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Design and Construction of a Programmable Password Operated Circuit Breaker

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ABSTRACT

The circuit breaker plays the role of electrical switch which is operated automatically during electrical fault and overload. Due to poor communication between lineman and electric substation personnel, fatal accidents have been recorded overtime when operating on the circuit breakers. To this effect, this work is centered on the design of a passworded circuit breaker which can only be operated by authorized persons. The work was carried out by using an 8-bit microcontroller. The microcontroller is connected with a keypad which is used to enter the password and the password is stored in an Electrical Erasable Programmable Read-Only Memory (EEPROM). The device was actuated as the password was rightly provided. Result obtained for the current limit test was satisfactory even with the little deviations due to expected fluctuations in the load current.

1. Introduction

Electrical power systems are advancing in structure across all sectors such as generation, transmission, distribution and connected loads. This can be ascribed to the increase in customer base leading to increase in demand for electrical power. Continuous increase in load demand imposes a burden on electrical grid system and at the same time makes it more susceptible to faults [1]. In power system, a fault can be defined as an abnormal state or electrical failure of the power system. Due to poor reliable power system in Nigeria, there is frequent fault in the system leading to regular system breakdown and downtime [2]. In a bid to restore the system back to normal, there are frequent activities of linesmen in the power network thereby exposing them to the risk in the system [3, 4]. Provided in power systems and networks are protection devices which actuates the systems under abnormal conditions or during scheduled conditions. These devices are largely switchgears, they include circuit breakers and relays. When the system is overloaded or short-circuited, the circuit breaker cuts off the circuit. During maintenance, the circuit breaker can also be used to take out power to create a safe condition for the linesmen to carry out maintenance.

Before work is carried out on the line, the service men put off the circuit breaker and earth discharges the line [5]. However, there have been cases of accidents to linesmen due to poor coordination, negligence and communication with fellow colleagues whereby a linesman is working on the system and someone else knowingly or unknowingly puts the system or circuit breaker back ON [6, 7]. This unsafe practice between maintenance staff and the electric substation staff during maintenance has resulted in injuries and death of some lineman.

Following the above shortcomings, this research seeks to find a solution to the exposure of lineman to increasing risk by designing a circuit breaker system with microcontroller embedded electronics for password operated capability. Incorporated in the system is a password feature for ON/OFF condition with display and a current protection function that is programmable from 1A to 30A capacity.

1.1 Programmable password based circuit breaker

The primary function of a circuit breaker is to detect fault conditions and interrupt current flow. Unlike a fuse, the circuit breaker can be reset either manually or automatically to resume its normal operation. This programmable password based circuit breaker is designed using an 8-bit microcontroller. The password is saved in an EEPROM, which is interfaced to the microcontroller. A keypad is used to input the password and a relay switches open or close the circuit breaker. The functional block diagram is as shown in Figure 1.

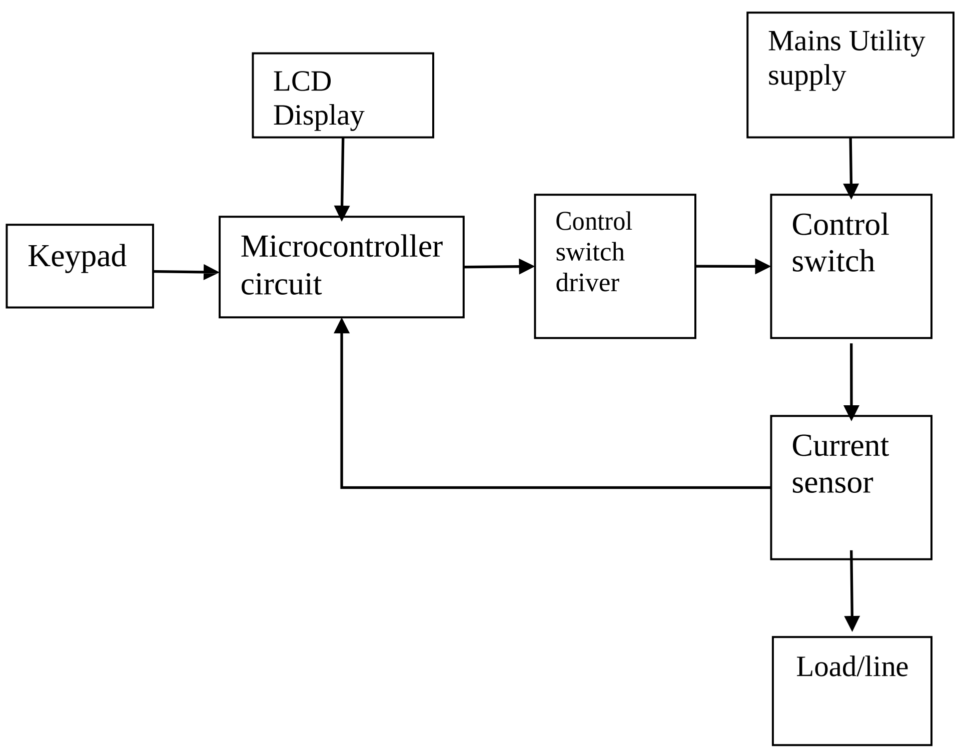

Figure 1: The functional Block diagram of the Programmable Password

2. Materials and Method

To successfully carry out this research on a programmable password operated circuit breaker, the following materials and methods are required.

2.1 Materials

The following materials were used in the study;
i) 1 x 12V Step-down transformer, ii) 10 x Diodes, iii) 10 x Capacitors, iv) 1 x relay,
v) 1x Vero-board, vi) Wires, vii) Soldering lead, viii) 3 x I.C socket,
ix) 1 x PIC16F6876A microcontroller, x) 1 x Soldering Iron, xi) 1 x 16 by 2 LCD,
xii) 1 x Switch, xiii) 1x Casing, xiv) 1 x 4MHz crystal and xv) Screws.

2.2 Method

The design of programmable password operated circuit breaker was carried out by;
i) Carrying out calculations to determine all components values and specifications.
ii) Designing the circuit diagram for the system with the circuit components and plan for the programmable password operated circuit breaker.
iii) Carrying out construction of the circuit and programming of the microcontroller used for the design.
iv) Testing to ascertain that all specifications of the design were met.
v) Conclusion and recommendation

i) Power supply

The circuit needs a DC power supply of +12V and +5V for the thermometer circuit. Figure 2 shows the power supply diagram. The transformer T1 is a step-down transformer of 220V to 24V AC. This AC voltage is rectified to DC by the bridge rectifier D1-D4. The capacitors C1, C2 serve as filter capacitors.

If output Secondary Voltage = 24Vrms, therefore, Peak Voltage Vp = 24 x √2 = 33.9V

Peak output voltage from bridge Rectifier is given by;

$$V_{P.R} = V_p - 2V_d \tag{1}$$

Therefore

$$V_{P.R} = 33.9 - 2(0.7) = 32.5V$$

An I.C bridge Rectifier RBPC6010A was used in the design and has the following specifications;

KBPC6010A Bridge Rectifier, Output Current = 6A @ 50^{o}C, I surge (max) = 125A, Reverse voltage V_{RRM} = 100V.

$$RipperVoltage = I_0 / 2FC \tag{2}$$

Where; Io = regulator Output Current, Vr = Ripple voltage.

For Io = 0.2A, Vr =1V

C1 = C2 = 0.2 / 2 x 50 x 1

C1 = C2 = 0.002F

C1= 2000 µF

This gives a capacitor with at least 2000uf and working voltage of 33.9V. The one chosen for the design is 35V and 2200 µF. C2 is an optional capacitor but put in place to remove any residual AC ripples from the supply and noise from the circuit operation and the chosen value is 25V, 10 µF.

A voltage regulator of 7812 and 7805 were used in the design to obtain the regulated +12V and +5V. The specification is as shown;

Regulator data: 7812

Maximum Input Voltage = 35V, Output Voltage = 12V, Drop out Voltage = 2V,

Operating temperature = 0^0C – 150^0C

7805 Voltage Regulator;

Maximum input voltage = 35V, Output voltage = 5V, Drop out voltage = 2V, Minimum input voltage = 7V, Output current = 1A

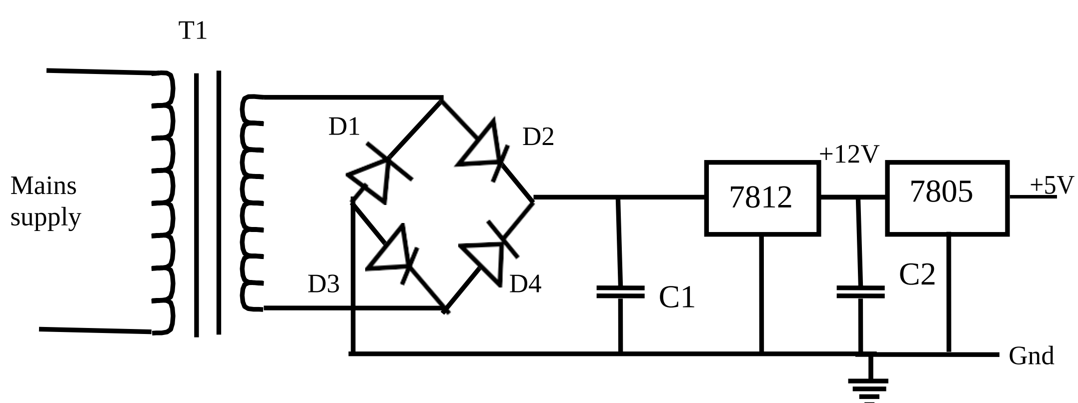

Figure 2: Power supply schematic

ii) Microcontroller circuit

The microcontroller used for the password programmable circuit breaker is the microchip PIC16F876A model. It was chosen for this work because of its large pin numbers (28) and ports (3) and EEPROM memory capacity. PIC16F876A has two timers labeled as Timer 0: 8-bit timer/counter with 8-bit prescaler, Timer1 with 16-bit timer/counter with prescaler. Their counters can be incremented during sleep via external crystal/clock and Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler.

It also has two Capture, Compare, PWM modules with 16-bit capture with maximum resolution is 12.5 ns and compare with 16-bit, maximum resolution of 200ns. It has a Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection. One of the most important feature for its use in the work is that it has a 10-bit, 5-channel Analog-to-Digital Converter (ADC) with Programmable on-chip voltage reference (VREF) module.

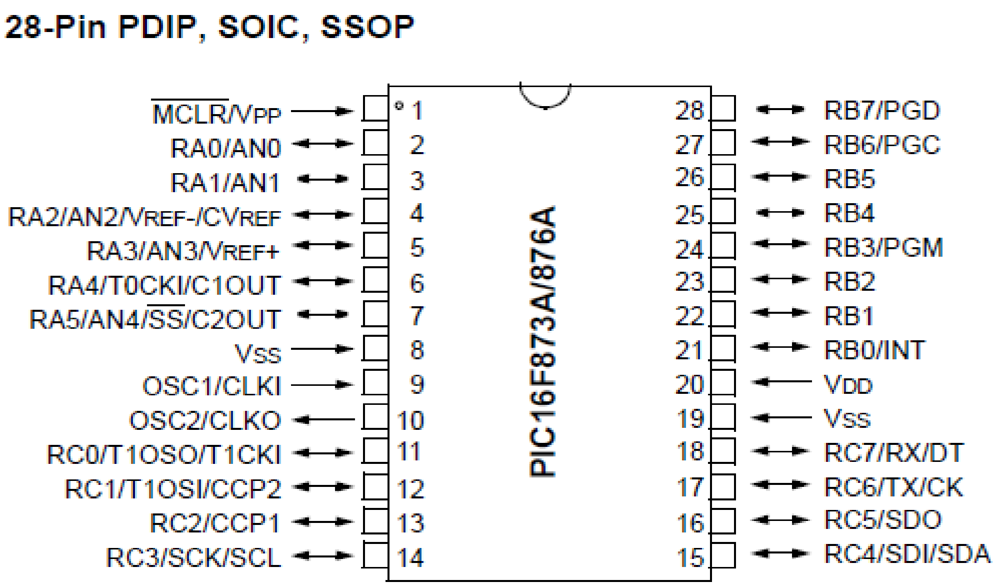

Figure 3: Pin layout of the PIC16F876A microcontroller

Figure 3 shows the microcontroller circuit and its associated components. Pin 9 and pin 10 are for oscillator. The oscillator of choice for the microcontroller (IC1) is the 4 MHz crystal oscillator for high speed operation which is programmed from the codes because the design needs precise control of timing in its control processes. Pin 4 is the master clear terminal and it was used to achieve external start-up delay for the microcontroller. R1 and C1 determine how long the microcontroller will remain in the reset state until power surge subsides before it will start working. This is necessary so that the microcontroller internal clock will not be affected by power supply surge transients when powered for the first time.

The keypad section consists basically of the soft touch switch arrangement for entering the current capacities and password data. The circuit uses the 3x3 matrix key arrangement. The circuit would use nine (9) key combinations for time sequence data entry. The switch arrangement is shown in Figure 4.

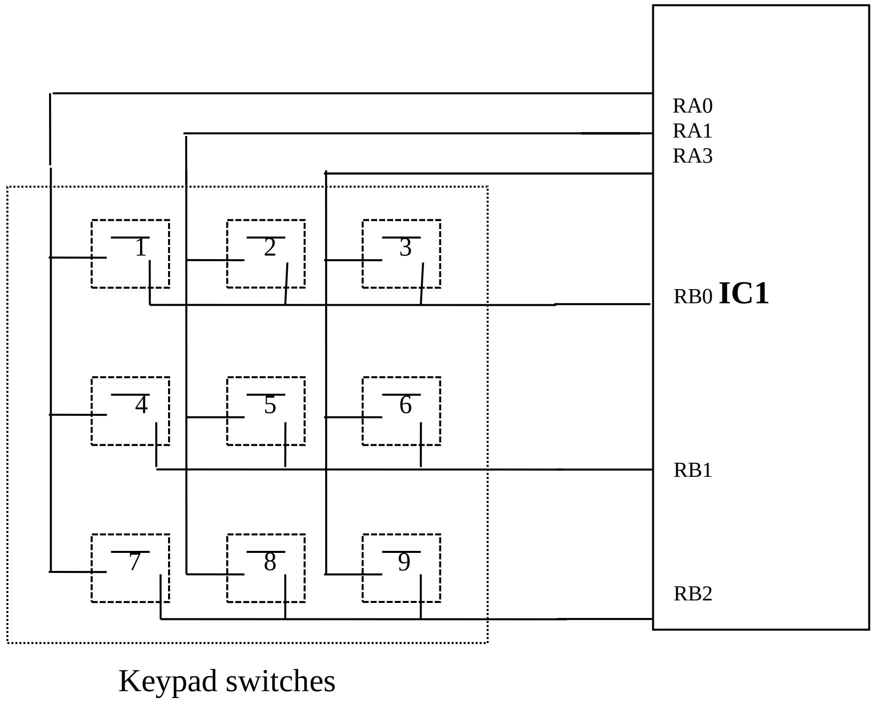

Figure 4: Keypad matrix switch arrangement

The microcontroller uses a 4 MHz crystal for the internal oscillator and this will result in the instruction cycle value as;
Oscillator frequency F = 4, 000, 000 Hz

$$\text{Period, T} = \frac{1}{F} \tag{3}$$

$$\text{Period, T} = 0.25\ \mu s$$

$$\text{Clock frequency, Fc} = \frac{\text{oscillator frequency}}{4} \tag{4}$$

Fc = 1 000 000 Hz

$$\text{Instructio n cycle, Ts} = \frac{1}{Fc} \tag{5}$$

$$\text{Instruction cycle, Ts} = 1\mu s$$

$$Ts = 0.7\, R_1 C_1 \quad (6)$$

For a time Ts = 40μs and C_1 = 10nF,

$$R_1 = \frac{T_s}{0.7\, C_1}$$

$R_1 = 40 \times 10^{-6} / 0.7 \times 10 \times 10^{-9}$

$R_1 = 5.6k\Omega$

The display unit for this work is a liquid crystal display (LCD). It is used to display the information on the time sequence programmed into the controller and to serve as the display unit for the system. The LCD is driven by the microcontroller using ASCII information generated internally for the data presentation on screen. R_3 is for LCD brightness control and its value is 10kΩ. The LCD used is the R1602A model. It is a 16x2 character screen type and it is powered by +5V.

iii) Load current transducer

The current transformer is the ac load current transducer for monitoring the load current levels. The current transformer chosen ratio is 1:100. This is due to the fact that we are dealing with low current. Thus;

$$\frac{N_p}{N_s} = \frac{I_s}{I_p} \quad (7)$$

$$Is = 0.01Ip$$

Where; Np and Ns are number of turns for primary and secondary of *CT*. For Np =1 turn

Ns = 100 turns.

Secondary current, Is = 0.01Ip = 0.01 x 100 = 1A

The output current must be converted to proportional voltage and this was done using a resistor connected to the output of the CTs.

For a maximum voltage of 10V the resistance would be;

$$R_L = \frac{V_{out}}{I_s} \quad (8)$$

$R_L = 10/\ 1 = 10\Omega$

The voltage from the CT is AC and must be converted to DC. This was done using a bridge rectifier. A capacitor filter circuit is meant to filter off some level of AC ripples from the rectified DC.

Vrms = 10V, Peak voltage $V_p = \sqrt{2}x10 = 14.14V$, V_0 = diode drop of 0.7V

$$\text{Rectifier output voltage} = V_p - 2V_0 \quad (9)$$

Rectifier output voltage = 14.14 – 1.4 = 12.74V

$$\text{Diode PIVrating} = V_p - V \quad (10)$$

Diode PIV rating = 14.14 - 0.7 = 13.44V

An I.C. bridge Rectifier kBPC6005 used in the design and has the following specifications:

KBPC005 Bridge Rectifier

Output Current = 6A @ 50^o C, I surge (max) = 125A, Reverse voltage V_{RRM} = 100V, Capacitor value was obtained from the expression of the ripple voltage given as;

$$V_r = \frac{I_0}{2FC} \quad (11)$$

Where; Io = Output Current, Vr = Ripple voltage

For Io = 10mA, Vr = 0.1V

$$C = \frac{(10x10^{-3})}{2x50x0.1}$$

C= 100µF

This is a capacitor with at least 100µf and working voltage of 16V is needed. The practical value chosen for the design due to market availability is 25V, 100µF.

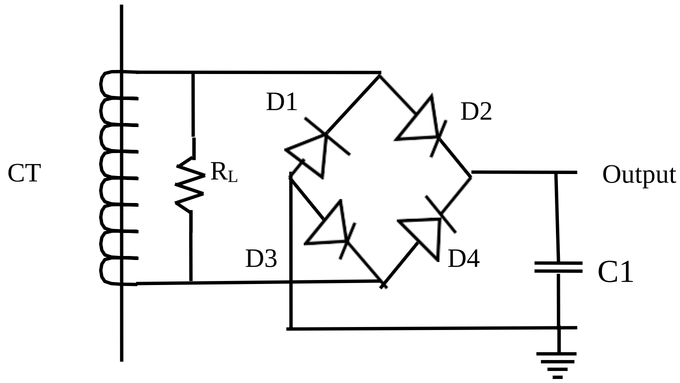

Figure 5: Current transducer signal conditioning circuit

A 12V transformer was used for this current transformer construction. The former wires were removed and it was rewired to the new specification of 1:100 turns ratio.

iv) Contactor switch and driver

The contactor switch is the main load switch for the circuit. The contactor was used because it is the best electromechanical device that can switch heavy load current automatically when it is operated on the 220V three phase line voltages. The contactors come up directly after the transistor- relay driver. It is rated to switch the load current to the switchover stage.

Power = 5kW, Voltage = 220V for single phase

Therefore, the current, $I = \frac{P}{V}$ = 5000/240 = 20.83A

The contactor used has the following current rating based on the surge current it would be subjected to while in operation;

Contactor rating, Cr = 4 x I = 20.83 x 4 = 83A

A contactor of 80A, 240vacVac with 240V operating coil voltage was used for the phase timer switch stage as the closest rating for the work.

The telemecanique 80A contactor was chosen for this work as it fits the design rating. The device can be used to switch any load. A transistor relay switch is used for switching mains voltage to the operating coil of the contactor. The circuit is shown in Figure 6.

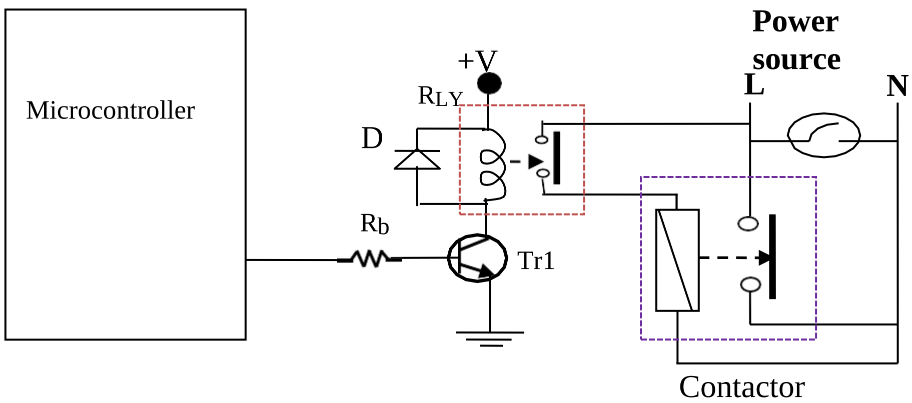

Figure 6: Contactor transistor-relay driver diagram

Relay specs:
Relay resistance = 400Ω, Relay operating Voltage = 12V, Operating Current, $I_C = V / R = 12 / 400$, $I_C = 30mA$

The transistor is the C945 NPN type and the specification is shown as follows:

C945 NPN (silicon) Specification

$BV_{CEO} = 40V$, $BV_{CBO} = 70V$, Ic(max) = 0.6A, Pd(watts) = 0.625W, Hfe = 100 typical,

Vce (sat) = 0.2V

For ß = 100

Base current $I_B = I_C / ß = 30 \times 10^{-3} / 100 = 30 \times 10^{-5}$ A. For effective base drive this value was increased by a factor of 1.4, thus;

Base resistor $R_B = (Vcomp – Vbe) / I_B = (5 – 0.7) / 1.4 x30 \times 10^{-5} = 10kΩ$

v) Operational principle of programmable password circuit breaker

The program for the circuit was written in assembly language. The assembler used is MPLAB 7.40. The codes were compiled by this compiler and downloaded to the PIC16F876A. The complete circuit diagram of the system is presented in Figure 8. The power supply stage consists of a step-down transformer T1 of 220V A. C. to 24V A.C. This is rectified to D.C. by a bridge rectifier D1-D4, while filter capacitor C1 and C2 were connected to filter of A.C. ripples from the D.C. To achieve a well regulated +12V and +5V D.C. supply, I.C. voltage regulators were used with 7805 to get +5V D.C. supply and 7812 for +12V.

IC1 PIC16F876A is the microcontroller that controls the circuit. Pin 9 and pin 10 are for oscillator. Pin 1 is the master clear terminal and it was used to achieve external start-up delay for the microcontroller. R1 and C3 determine how long the microcontroller will remain in the reset state until power surge subsides before it will start working. This is necessary so that the microcontroller internal clock will not be affected by power supply surge transients when powered for the first time.

The keypad switches are arranged in matrix format and they are the keys for programming the load current limit and password data. The microcontroller is programmed to save the correct password code and to compare with future password. It grants access for further data and control once the password have been applied. Based on the key commands, it can carry out control for load current limit and cutoff or simply ON/Off switching as done for maintenance routine. When it checks the data for load current limit entered with that already stored in memory and see that it has reached it sends out a pulse to the transistor relay to operate the contactor to cutoff power to the load.

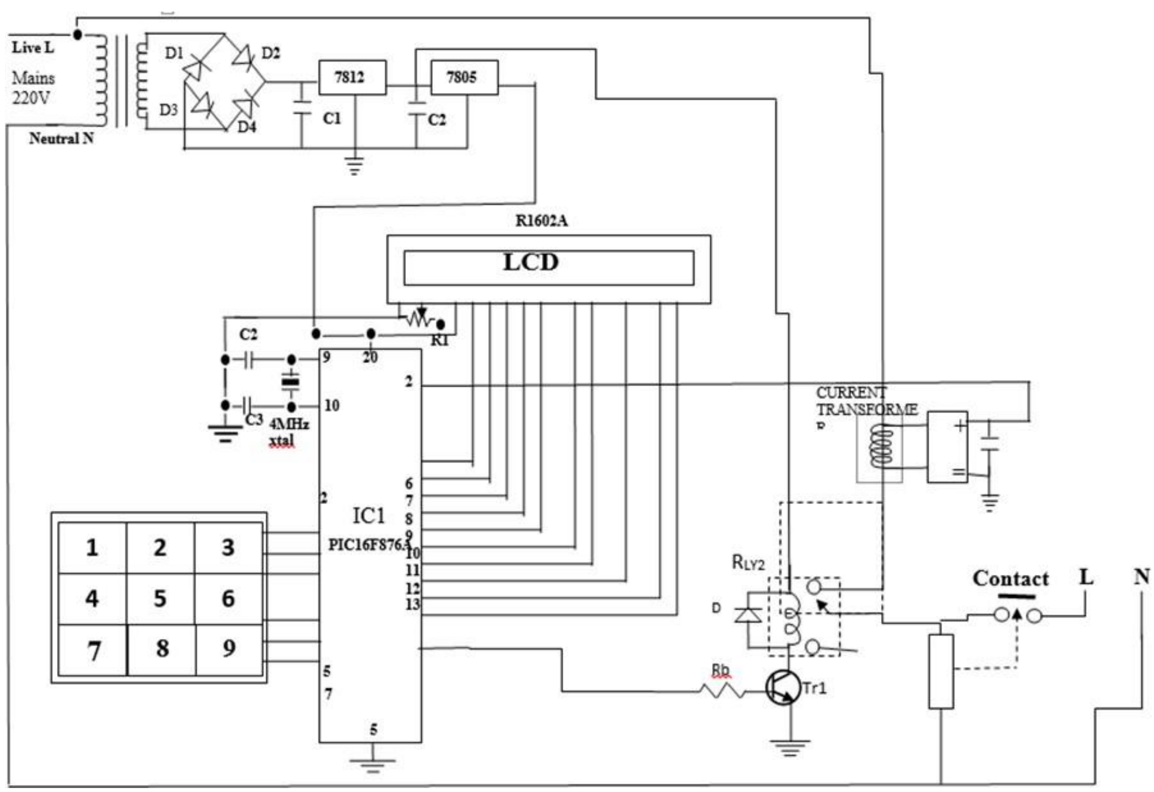

Figure 8: Complete circuit diagram of Programmable Circuit Breaker

3. Results and Discussion

After the design of the work construction was carried out using veroboard. The codes for the microcontroller was developed using MPLAB compiler. The MPASM section of the compiler is for assembly language files conversion to Intel HEX file format. The hex file was downloaded to the microcontroller using WinPIC800 downloader software. As the device would be utilized at substations to operate the circuit breakers, it has a backup power source in the control room. The control room is redundantly served with backup power supply from the battery bank such that the devices at the substation can still be activated during power outage. This makes the device very reliable even in times of power outage.

3.1 Testing

The individual stages of the work were tested to ensure they are working properly using digital voltmeter. All operating voltages at every nodes were checked too and at the end the full device tests were conducted.

The full test of the device was done after casing of the circuit board. The final tests conducted on the completed work and the ones of interest that was recorded are the password entry test, load current limit testing and ON/OFF test.

3.1.1 Password Entry Test

This test involves entry password to see if the system recognizes the password and if password change feature will also work out as designed. Table 1 presents the table of the password verification test. And it can been seen that when the wrong password is entered the device does not accept or recognize it until the right password was inputed.

Table 1: Table of the password verification test

S/No.	Correct Password (Programmed)	Keypad entry password	Remarks
1	45233254	45233254	Recognized
2	45233254	45231254	Not Recognized
3	6543280	6555280	Not Recognized
4	6543280	6543280	Recognized
5	6543282	6543282	Recognized

3.1.2 Current limit Test

This test was carried out to check how reliable it is with monitoring and performing current limit protection as circuit/device is loaded and if there is a trip off. Table 2 presents values of the load current limit test. Trip point column shows the actual current value using a digital clamp meter. The test result shows a slight difference between the values obtained for actual tests to that of the device. This was okay as the device was very sensitive to fluctuations in the load current.

Table 2: Test results of Load Current limit test

S/No.	Programmed current (A)	Trip point (A)
1	5	6
2	10	10
3	15	16
4	20	22
5	25	23

3.2 Casing

The completed hardware section of the work was housed in a white panel plastic box (casing) as shown in Figure 9.

Figure 9: Casing

3.3 Bill of engineering materials and evaluation

The components and their relative cost are as shown in the table at the time of this publication. The total would give an estimated total cost as shown in Table 3.

Table 3: Tables of Engineering Materials and Evaluation

S/N	ITEM	UNIT PRICE (₦)	QUANTITY	AMOUNT (₦)
1	12V stepdown transformer	3500	1	3500
2	Diodes	50	10	500
3	Capacitors	50	10	500
4	Relay	200	1	200
5	Veroboard	250	1	250
6	Wires	----	----	600
7	Soldering lead	----	----	450
8	I.C socket	20	3	60
9	PIC16F6876A microcontroller	3500	1	3500
10	Soldering Iron	500	1	500
11	16x2 LCD	3200	1	3200
12	Switch	500	1	500
14	Casing	2000	1	2000
15	4MHz crystal	3800	1	3800
16	Screws	600	---	600
		TOTAL		**20,160:00k**

From Table 3, it can be seen that the system is economical (with a total cost of ₦20,160:00k) and can be effectively applied in our current day power systems setup.

4. Conclusion and Recommendation

With this work, an authorized personnel or lineman will require to provide the password before operating a circuit breaker. Thus, no other person can operate the circuit breaker other than the authorized personnel. An effective application of this device will help to bring to the barest minimum cases of electrocution suffered by linemen in the field during maintenance or fault rectification. The system has shown to be economically viable and can be effectively applied in our current day power systems setup.

Due to the amount of current the circuit breakers of power systems are designed to accommodate a device of higher load current capacity should be designed and implemented.

Secondly, GSM/SMS call alert in the case of false attempt of unauthorized user.

Nomenclature

AC	Alternating Current (A)
ADC	Analog-to-Digital Converter
BV_{CBO}	Collector to base breakdown voltage of the common emitter bipolar with the base floating (V)
BV_{CEO}	Collector to emitter breakdown voltage with the base open (V)
C	Capacitor (F)
CT	Current transformer
D	Diode
DC	Direct Current (A)
DOE	Design of Experiment
EEPROM	Electrically Erasable Programmable Read-Only Memory
F	Frequency (Hz)
Fc	Clock frequency (Hz)
GSM	Global System for Mobile communications
I	Current (A)
I_B	Base current (A)
IC	Integrated Circuit
I_C	Collector current (A)
Io	Output Current (A)
Ip	Transformer primary current (A)
Is	Transformer secondary current (A)
L	Live
LCD	Liquid Crystal Display
MPLAB	Is a proprietary freeware integrated development environment for the development of embedded applications on PIC
N	Neutral
Np	Transformer primary turns
Ns	Transformer secondary turns
NPN	Negative-Positive-Negative
P	Power (W)
Pd	Power dissipation (W)
PWM	Pulse Width Modulation
R	Resistance (Ω)
R_B	Base resistor (Ω)
R_L	Load resistance (Ω)
R_{LY}	Relay

SMS	Short Message Service
T	Period (S)
Ts	Instruction cycle (S)
USART	Universal Synchronous Asynchronous Receiver Transmitter
V	Voltage (V)
V_B	Base voltage (V)
V_{BE}	Base-emitter voltage (V)
V_{CE}	Collector-emitter voltage (V)
Vcomp	Compensation voltage (V)
V_P	Peak voltage (V)
$V_{P.R.}$	Peak voltage from rectifier (V)
V_{RRM}	Maximum Peak Repititive Reverse Voltage (V)
Vr	Ripple voltage (V)
Vref	Reference Voltage (V)
Vrms	Root mean square voltage (V)
Vout	Output voltage (V)
₦	Naira

Greek letters

ß	Beta
Ω	Ohms

5. Acknowledgement

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6. Conflict of Interest

There is no conflict of interest associated with this work.

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