DESIGN AND SIMULATION OF VOLTAGE OPTIMIZATION SYSTEM

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Abstract

The supply voltage to household appliances and industrial equipment are by UK law, BS EN 50160:2007, required to be confined within the limits of ±10% of the nominal 230V. These household appliances are able to run above the optimal voltage but within the regulated voltage band limit. However, a higher voltage does not translate into better performance of these appliances but rather contributes to the problem of higher bills, shortened lifespan of appliances and higher carbon emissions.

Keywords: *Voltage optimisation; voltage power optimisation; conservation voltage regulation; voltage correction; tap changer, solid-state switching, PIC microcontroller.*

1. Introduction

Electrical appliances commonly used at homes, industries and offices are designed to operate within a standardized voltage range. A good utilization of these appliances will requires they operate at the recommended or nominal voltage range which are approved by the standard institute of the country in view. One of the challenges associated to nominal voltage supply is that it creates a less efficient usage of these appliances. However, operating these electrical devices above the required optimum voltage for example does not increase the performance but rather causes increases in losses. These losses are generally in the form of heat and contribute to insulation breakdown and shortened the lifespan of the appliance. The European Union's directive on low voltage stipulates a tolerable range of ±10% of the nominal 230V voltage fluctuations acceptable for normal system operation within Europe and some allied countries. This regulation is aimed at energy savings within households which also implied energy conservation on the national grid.

Based on the studies carried out on published works, the use of power electronics in tap switching proved to be a leader in Voltage optimization. These devices are use for domestic and industrial applications to control the voltage level to a relatively stable level.

2. Literature Review

Several techniques for optimum operation of electrical appliances in homes and industries have been made known in publications as well as in real time designs. In publications, Xiaoming et al [1] have published a report using power electronics in the regulating of transformer voltage and highlighted its advantage over mechanical tap changers.

Robinson et al., [2] defined voltage fluctuations as repetitive changes in the magnitude of the voltage. These fluctuations are usually random changes and could be higher (Spikes) or lower (Dips) than the nominal value. Fluctuations may be caused by system faults such as short circuits, system operations for instance switching of loads and also by transient conditions for example, lightning strikes. Continuous variations of loads within a power system also contribute to this problem, Pyone [3] and rapid changes in the real and reactive power drawn by the load.

Transformer design is also vital in controlling the power losses of electrical appliances Marketos and Meydan [4] reported a new method for transformer core design and made use of material properties of steel. The report explained the limitations in previous core designs and their contribution to high core losses in transformers. Also, the nature of the conventional core design accounts for the longer construction time which leads to higher cost of the transformer. The primary focus of their research was targeted at the joints of the transformer core. The larger the joint area, the greater the flux deviation and hence greater losses.

Faiz and Siahkolah [5] published several articles in the research area of transformer design and presented in their publication, a better method for tap-changer design of transformers as well as the various control techniques. A tap changer controller was proposed in the design. The purpose of this controller was to protect the tap-changer mechanism from possible faults or undesirable conditions. Due to problems inherent in conventional tap-changers, they proposed a solid-state switch and tap winding structure to minimize the number of taps and also to maximize voltage steps. An electronic tap-changer control was discussed along with the developed software.

Xiaominget al [6] reported on a different approach in the regulating of transformer voltage. The report proposed the use of power electronics in the transformer circuit design. Conventional designs made use of mechanical tap switching mechanisms and the major flaws in these designs were also discussed as well as the advantages of the proposed design. The proposed approach promised a much greater efficiency and lesser cost of maintenance. The inclusion of a control circuit in the design gave a better operational performance to the design as compared to the fixed tap.

Fourie and Mouton [7] presented an electronic tap switching for Medium Voltage transformers by the use of IGBTs. They achieved a lesser taps and improved response time to voltage fluctuations. In conclusion, the conservation of energy and savings from the use of voltage optimization techniques is of great significance to all stakeholders, Khurmy& Alshahrani [8].

3. Design and Simulation

3.1 Schematic Capture

A better design approach was to capture the proposed circuit design using software tools. Circuit schematic tools such as Proteus ISIS, Multisim and OrCAD, allow the capturing and simulation of circuits. Within the desired software, other considerations were the availability of spice models for the desired components. The availability and ease of use meant the Proteus ISIS was selected as the tool for this task. In the area of transformer simulation, the Proteus ISIS gave no such suitable model for analysis so a different simulation tool, Matlab, was used for the transformer analysis.

3.2 Software and Hardware Development Processes

The software aspect of the research project involves the simulations and programming of the microcontroller. Simulations were carried out for the Rectification, Switching and the Main control PCB prior to fabrication. While the hardware designs is archived using the block diagram of the system given in Figure 1.

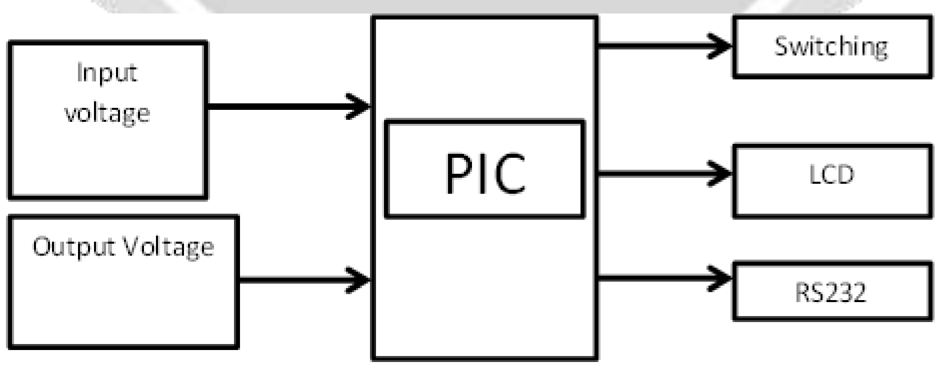

Figure 1. Inputs and Outputs of the PIC 16F876A

Upon a successful analysis, of the system requirements**,** an in-depth analysis of the microcontroller in the main control PCB was done and summarized. The analogue to digital conversion (ADC) and serial communication functions of the PIC were key focus in the programming.

MPLAB's IDE and "HiTech C" compiler were used for the programming of the PIC. The flow chart for the program is shown in Figure . The PIC microcontroller pins where assigned specific roles based on the schematic and datasheet, Microchip [9]. At start-up, the PIC configuration bits are read from memory. The ADC function and communication functions are then initialized. Next, the ADC function gets inputs from RA1 (AN0) and RA2 (AN1), and results stored in a variable as shown in the block of code shown below;

```
unsigned int ADC_Val_AN0 [3] = {0, 0, 0};

unsigned int ADC_Val_AN1 [3] = {0, 0, 0};
```

The ADC_Val_AN0 was set up as an array and initialized to contain values of zero (0) at start-up. The purpose of this approach was to store three different values from which an average value will be computed and stored as the ADC value.

During runtime, an infinite loop allowed continual read-convert-store process to obtain the ADC values of the input and output voltages. The following block of code within the "while (1)" loop gave this continual ADC operation.

```
ADC_Val_AN0 [0] = GetADCValue (AN0);

ADC_Val_AN1 [0] = GetADCValue (AN1);

ADC_Val_AN0 [1] = GetADCValue (AN0);

ADC_Val_AN1 [1] = GetADCValue (AN1);
```

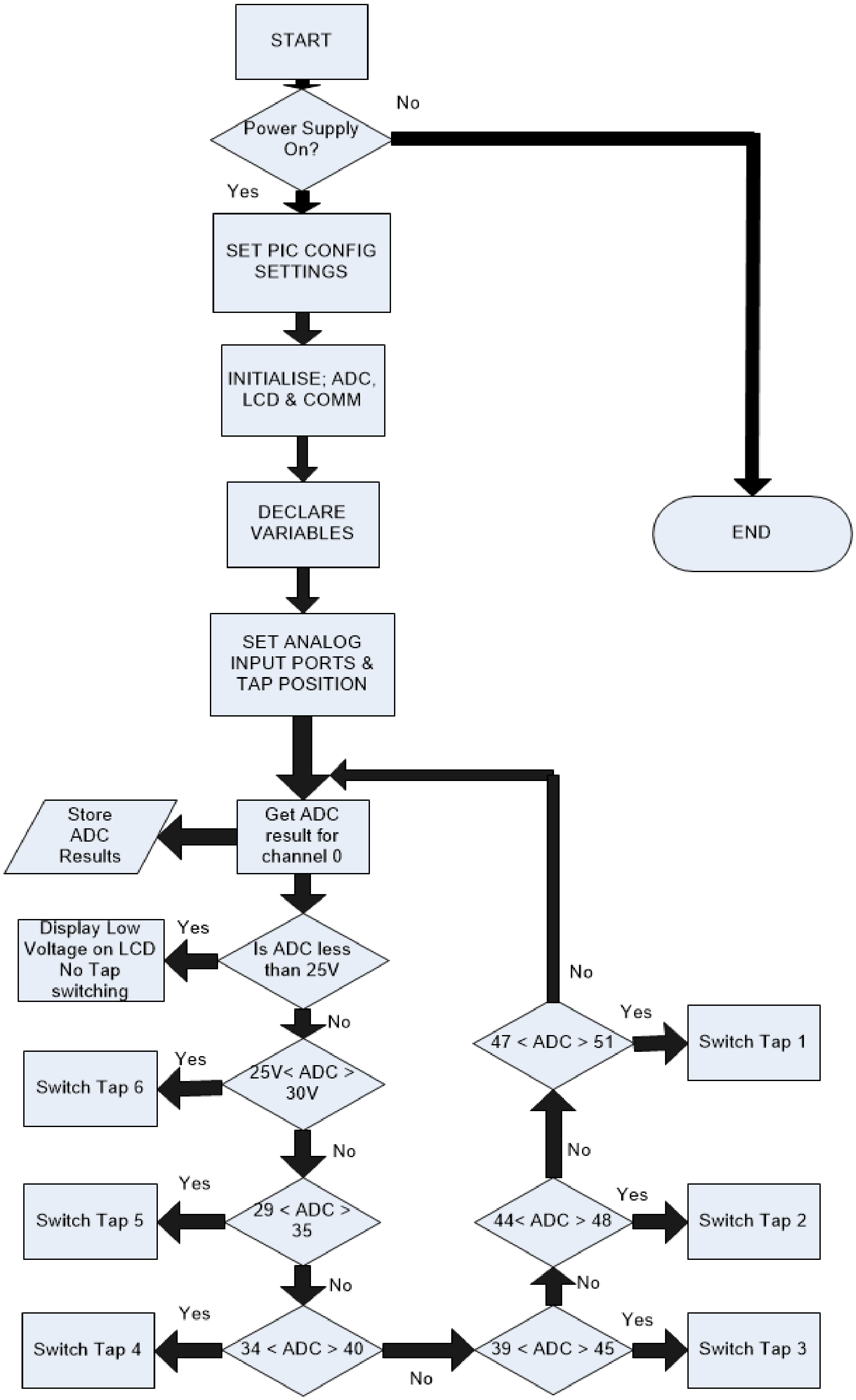

Figure 2. Flow chart of PIC program

The average value of the ADC was computed and stored in a variable "AV" by the block of code;

AV = (ADC_Val_AN0 [0] +ADC_Val_AN0 [1] +ADC_Val_AN0 [2])/3;

The average value was now reconverted to AC equivalent for the purposes of displaying on the LCD and on computer screens via MM232R. The following block of code implemented this;

AV = (unsigned char) (round ((AV*2)/41));

For the switching of the transformer taps, the computed and stored ADC value was passed through a conditional statement, evaluated and execution of the tap switching was effected as shown in the program flow chart. A full listing of the code was included in **Error! Reference source not found.**.

4. Software Results

Results presented in this section were obtained from the use of software; MATLAB, Proteus ISIS, Proteus ARES and MPLAB. The results were obtained from simulation of components used in the implementation.

4.1 Modelling and Simulation (MATLAB)

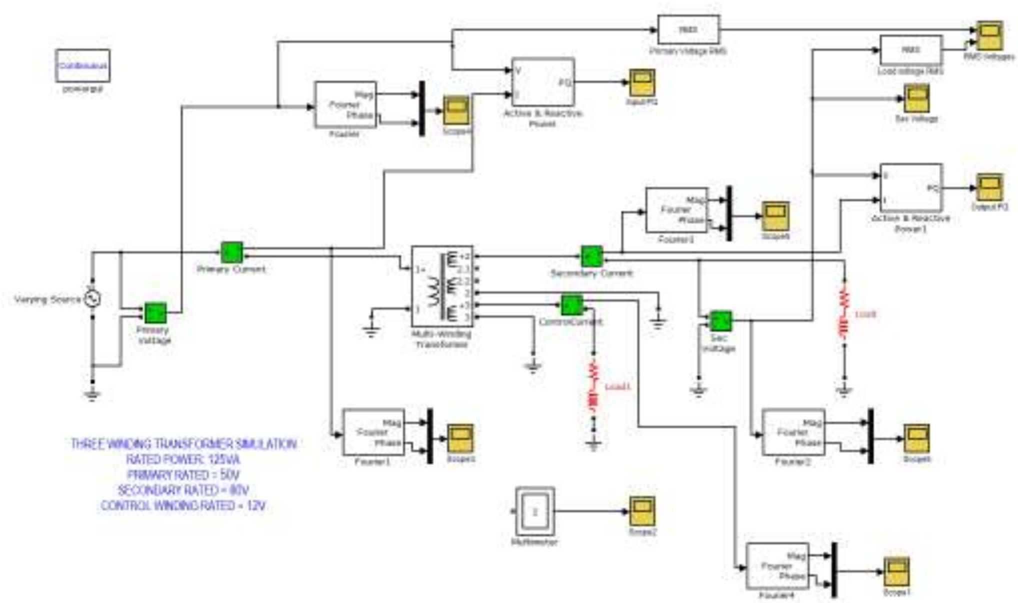

Figure 3. Model of the transformer in an ideal three winding form

The transformer model was used in the studying of the transformer's voltages and currents. The parameters considered in the model were the primary voltage and current, secondary voltage and current as well as the magnetizing current by short circuit and open circuit tests.

4.2 Proteus ISIS Simulation Results

Due to the complex nature of the control circuitry and limitation in transformer design in ISIS, the control circuit was designed and simulated to an approximate level as possible.

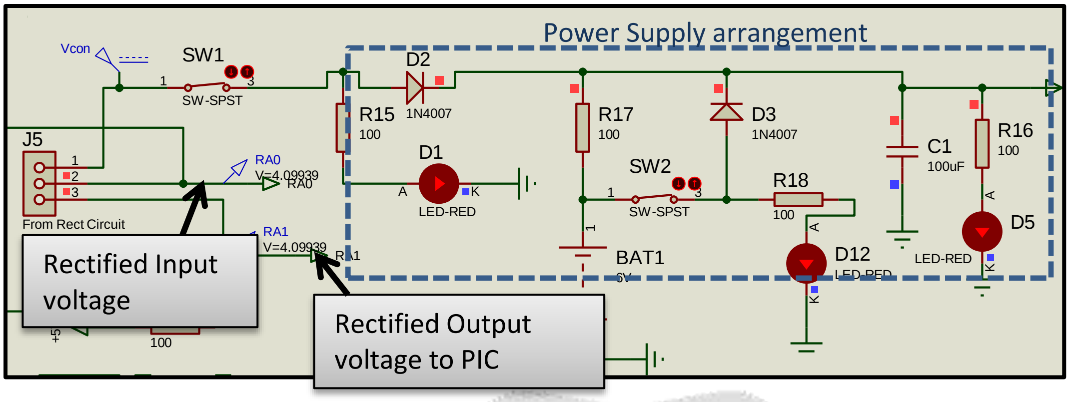

Figure 4 Power and Input Signals from the Rectification PCB

The result shown above was obtained for the simulation of the alternative power supply arrangement. The arrangement worked as expected. The simulation results for the control circuit and switching circuits were obtained and it gave expected results. The results are shown in Figure 5 and Figure 6.

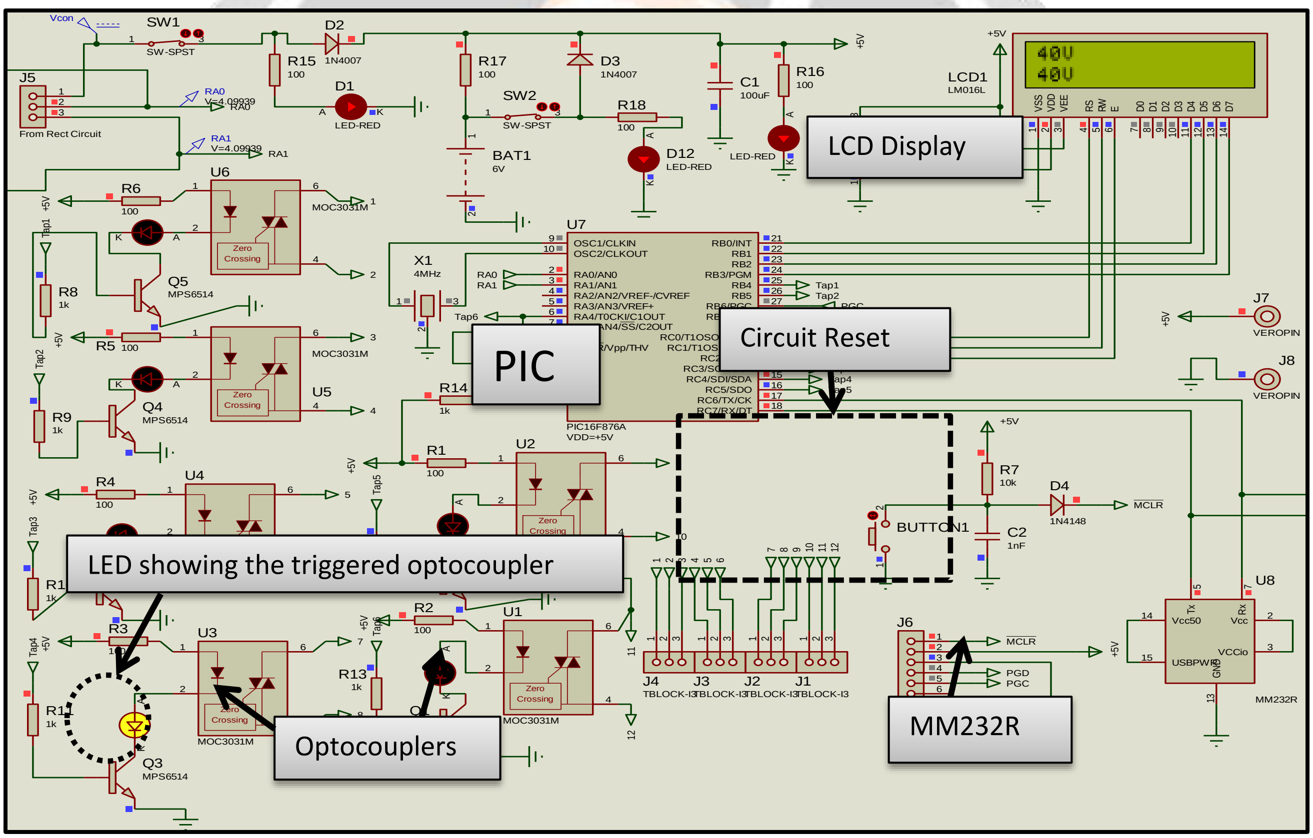

Figure 5. Screenshot of System simulation showing selected tap switching signal at specified input voltage

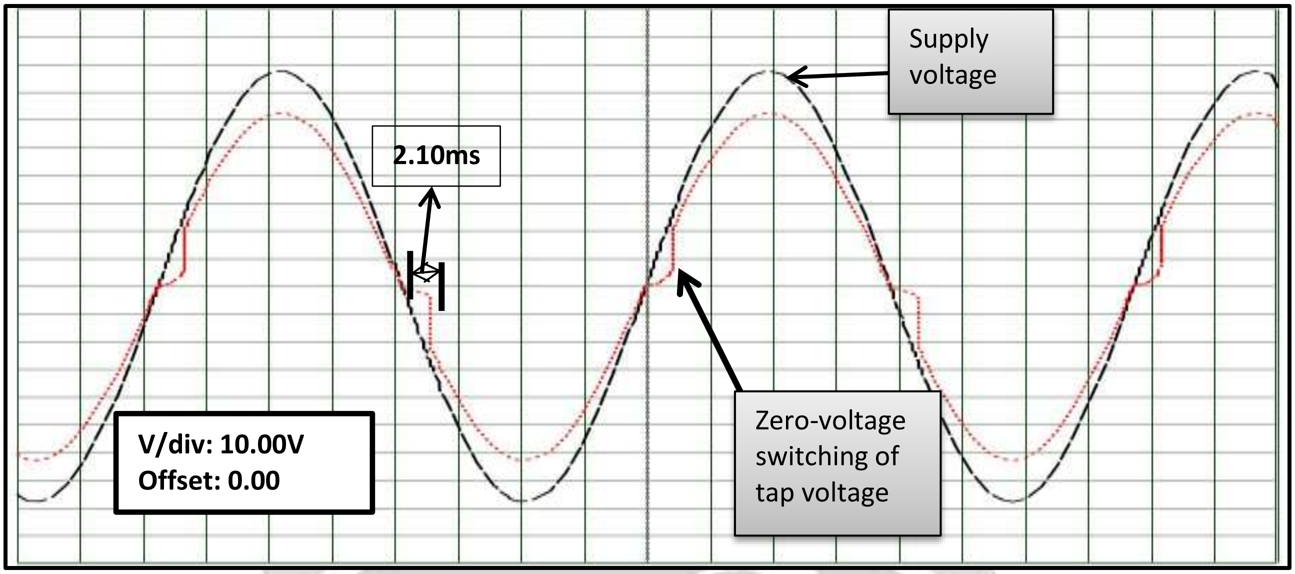

Figure Error! No text of specified style in document.**.** DSO capture of input and output voltage after TRIAC switching with a switching time of 2.10ms

4.3 MATLAB

Open Circuit Test

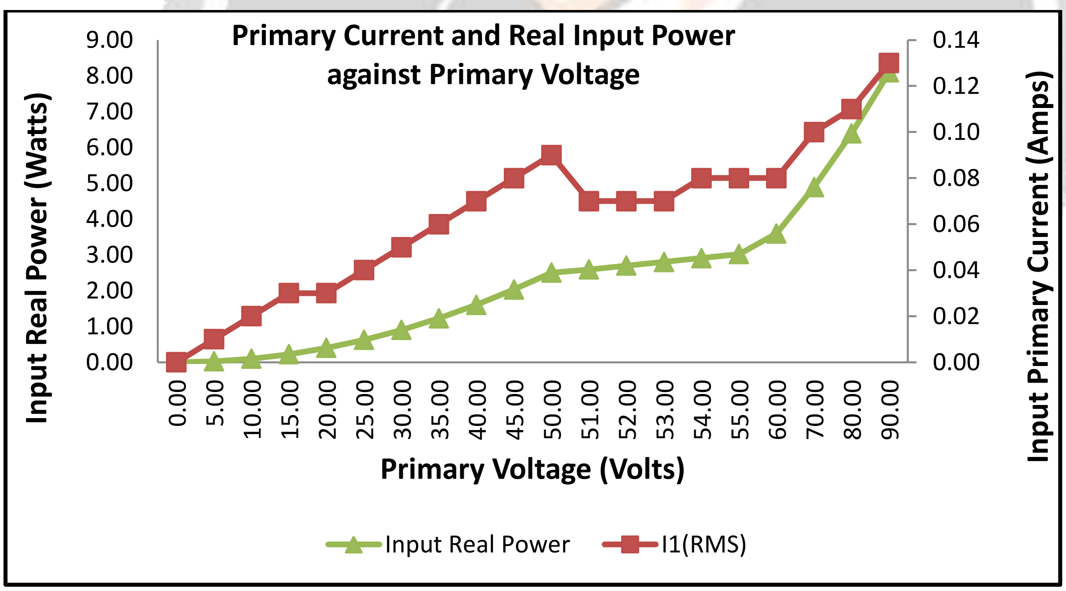

Figure 7 Open Circuit Test results

Short Circuit

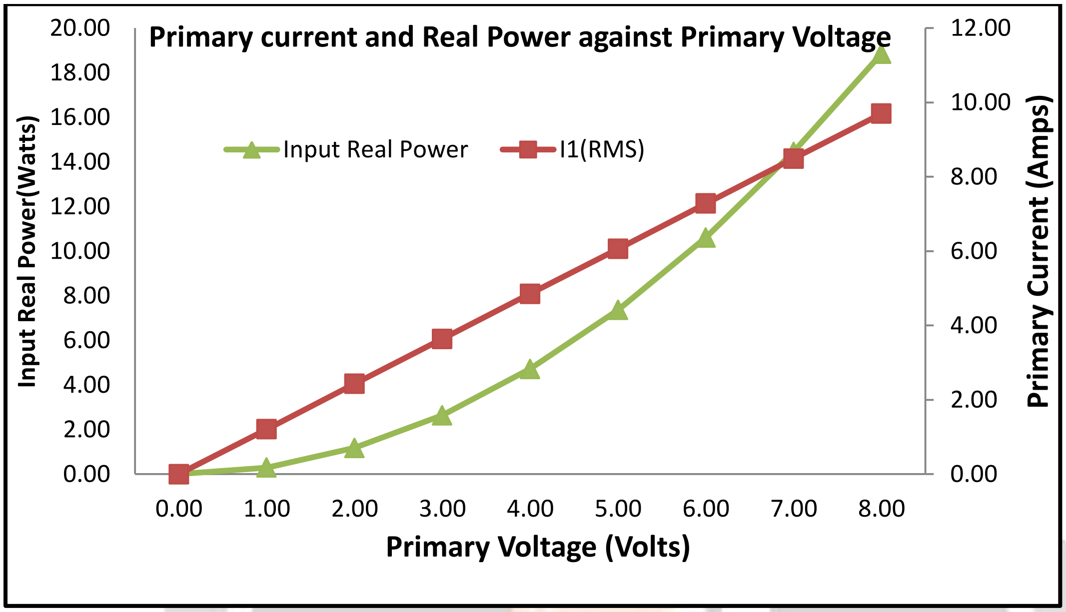

Figure 8 Short Circuit Test results

4. Conclusion

In this report, the design and implementation as well as the benefits of the voltage optimization device have been presented. Key design features included the use of a PIC microcontroller and power triacs for the effective control and switching of the device respectively. The major design principle behind the use of the microcontroller was the ease to effect changes to the device by reprogramming as compared to expensive approach of changing many individual components. Important design features of the voltage optimizer were speed, selectivity and lower cost in modification. The benefits of the device was calculated and found to be of sound economic and environmental significance. Protection of electrical loads was also achieved by the interruption of supply in the presence of excessive voltage or under voltage conditions.

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