Development of an Undervoltage and Overvoltage Device Using Programmable Interface Controller (PIC)

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Abstract—Fluctuations and irregularities in power supply over the years has become a worrying phenomenon whose effects pose risks not just to industrial consumers but also to domestic consumers. Due to the fluctuations in the ac-mains supply to electricity consumers, there are chances of voltage over-hikes and under-voltage. Protection system is necessary in both industrial and residential power consumption, there are some shortcomings on previous project such as unreliable time delay, voltage readout assumptions in the output and narrow voltage window. However, this propose protection system is precise in output, wide voltage window and switches within microseconds. This protection system uses programmable interface controller (PIC 16F877A), which mirrors the mains supply voltage and provide a means of controlling the applied load. the switching operation is achieved by using a transistor and electromechanical relay. The system was realized using fewer components and reduced power consumption, thereby making it less expensive. However, the project is limited to domestic use only and the voltage window is between 150-240V. Some components can be added for commercial or industrial use and likewise to increase the voltage window.

Keywords—Over-voltage, Undervoltage Programmable Interface Controller (PIC)

I. INTRODUCTION

For safety purpose, all electrical and electronics devices, must be powered at prescribed voltage limits. Voltage fluctuations in electrical power supply certainly have adverse effects on connected loads. These fluctuations can be of under-voltage and overvoltage which can be caused by voltage surge, lightning overload and so on. Under-voltage causes overloading of the equipment leading to lamp flickers and inefficient performance. Similarly, overvoltage are the voltages that exceeds the normal or rated values which causes insulation damage to electrical appliance leading to short circuit. Electrical power system protection is required for both user and the system equipment itself from faults, hence system must not be operated without installed protection devices. Fault is defined as undesirable conditions that occurs in the power system such as short circuit, current leakages, under-voltage and overvoltage [1]. Protection has become more important today. The ability of protection system is demanded not only for economic reason but also customer just expect reliable service [3]. When the voltage in circuit or part of it is raised above its upper design limit, this is known as overvoltage. The conditions maybe hazardous, depending on its duration. The overvoltage event can be transient, a voltage spike, or permanent, leading to a power surge. This could be caused by lightning strike or switching operations of inductive or capacitive loads. Overvoltage can also occur due to single line to ground fault, which in turn will raise the voltage of the other phases. It can also be caused due to disconnection of heavy industrial loads or switching on the capacitor banks [1]. the load drawing more current from the supply and in turn may cause damage to the load. This Under-voltage is a term which describes a drop in voltage in a circuit or part of it this leads to could be caused by opening and closing of circuit breaker at substations, transformer energizing, bad weather (lightning strike leading to line ground fault), and equipment failure [1]. Overvoltage and under-voltage protection are essential so as to improve power quality supplied to electric power users and this can be realized in a number of ways which include the use of programmable interface controllers (PIC). Electronic or electrical equipment is dependent on power to operate. While voltage and current bring life to a circuit and also cause harm. Therefore, the common sources of failure are when the equipment exceed or below its rated working voltage. The common example of an over-voltage is lightning. Lightning strikes and other similar type of transient over-voltages are often referred to as surges. Transient over-voltages have a short duration of a few microseconds after which they disappear [2]. Surge appear when large amounts of energy are released in a system. This may be due to the switching of capacitive and inductive elements, connection or disconnection of power-lines and general switching in and out of other circuit elements. Furthermore, poorly designed supply and distribution grids can increase the susceptibility to disturbances. Transient over-voltages can enter the equipment from the outside through power lines and other mediums. However, they may also arise from inside. Example is the operation of electric motors as they are inductive elements. Moreover, sudden decrease in load conditions where more energy is supplied than is needed could cause an overvoltage [2]. Large enough transients may damage or immediately destroy equipment or shorten the lifetime of the equipment. Likewise, under-voltage is caused due to overloading of equipment leading to inefficient performance of the equipment. A voltage which is below the optimum operational or rated value of a component, circuit or device is called an under-voltage. When there is a sudden drop in the root mean square (r.m.s) voltage and is usually characterized by remaining or retained voltage, it is said to be under-voltage. Thus, it is a short duration reduction in r.m.s voltage, caused mainly by short circuit, starting of large motors and equipment failure.it also occurs in electrical circuit due to load switched or on and power factor correction capacitors switched off, likewise poor system voltage regulation results in the undesirable effect called under-voltage [3]. Voltage irregularities are one of the greatest power qualities facing industry and homes today and often times, is responsible for damaging valuable electrical equipment. Electrical power system protection is required for protection of both user and the system equipment from fault, hence electrical appliances are not allowed to operate without any protective device.

A. *Causes of Over-voltage*

Overvoltage are caused in power systems due to external and internal factors. The voltage stress caused by overvoltage can damage the lines and equipment connected to the system. Overvoltage arising in a system can be generally classified into two main categories: External overvoltage is type of overvoltage which originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes: Direct lightning stroke, electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke', voltages induced due to atmospheric changes along the length of the line, electrostatically induced voltages due to presence of charged clouds nearby and electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change on the altitude of the line. [4]

Internal over voltages, these over voltages are caused by changes in operating condition of the power system. These can be divided into two groups as: Switching over voltages or transient over operation voltages of high frequency. This is caused when switching operations is carried out under normal conditions or when fault occurs in the network. Likewise, when a side of a transformers or reactors is switched on, over voltages of transient nature occurs [4, 16]. Temporary over voltages are caused when some major loads get disconnected from the long line under normal or steady sate conditions.

B. *Effects of over voltages on power systems*

Over voltage tends to stress the insolation of the electrical equipment and probable to caused harm to them when it occurs. Over voltage caused surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/liquid insolation, failure of transformer and rotating machines [4, 18]. The quantity of the exhausted power by a load depends not only on the magnitude and nature of the load, but also on the voltage useful to the load. Precisely, in engineering terms, power is the rate of energy distribution and is proportional to the product of the voltage and current.

$$P = v(t) \times i(t) \quad (1)$$

The effects on power consumption that are caused by the over-voltages, today, are a key problem for study and resolution [1]. Essentially, their undesirable effects include a variety of negative consequences, mostly to the economy and the life duration of the loads or equipment. There are always a chance of suffering an electrical power system from irregular over voltages. These irregular over voltages may be caused due to various reason such as, sudden lightening impulses, switching impulses, interruption of heavy load, etc. These over voltage strains may damage insulation of various equipment and insulators of the power system. Although, all the over voltage strains are not robust enough to damage insulation of system, but still these over voltages also to be evaded to safeguard the smooth operation of electrical power system.

C. *Causes of under-voltage*

Some of the various causes of under-voltage in a system are as follows:

Closing and opening of circuit breakers: When the circuit breaker of a phase is opened suddenly, the line in which it is feeding will be temporarily disconnected. The other feeder lines from the same substation system will act as an under-voltage. Under-voltage due to fault can be critical to the operation of power plant. The magnitude of under voltage can be equal in each phase or on equal respectively and it depends on the nature of the fault, whether it is symmetrical or unsymmetrical [3,19, 22]. They are mainly two causes of under voltage due transformer energizing. One is normal system operations which include manual energizing of transformer and another is reclosing actions. This under voltages are unsymmetrical in nature [3, 11]. Equipment Failure: Failure of electrical equipment occurs due to insolation breakdown or heating or short circuit etc. Bad weather: Lighting strike in the power line cause a significant number of under voltages. A line to ground fault occurs when lightning strikes the line and continues to the ground.

D. Effects of under-voltages on power systems

Under-voltage causes several problems with the equipment that required steady voltage, particularly existing load, so it results in malfunction, miss-operation and in some times full operation stoppage [4]. Under voltages are the most common power disturbance whose effect is quite severe specifically in industrial and large commercial customers such as the damage of the sensitivity equipment's and loss of daily productions and finances[5, 11,19]. The examples of the sensitive equipment's are Programmable Logic Controller (PLC), Adjustable Speed Drive (ASD) and Chiller control. Under voltage at the equipment terminal can be due to a short circuit fault hundreds of kilometers away in the transmission system. n under voltage is a decrease in the RMS value ac voltage to less than 90 percent or 0.90pu at the power frequency for a time period longer than 1 min. Under voltages are the result of switching events that are the opposite of the events that cause over voltage.

II. Review of Related Works

In this section, a review of related works and their shortcomings are briefly presented. An automatic changeover system with a high and low voltage detector ranging from 180- 240V was presented in [6]. However, the voltage range was not as wide as that of the proposed project which is 150-240V. the wider the voltage ranges the better.

[10] implemented an overvoltage and under-voltage protection system, which has a prolonged time delay. It has a fixed time limit, the time delay is too long, since it has largely fixed time limit to the extent of disconnecting from the appliance if there is high or low fluctuation.

[21] designed an overvoltage and under-voltage protection system for domestic load using comparator. The major drawback is that comparator normally changes its output state when the voltage between its inputs crosses through approximately zero volt. Small voltage fluctuations due to noise always present on the inputs. This can cause undesirable rapid changes between the two output states when the input voltage difference is near zero volts.

[22] presented a low-cost under-voltage and overcurrent protection device using a micro controller. The main purpose of the device is to isolate the load from overvoltage and under-voltage conditions by controlling the relay tripping coil using micro controller. The microcontroller compares the supply voltage with the desired pre-set voltage and operates the tripping coil in the relay if the input voltage falls below or above the pre-set range of values. The type of programmer used for the microcontroller was a USB programmer, while the programming code used was compiler CCS. The programming of the microcontroller was done by first writing the program code in C+, after which it was compiled using the CCS complier, it is easy to repair and maintain and is economical. However, the pre-set was at the voltage range of 200-240V.

[3] presented fault detection and load protection with sensors which protects the devices from under-voltage and overvoltage faults. The sensors detect the faults and cut the supply from the supply mains. According to the authors, the ability of protection system is demanded not only for economic reason but also for expert and reliable service. However, it has not been adopted and adapted to protect overvoltage and under-voltage using programmable interface controller.

III. Methodology

This project utilizes the principle of voltage sensor and control. It converts the high voltage mains supply to a type and range with which the microcontroller can access through its input terminal, processes it and gives output at its output terminal. It uses the PIC16F877A microcontroller (from microchip) to control the activities of the various stages and design circuitry involved. The Project has been preset to create a voltage window whose low and high thresholds are set at 150 and 240 V. The microcontroller scans the mains voltage and sends out a digital high output to the peripheral switching circuit. This closes the switch and allows the mains input voltage to be passed to the output thereby powering the connected loads.

For extremely low (< 150V) and high voltages(>240V) the microcontroller sends out a digital low output signals which de-energizes the relay, and disconnects utilities. This prevents the connected loads from getting damaged as a result of the bad mains voltage. It encompasses ensuring that the objective and requirements of the device, equipment and facility are right. The main challenge is to design an electronic circuit that allows all voltage level to be passed except the ones less than 150 V and greater than 240 V.

IV. Principle of Operation

The principle of operation of the proposed device can be explained using the block diagram shown in Figure 1.

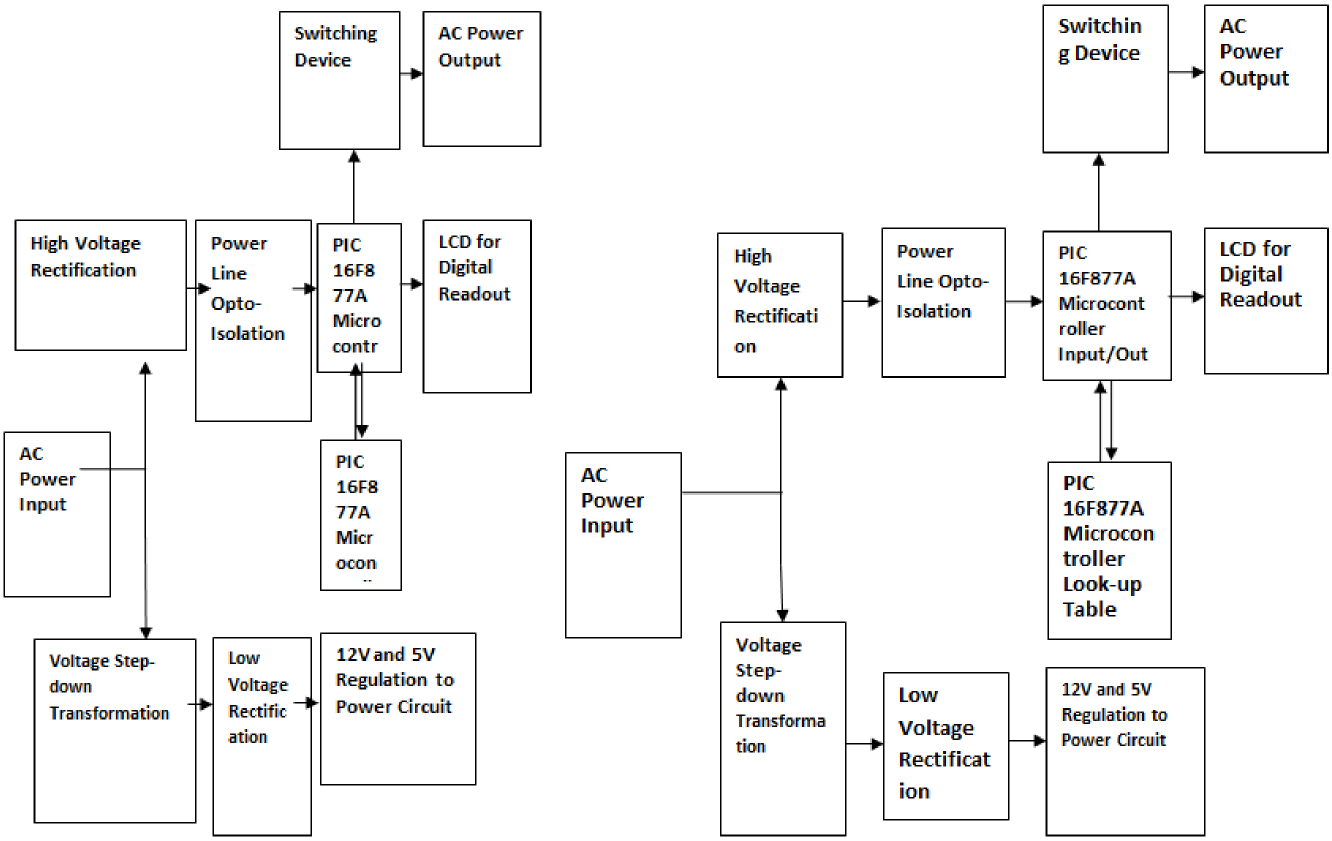

Figure 1: Block Diagram of Microcontroller Based Over/Under Voltage Control.

The whole system is basically made up of three units namely;
Power supply unit.
Programmable Microcontroller interface unit.
The switching and the relay driver unit.

A. Power system unit

The 220V from the mains is stepped down into 12V AC at the secondary side of the transformer. This is the source of power for both the microcontroller and the peripheral circuitry as well the connected load. It is therefore of uttermost important quantity without which this project is useless. However, this AC input may have abnormal values which can pose threat and danger to the connected loads. The expected AC input voltage range between 150 and 240 V. The power supply unit must be able to achieve the following:

1. Supply each component part with the required voltage.
2. Account for all voltage drops in the system.
3. Deliver voltage at the required current rating of the device/ components.

B. Design calculations

Calculation of the transformer output voltage;
Transformer T is a 230/12V, 500mA step down transformer, and the maximum value of the transformer secondary is given by;

V (The maximum value of the transformer's secondary) is:-

$$V_s = \sqrt{2} \times V_{rms1} \quad (2)$$

Where, V_{rms1} = 12V (the transformer secondary voltage)

$$V_s = \sqrt{2}\, x\, 12 \quad (3)$$
$$V_s = 16.97\, V \quad (4)$$

The maximum output of the rectifier is calculated using the formula,

$$V_{s2} = V_s - 2V_D \quad (5)$$

Where, V_{s2} is the maximum output voltage of the rectifier, and is the voltage drop across the diode (0.7V for a silicon diode)

Therefore;

$$V_{s2} = 16.97 - (2 \times 0.7) \quad (6)$$
$$V_{s2} = 16.97 - (2 \times 0.7) \quad (7)$$
$$V_{s2} = 15.57\ V \quad (8)$$

Where V_{rms2} (The rms value of the output voltage of the rectifier) is:-

$$V_{rms2} = \frac{Vs2}{\sqrt{2}} \quad (9)$$
$$V_{rms2} = \frac{15.57}{\sqrt{2}} = 11.01\ V \quad (10)$$

Calculation of the ripple factor and the filter capacitance

The ripple factor is given by the formula:

$$\text{Ripple factor (r)} = \frac{rms\ value\ of\ a.c}{rms\ value\ of\ d.c} = \frac{Va.c}{Vd.c} \quad (11)$$

But V_{dc} which is the mean value of the rectifier's output voltage is given by the formula;

$V_{dc} = \frac{2Vs2}{\pi}$ [11] (12)

Recall from (8), Vs2 = 15.57 V,

Therefore,

$V_{dc} = \frac{2 \, x \, 15.57 \, x \, 7}{22}$

$V_{dc} = \frac{217.98}{22}$

V_{dc} = 9.91 V

V_{ac} is calculated using the formula;

$V_{ac} = \sqrt{(V_{rms2}^2 - Vdc^2)}$ (13)

From (10), V_{rms2} = 11.01V,

$V_{ac} = \sqrt{121.22 - 98.21}$

$V_{ac} = \sqrt{23.01}$

V_{ac} = 4.80 V

Therefore, the ripple factor can be calculated as follows,

$r = \frac{Vac}{Vdc}$ (14)

$r = \frac{4.80}{9.91}$

r = 0.48

Also, determining the rectifier output current

The mean value of the rectifier's output current

$I_{dc} = \frac{2Im}{\pi}$ (15)

I_{rms} = 500mA

$I_m = \sqrt{2} \times Irms$ (16)

$I_m = \sqrt{2} \, x \, 500$

I_m = 707mA

$I_{dc} = \frac{2 \, x \, 707 \, x \, 7}{22}$

I_{dc} = 449.91mA

The value of the filtering capacitance C_6 is obtained from [11]

$r = \frac{I_{dc}}{4\sqrt{3}FC_6Vs}$ (17)

Where, r =ripple factor,

$C_6 = \frac{I_{dc}}{4\sqrt{3}FrV_s}$ (18)

Substituting the values of F, Vs, I_{dc}, and r in equation (18); where F=50Hz, V = 16.97 V, r = 0.48 and I_{dc} = 449.91mA, then

Therefore;

$$C_6 = \frac{0.449}{4 \, x \, \sqrt{3x50x0.48x16.97}}$$

$$C_6 = \frac{0.449}{2821.64}$$

$$C_6 = 0.000159\text{F}$$

$$C_6 = 159\mu\text{F}$$

A capacitor of 470µf was chosen due to market availability and because it still functions to smoothen the rectified output of the transformer.

Other capacitors = 0.1µf, the value was chosen because they will be used as a by-pass filter used to eliminate frequency noise generated by the load which also follow the microcontroller design.

Using the IN 4001 diode (specification sheet);

The bias voltage is 0.7V

The maximum voltage is 50V

The max current is 1A

The bias voltage for D1 = D2 = 0.7V

The maximum voltage for D1 = D4 = 50V

The maximum current for D1 = D4 = 1A

The circuit diagram for under/over voltage switch is shown in the Figure 2.

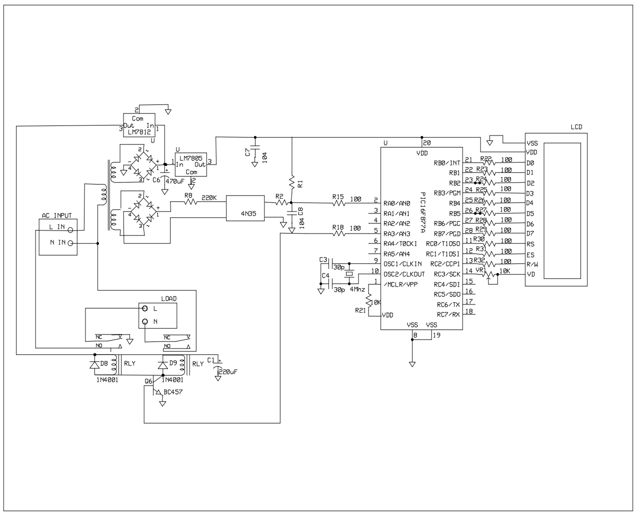

Figure. 2: Circuit diagram for Under/Over voltage switch

C. High voltage Opto-Isolation

AC voltage from the mains has some characteristics that do not match the operating environment of the microcontroller. There is therefore a need to remove or avoid this strange and dangerous inherent environmental conditions of the mains from affecting the quiescent operating environment of the microcontroller. The properties of the mains include line noise, frequency compromise, ac voltage, and high voltage spike among others. This property must be changed to a low dc voltage and must have immunity against noise and impurity bypass.

To effect these changes, the high voltage ac supply needs to be rectified to high voltage dc voltage using 1N4007 (D5-D7) which can handle up to 700 ac voltage without breaking down. A voltage dropper and current limiting 220kΩ resistor R8 is used in series with the four-bridge rectifier (D5-D8). It is then passed to the opto-isolator which removes noise and prevents other dangerous quantities from passage to the microcontroller.

D. Signal Conditioner

Since the output from the filter cannot be passed to the digital input of the Microcontroller directly, a signal conditioner is used. The purpose of the signal conditioner is to change the un-damped analog signal at the output of the filter to a digital form as near as possible.

The test switch is however used to test whether the circuit would respond in the event of serious errors.

E. Programmable interface controller

The heart of this project is the PIC16F877A, a 40-pin microcontroller. The sampling rate of the microcontroller depends largely on the speed or otherwise the frequency of the crystal oscillator used.

For this project a 4MHz crystal oscillator was used thus enabling the microcontroller to be pre-scaled to (1/ (4000000)4) *4)10 microseconds. It receives dc signal from the output of the opto-coupler, processes it, generates a binary code for it and compares it with the binary code that has been programmed and stored inside the look-up table. It uses these two signals/ codes to reproduce the mains input ac voltage which is then sent to be displayed on the LCD. It monitors the voltage reading, making sure that any voltage outside the voltage window of 150 and 240 V is flagged by sending a low voltage output through its RA3 digital output pin which goes to the base of the transistor BC457 controlling the triggering of the relay. The assembly code used in programming this microcontroller can be found in the appendix and can work seamlessly with any compiler.

F. *Relay Switching*

The action of this switching device allows or disallow the passage of input mains voltage to the output and connected loads in response to the triggering pulse received from the microcontroller PIC16F877A through the switching transistor BC548. If the signal from the microcontroller is high, it is sufficient enough to send a triggering pulse to saturate the transistor which in turn sends a triggering pulse to the relay and consequently switches it ON allowing power to be transferred to the connected loads. On the other hand, a low digital signal from the microcontroller causes the transistor T1 to operate at the cut off mode with no triggering pulse to the relay hence the relay switches/remains in OFF position, cutting off the transfer of power to the connected loads. D9 is a freewheeling diode. Its function is to prevent high inductive ‘voltage kick’ (which can amount to several hundreds of volts in a transient spike) from destroying the transistor, apart from this it also provides a smooth hysteresis loop for the relay coil. The capacitor C8 helps to filter out ripples during the switching action of the transistor and improves the transient response of the circuit.

G. *LCD Readout*

This concept of feedback is important as it ensures system stability. The Liquid Crystal Display (LCD) provides useful feedback to the user on the (internal) activities of the microcontroller vis-à-vis the prevailing voltage trend of the input voltage and the status of the connected load, whether they are receiving power or not as a result of extremely low or high mains input voltage. It provides the user with all the information needed per time.

V. CONSTRUCTION

All components shown in the circuit diagram were purchased locally and the necessary tools required for the construction of the project were purchased locally. During pre-soldering assembly and testing stage, the circuit diagram was simulated to determine the effectiveness of the circuit. The circuit was then assembled on a Breadboard to determine the performance of the design.

After the assembly of components on a Breadboard, the entire circuit components were transferred to the Vero board and proper soldering was carried out. All connections were properly and neatly soldered so as to ensure that soldering joints are electrically continuous and firm. The following precautions were taken in the process:

1.The soldering bit was tinned before soldering.

2.The soldering iron was carefully applied to the soldered joint to prevent overheating.

3.Excess application of soldering lead was avoided so as to prevent gating of the component next to each other.

The photograph of prototype of a breadboard is shown in Figure 3.

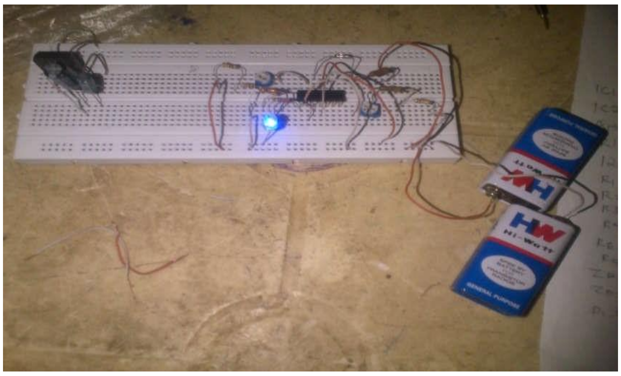

Figure 3: Photograph of prototype of a breadboard

The response from the breadboard implementation has satisfy the desired output, the implementation on the Veroboard is carried out. Figure 4 and 5 shows the process at which the component is soldered on the Veroboard.

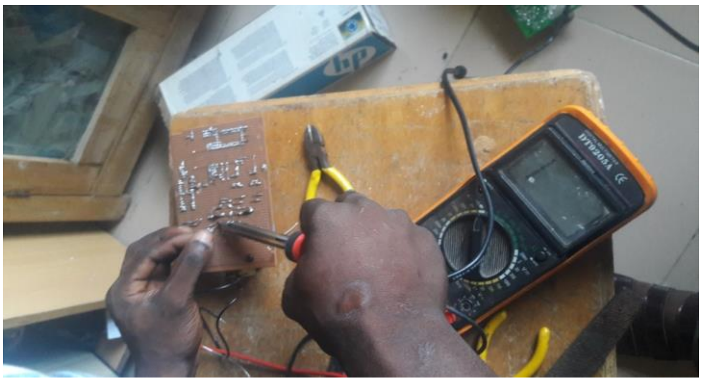

Figure 4: Photograph of prototype soldered on a Veroboard

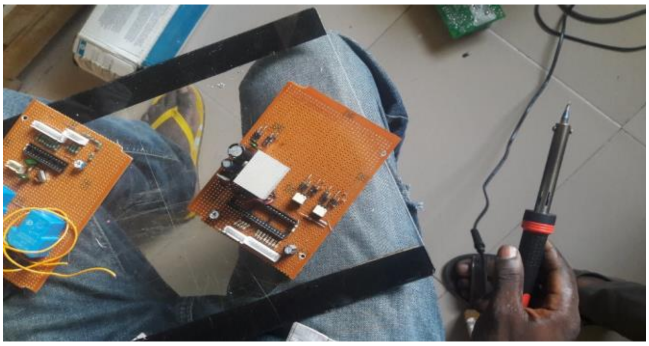

Figure 5: Photograph of the circuit components

VI. Casing

After all the components were tested and the faulty ones replaced, then the entire circuit was housed in a plastic material. Plastic was chosen for the casing because of its light weight and also has a high resistance to corrosion which makes it a better alternative compared to materials like metal. The cost and availability of the plastic material can also be seen as others reason for choosing a plastic material. The casing used is shown in Figure 6.

Figure 6: Casing

VII. Testing

The circuit was tested by connecting the input of the circuit through a variac (regulating transformer) to the mains power supply. The variac was then used to vary the power supplied to the circuit within the scope of the project (150V-240V). The output of the circuit is connected through a relay whose connection is done through the normally open (NO), to a lamp which is used as the demonstrative load. When the voltage goes below 150V, the relays trips and is normally closed (NC), thereby disconnecting the load, this is the under-voltage protection. Also, when the supply goes above 240V the relay also trips and is normally open also disconnecting the load, this is the overvoltage protection. During both conditions, the LCD comes on indicating that there is an abnormal supply from the mains.

The tripping time for disconnecting the load is given by:

$$T = \frac{1}{F} \qquad (19)$$

Where F =50Hz, the supply frequency

Hence, T =20mS

VIII. Results

At the end of the careful integration of the developed components, the result is an under-voltage and overvoltage protection device with a function the enables consumers to use unstable power supply effectively without damaging the loads.

After implementation of the circuit and casing the device was turned on and it was able to switch on and off the loads connected to it. The switching was fully operative within the above specified period. Variable transformer was connected at the input side of the device and loads were connected to the output to affirm its effectiveness. Also the values of voltage of the corresponding input were display on LCD as the output. The following readings were taken at intervals as shown in Table 1.

S/N	Nominal voltage (v)	Variac voltage (v)	LCD readout voltage (v)
1	230	241	Error (since the voltage value is above the designed voltage window)
2	230	239	Fit to use
3	230	150	Fit to use
4	230	148	Error (since the voltage value is below the designed voltage window)

The test above and the result demonstrate that the circuit achieved its design aim and purpose. The system worked according to specification and quite satisfactorily.

Figure 6 and 7 show photographs of the protective device when connected to the mains and when load is connected respectively.

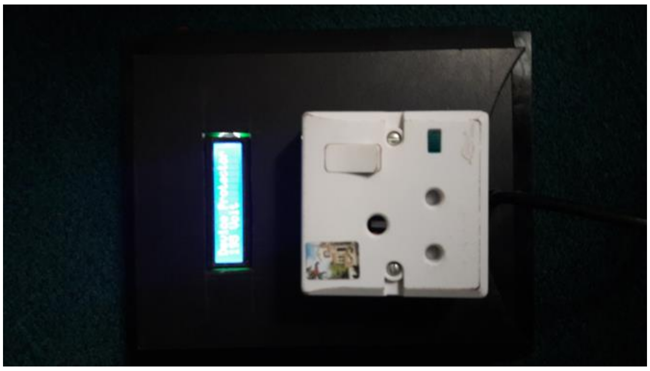

Figure 7: Photograph of the protective device when connected to the mains

Figure 8: Photograph of the protective device when load is connected.

IX. CONCLUSION

In this work, the causes and impacts of undervoltage and overvoltage in electrical appliances were discussed. This paper described the design, testing, and implementation of a PIC-based over/undervoltage safety system for electrical appliances. It will be a handy and dependable gadget for improving the quality of power supply to household appliances while also ensuring their safety.

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