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Development of a Low Cost Microcontroller Based Under and Over Voltage Protection Device

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Abstract— This paper presents the design and construction of a low cost under and over voltage protective device, which was fabricated using a microcontroller, transistor, IC and other discrete components. A microcontroller PIC16F877 is at the heart of the device which performs the major control of the device. The device is simple and of low cost. It can withstand loads up to 2KVA and the required set voltage range for the device to allow supply to the connected load at the output varies from 200 – 240 Volts. It can be used to protect loads such as refrigerator, T.V., VCR/DVD players etc. from undesirable over and under voltages, as well as surges caused due to sudden failure/resumption of mains power supply. This device can be used directly as a standalone equipment between the mains supply and the load, or it may be inserted between an existing automatic/manual stabilizer and the load. The over/under voltage cut-off with time delay provides over/under-voltage protection, and protection against transients.

Keywords— microcontroller, over voltage, under voltage, protection.

I. Introduction

Voltage irregularities are one of the greatest power quality issues facing industry and home 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 installed. Power System fault is defined as undesirable condition that occurs in the power system, and the undesirable conditions are short circuit, current leakage, ground short, over current, under and over voltage. The ability of protection system is demanded not only for economic reason but for expert and reliable service (Bayindar *et al*., 2008).

Technically speaking, an over/under voltage condition is reached when the voltage exceeds/lags the nominal voltage by 10% for more than 1 minute. Short duration voltage events can also occur such as transients (both impulsive and oscillatory), sags/dips and swells. Short duration intermittent supply failures can last anywhere from 0.5 cycles up to 1 minute and can be caused by a number of occurrences such as supply system faults, equipment failures, or malfunctions in control equipment. Under-voltage might result into brownout, distortion or permanent damage while overvoltage in the form of spikes and surges could cause distortion, burn-out, melt-down, fire, electro-pulsing and permanent damage.

Owing to the incessant damages done by fluctuations in the power supply, there is dire need to address the problem through other alternatives, which give birth to design and construction of an equipment to protect the connected loads against under and over voltage supply. Under and over voltage protection is needed between supply terminal and the appliances (connected loads).

II. Materials and Methods

The main purpose of the device is to isolate the load from over voltage and under voltage conditions by controlling the relay tripping coil using a PIC micro controller. The microcontroller will compare the supply voltage with the desired pre-set voltage and will operate the tripping coil in the relay if the input voltage falls below or above the pre-set range of values. The under voltage and the over voltage protective device is shown in block diagram in Figure 1.

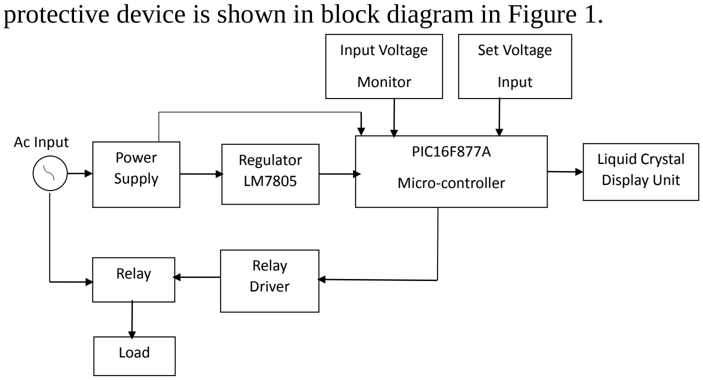

Figure 1: Functional Block Diagram of the Under and Over Voltage Protective Device.

A. *Brief Explanation of Each Block*

(1) AC Input: This is the input supply from the public utility where the device will be energized. It is also supplied directly

to the relay contacts in the device which connects the load to the supply when the supply is within 200V – 240V range.

(2) Power Supply: The power supply uses a step down transformer to step down the input mains voltage to a voltage level suitable for the electronics within the device. A centre tapped transformer, with two diodes for full wave rectification is used to convert the ac voltage to a pulsating dc voltage followed by a filter, comprising of a capacitor to filter out (smooth) the pulsation (Close and Yarwood, 1979; Maddock and Calcuta, 1994; Ian, 2000).

After the rectification and smoothening, a sample of the output voltage is fed to the microcontroller through a potentiometer. This voltage is unregulated and therefore varies as the input mains voltage varies. The output voltage is also passed to an LM7805 positive voltage regulator to provide a regulated +5V supply for the micro-controller. The regulator served to reduce further the ripple and noise in the regulated supply to the microcontroller. The regulator also provides current limiting and protects the power supply and attached circuit from over current (Paul and Winfield, 1989; Delton, 1989). Since the system is to prevent against over and under voltage, the transformer was designed and the windings were so selected for the device to be able to sense and withstand input mains voltage up to 600Vac.

(3) PIC 16F877A Micro-Controller: The PIC16F877A microcontroller, performs the major functions of decision and control. The input voltage monitor is connected to the micro-controller which provides a sample of the input supply voltage to the microcontroller for comparison with the programmed set values in the microcontroller. The PIC16F877A microcontroller was used in the design in order to reduce the complexity of the design and to ensure an easy interface with a liquid crystal display.

(4) Input Voltage Monitor: This provides a sample of the unregulated dc supply voltage through a potentiometer to feed the microcontroller. It helps the microcontroller to monitor the supply voltage, as the value of this voltage varies as the input mains voltage varies. The unregulated dc supply voltage is scaled down by the potentiometer to values suitable for the micro-controller. Input mains voltage up to 600Vac can be monitored.

(5) Liquid Crystal Display (LCD): This displays the supply voltage as well as some information at 'switch on' or when the supply voltage is out of range of the desired pre-set range of values. The LCD used is LM016L having a 2 x 16 display. The picture of the LCD is shown in Figure 2.

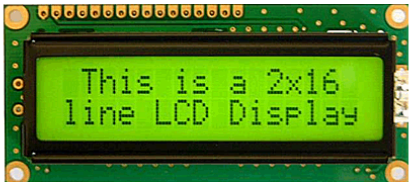

Figure 2: The LCD used.

6) Relay Driver: This is an NPN transistor that controls and supplies current through the coil of the relay that connects the mains supply to the load. The relay is a single pole relay which, upon being activated by the PIC via the transistor, makes under normal mains supply voltage and brakes under abnormal mains supply voltage.

B. Relay Driver Design Analysis

The relay driver circuit is shown in Figure 3. The relay driver uses NPN transistor BC547.

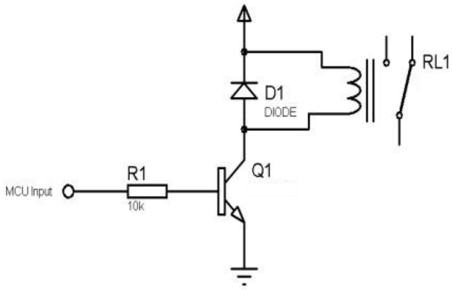

Figure 3: The Relay Driver Circuit.

The relay coil is connected between the positive rail and the collector of the transistor. When the input signal passes through the resistor R_1 to the base of the transistor Q_1, it conducts and activates the relay RL_1. Since a relay coil is not only an electromagnet but also an inductor (Gurevich and Vladimir, 2005), a flyback diode D_1 in parallel with a resistor is used to eliminate fly back, which is the sudden voltage spike seen across an inductive load when its supply voltage is suddenly reduced or removed. The diode also clamps the voltage across the coil to about 0.7V protecting the transistor and other associated components. The stored energy dissipates quickly in the diode and the resistor. The diode used is IN4007.

DC current gain of the transistor, β is expressed as (Maddock and Calcuta, 1994),

$$\beta = \frac{I_C}{I_B} \tag{1}$$

where I_C is the collector current (through the relay coil), and I_B is the base current.

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To calculate the value of the base resistor, the following were considered:
V_{IN} = 5V (from microcontroller), and the relay that is used has a coil resistance of 120Ω.
Therefore, the relay coil current = collector saturating current = I_{CSAT} = 12V/120Ω = 100mA.
Assuming β = 100 (for BC547),

$$I_B = \frac{I_{CSAT}}{\beta} \quad (2)$$

I_B = 100/100 =1mA.

The actual base current flowing, I_{BSAT} must be higher than the calculated base current I_B to ensure base saturation. The base resistor, R_1 must be able to provide this saturating base current.
Using a 1KΩ resistor would ensure that the transistor is fully "ON" when current passes out from the micro-controller 5V source, i.e.

$$I_{BSAT} = \frac{V_o - V_{BE}}{R_1} \quad (3)$$

$$= (5 – 0.7)/1x10^3$$
$$= 4.3\text{mA which is} >1\text{mA}.$$

C. Explanation of the Circuit Diagram

The circuit diagram of the developed device is shown in Figure 4. The circuit was designed, and its functionality was simulated using Proteus Software. The input mains supply is stepped down by the centre tapped transformer TR_1 to 12Vac at input mains voltage of 220Vac. TR_1 with diodes D_1 and D_3 provide centre tapped full wave rectification, which is smoothened by capacitor C_3. The unregulated dc output is fed to the positive fixed voltage regulator U_1 (LM7805) with regulated output voltage of +5V.

The PIC monitors the input voltage through a potentiometer RV_3 and toggle switch SW_1; set the input voltage range (as presented by RV_3) at which the relay will be energized; and activates the liquid crystal display LCD_1 which displays the input mains voltage level and other information as the case may be. The microcontroller sends signal to the relay driver Q_1 and thus energize the relay RL_1 thereby connecting the mains supply to the load. LED D_4 indicates when there is mains supply to the load. LED D_4 used is a high current and high reverse voltage LED. Diode D_5 helps to provide a dc current through the LED while resistor R_2 limits the current to a safe value for the LED. Diode D_5 used is 1N4007.

Switch SW_1 was incorporated to allow for manual test and calibration of the device. The manual test is to ascertain the functionality of the microcontroller after assembly and coupling of components. The calibration is to set the potentiometer for threshold tripping of the relay in accordance to the pre-set values in the microcontroller.

To protect the load from switching surges as well as from quick changeover (off and on) effect of over/under-voltage relay, in case the mains voltage starts fluctuating in the vicinity of under or over voltage pre-set points, an 'on-time' delay was programmed in the microcontroller. When the mains supply goes out of pre-set (over or under voltage) limits, the relay/load is turned off immediately and it is turned 'on' only when A.C. mains voltage settles within the pre-set limits for a period equal to the on-time delay period. The on-time delay period was made programmable for 500 milliseconds to 20 seconds duration. In the device, programmed on-time delay of 1 second was found satisfactory.

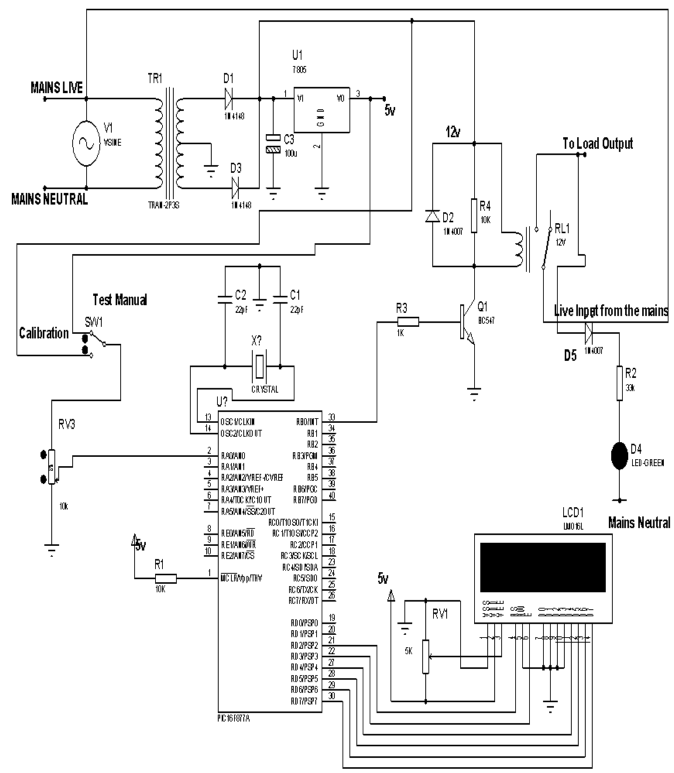


Figure 4: Circuit Diagram of the Microcontroller Based Under and Over Voltage Protective Device.

III. Construction and Testing

A. Construction

The design and the programming was simulated several times on Proteus software until the code for the design worked satisfactorily before the final programming of the microcontroller and assembly of the components (Martin, 2008). The microcontroller is shown in Figure 5(a); the type of programmer used for the microcontroller is a USB programmer shown in Figure 5(b), and the programming code used is 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 compiler; then later the hex file was burned to the PIC through the USB programmer.

(a)

(b)

Figure 5: (a) The PIC16F877A microcontroller, (b) The USB programmer that was used.

The circuit was first bread boarded for effective manipulation of the design, and was tested to ascertain satisfactory operation. The device was tested based on each stages of the design. The components were then assembled and soldered both on Vero board and PCB, and then placed in a plastic casing. The complete and populated circuit boards were assembled and coupled in the plastic casing together with accessories such as output and input terminals, potentiometer knobs, input power cable, toggle switch, liquid crystal display and output triggering indicator green light. Figure 6 shows the device under construction; Figure 7(a) shows the dimension of the casing, and Figure 7(b) shows the completed device.

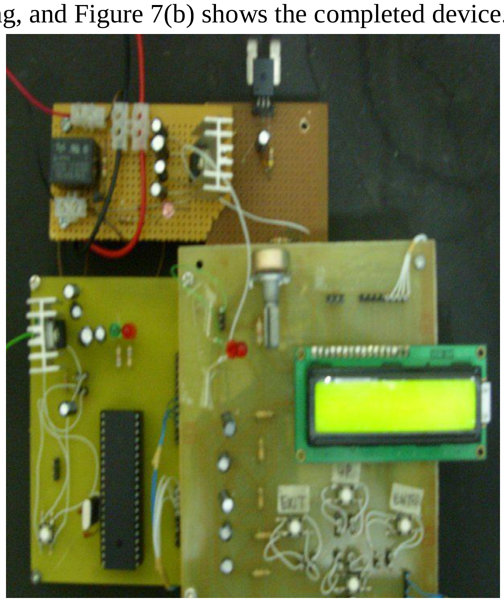
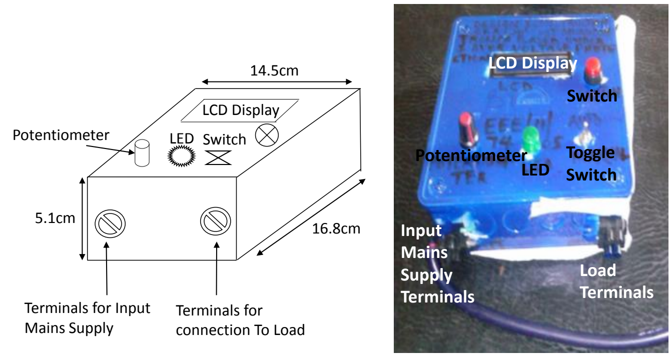


Figure 6: The device under construction.



(a) (b)

Figure 7: (a) Casing dimensions. (b) Completed device.

B. Testing

There are two types of test carried out on the developed device, they are Manual Test and Calibration.

1) Manual Test

During the process of carrying out this test, the toggle switch was put on the ‘Manual’ test position. Then, the voltage protection device was turned ON, and it initially displayed “Please wait” on the LCD unit, before the pre-set input voltage (200-240 volts) was finally displayed. The potentiometer was varied until mains voltage is supplied to the load. The purpose of the manual test is to verify the functionality of the microcontroller.

2) Calibration

With the switch in ‘Calibration’ position, the potentiometer was adjusted to divide down the voltage being monitored by the microcontroller to a safe value. Also, as the input mains supply voltage is varied using a variac, the potentiometer was used to set the threshold for tripping of the relay. Immediately the output set voltage is reached, the load received mains supply without any problem.

The completed device was tested with 200W incandescent bulbs and house appliances such as television, DVD players, refridgerator, and single phase surface pump; and the performance was satisfactory. The condition for output triggering was stable after several testing. The output set voltage of 200-240 volts was maintained throughout the test period.

IV. Conclusion

The aim of designing and constructing a low cost micro – controller based under and over voltage protective device was achieved in this work. The device supplies power to the connected load whenever the input supply is within the required pre-set voltage, thereby protecting the output connected loads from un-necessary damages. The device is found to be economical, easier to maintain and repair. The device cost about $50 to produce.

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