

Figure. 15: W=7; 68.6 – 71.4% Power Saved by the Smart System

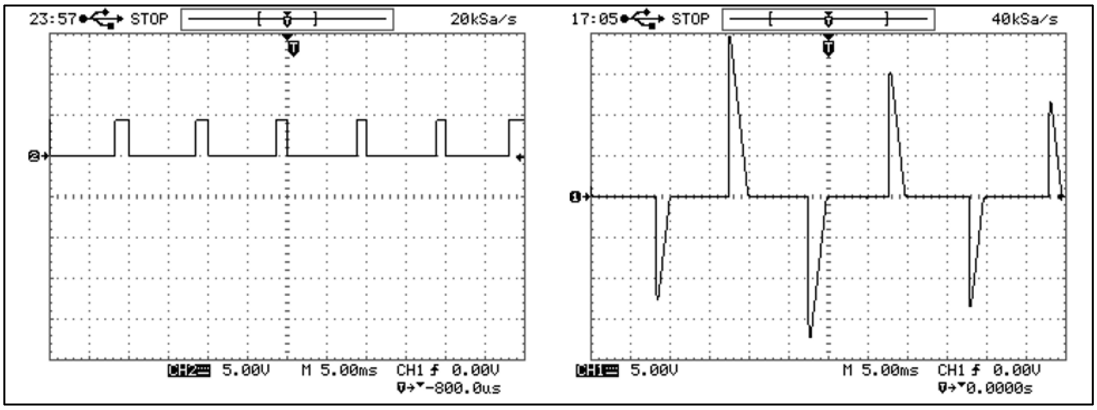

Figure 16: W=8; 78.4 – 81.6% Power Saved by the Smart System

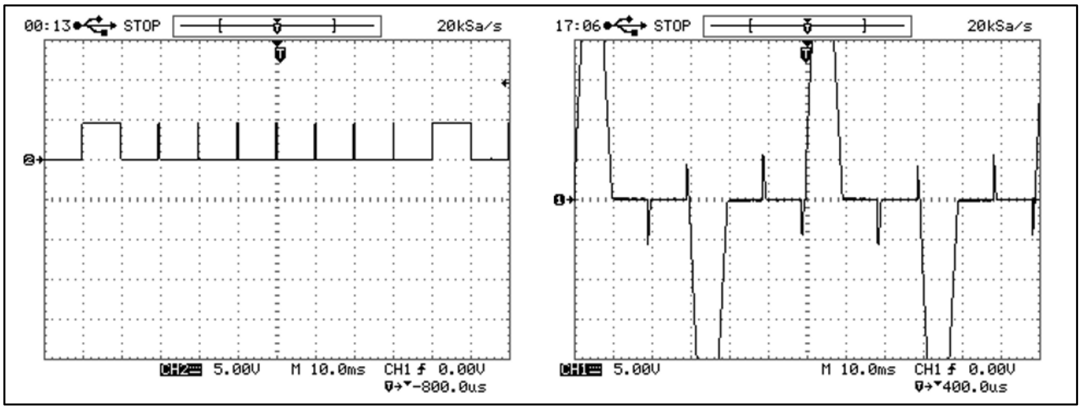

Figure 17: W=9; 10 – 50% Power Saved by the Smart System

C. Waveform of Load Voltage for a 60W AC Fan

We have also tested our home appliance controlling system for a 0.3A, 60W AC fan. The noise present in the wave shape is created by the inductive effect of fan. The fan goes to the OFF state at w=7. That means, depending on the load type, we must carefully select the parameter “w”.

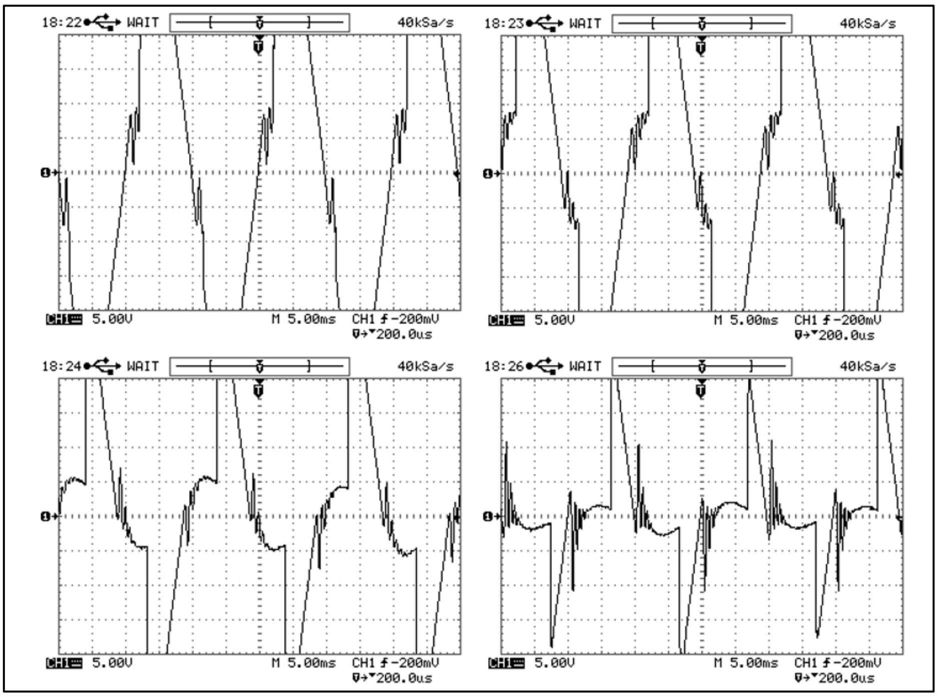

Figure 18: AC Fan Voltage Waveform when W=2, 3, 5, and 7

CONCLUSION

This research presented the development of an intelligent system designed to cut down on electricity costs. The device automatically reduces the power consumption of appliances, like dimming lights or slowing down fans, whenever electricity prices are at their peak. The device has successfully passed the test in running a 60W bulb, a 60W AC fan, and a 1000W electric iron. The core intelligent feature of the smart home appliance controlling system developed here is its ability to regulate energy consumption during peak and off-peak hours to save money, energy, and the environment for a sustainable future. The microcontroller-based device, which employs SCR and Opto-diac circuitry, effectively minimizes energy consumption to save power and maintains performance. Owing to its low purchase and maintenance costs, the proposed system is a great fit for middle-class households. By boosting energy efficiency, cutting down on waste, and profiling demand, this smart controller offers a practical solution with real value for society. Ultimately, such technology can play a vital role in advancing energy conservation and supporting the vision of a smarter Bangladesh and the similar context in such regions.

REFERENCES

1. K. F. Tuly, "A Survey on Novel Services in Smart Home (Optimized for Smart Electricity Grid)," NTNU, 2016.
2. J. Alam and M. Azam Koreshi, "Infrared Remote Controlled Home Automation System Based on Microcontroller," East West University, 2016.
3. R. Roy, S. Das, J. K. Ray, S. Barat, and B. Neogi, "Automatic speed control of single phase induction motor with the variation of ambient temperature," *International Journal of Scientific and Research Publications,* vol. 2, no. 11, pp. 2250-3153, 2012.
4. H. Xie, P. Huang, Y. Li, L. Zhao, and F. Wang, "Design of real-time electricity prices and wireless communication smart meter," *Energy and Power Engineering,* vol. 5, no. 4, pp. 1357-1361, 2013.
5. M. Saad, H. Abdoalgader, and M. Mohamed, "Automatic fan speed control system using microcontroller," in *6th Int'l Conference on Electrical, Electronics & Civil Engineering (ICEECE'2014)*, 2014, pp. 27-28.
6. S. Morimoto, Y. Takeda, and T. Hirasa, "Current phase control methods for permanent magnet synchronous motors," *IEEE Transactions on Power Electronics,* vol. 5, no. 2, pp. 133-139, 1990.
7. A. Gupta, R. Thakur, and S. Murarka, "An efficient approach to zero crossing detection based on opto-coupler," *International Journal of Engineering Research and Applications,* vol. 3, no. 5, pp. 834-838, 2013.
8. T. Nussbaumer and J. W. Kolar, "Comparison of 3-phase wide output voltage range PWM rectifiers," *IEEE Transactions on Industrial Electronics,* vol. 54, no. 6, pp. 3422-3425, 2007.
9. N. Crisan, "High Linearity Analog Optocouplers-Applications Inside the RF Shielded Enclosures," *Acta Technica Napocensis,* vol. 55, no. 1, p. 10, 2014.
10. Z. Li *et al.*, "SCR series technology based on high-speed transient protection," in *2011 1st International Conference on Electric Power Equipment-Switching Technology*, 2011: IEEE, pp. 657-660.
11. F. Zhu, F. Liu, W. Liu, K. Feng, and X. Zha, "Performance analysis of RCD and MOV snubber circuits in low-voltage DC microgrid system," in *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2017: IEEE, pp. 1518-1521.
12. J. Iovine, *PIC microcontroller project book*. McGraw-Hill, Inc., 2004.
13. P. de Boer, "Accuracy and stability of the 50 Hz mains frequency," *En línea]. Available: http://wwwhome. cs. utwente. nl/~ ptdeboer/misc/mains. html,* 2020.