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Automatic changeover switch as a remedy to incessant attack on users of domestic generators in developing countries

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Abstract
In this paper, a three phase automatic changeover switch (ACS) having a timer circuit and over-current protector is developed to save industries and individuals of the drawbacks of using manual method of power supply changeover. This switch senses when the main supply is disrupted and/or when the generator set time is reached for operation and automatically starts the alternative power source (generator) and transfers the load unto the generator and monitors its circuit to know when the utility supply is restored in order to reconnect the load back to the former while powering off the generator. The ACS was developed based on a programmable logic controller (PLC) which coordinates the following components such as; contactor, transformer, relays, comparator, 555 timer, regulator, transistors, resistors, capacitors, diodes, sensor, etc. The simulation of the designed circuitry was done using Proteus 8 software and the microcontroller programmed with M-ICU studio that has emulator of emul8051 (TS control emulator 8051 v.1.0). After which the physical construction was done. The designed system worked satisfactorily and it takes approximately 15 seconds for the entire process of power supply changeover.

Keywords: automatic switching, microcontroller, generator, comparator, public utility supply

1. Introduction

Due to incessant power outage in developing countries like Nigeria, economy development has been handicapped as foreign Investors are discouraged from investing and businesses that require constant power supply has been less functional and expensive to operate in Nigeria [1, 2, 3]. Alternative sources of power such as inverters, solar panels and generators especially are now being used during power outage to generate power in almost every household [4, 5, 6]. These sources are connected to buildings in such a way that when public supply is disrupted, a manual changeover is carried out to connect any of the alternatives above to the building and power supply is maintained. This Automatic Changeover Switch (ACS) is made to overcome the challenge of manual switching and to make power available from secondary sources (especially generator) at set time during outage. In developing countries, the period of utility outage where an individual go out to put on generator at night is used by criminal underworld to rob innocent citizens, and these has resulted in death in some cases [7]. An automatic changeover or transfer switch does sense when the mains or utility supply is disrupted and automatically starts the alternative power source (generator) and transfers the load unto the generator and monitors the circuit of the utility to know when supply is restored in order to reconnect the load after some seconds delay, to ensure that the utility line voltage is stable, back to the former while powering off the generator [8, 9].

In this paper, an automatic changeover switch is designed and developed to help curb the activities of the underworld. This is done by setting the time an individual wants the alternate source of power to operate at night before switching of the source automatically or switching over to the public utility.

2. Design Methodology

The methodology adapted is in several stages. First, various units of the automatic changeover switch was designed. The units were integrated into the AT89C52 microcontroller that has been programmed with M-ICU studio which has emulator of emul8051 (TS control emulator 8051 v.1.0). Proteus 8 was used to simulate the designed system, after which a prototype of the system was built. Finally, test was carried out on the system to check its functionality. The building blocks for the automatic changeover switch are as presented in Figure 1. The design calculations of each unit of the building blocks are presented in the following subsections.

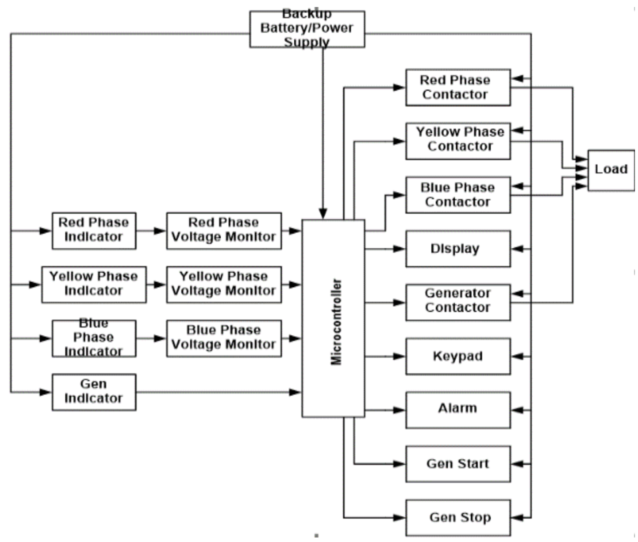

Fig 1: Block diagram of the automatic changeover switch

2.1 Main Control Circuit

This circuit selects either one of the three phases or the generator and it decides which will be connected to the load based on existing protocol. From sampling, it was found that a standard flat consumes a load of between 5-10kVA at a time. Thus, power is given by Eq. (1):

$$P = I_L V \qquad (1)$$

Where P is the power supplied, I_L is the load current, V is the supply voltage. For V = 220V and P = 5kVA, I_L is 22.7A based on Eq. (1) and when P = 10kVA, I_L is 45.5A. Thus a contactor that has a current rating within the range of 22.7A-45.5A was necessary. However, in this design a contact of 40A was chosen since domestic loads rarely get above 40A from our survey. Circuit breaker of 150% [10] of rated contactor current which is 60A is required. However, 60A circuit breakers were not available in the market so a 63A circuit breaker was chosen.

2.2 Power Supply Unit and Battery Charger Circuit

The power supply unit delivers power to the entire system. It has an input backup power supply source from a battery. This unit is also responsible for charging the 12V rechargeable battery with current rating of 1.2-1.4A. The battery can also be charged from the generator or mains. The circuit is designed to deliver 12V and 5V. The circuit incorporates an AC-DC converter and a battery charger. From datasheet, the peak inverse voltage (PIV) of the diode is at least twice the peak voltage of the transformer for higher reliability and it is given as in Eq. 2:

$$PIV \geq 2V_{s(max)} \qquad (2)$$

In this work, a 220/15V step-down transformer of 2A rating was selected and full wave rectifier (D_1-D_4 diodes) was used. The circuit design is as follows

The maximum voltage is $V_{max} = \sqrt{2} \times V_{rms}$ [11]. Hence, the maximum secondary voltage is

$$V_{s(max)} = \sqrt{2} \times 15 = 21.21V \qquad (3)$$

$$\therefore PIV = 2 \times 21.21 = 42.42V$$

The forward current of the diode (I_f) is at least one and half times the supply current from the transformer [12], thus

$$I_f \geq 1.5 I_{tf} \qquad (4)$$

$$\therefore I_f = 1.5 \times 2 = 3A.$$

Therefore, the diode used in the design should have at least a PIV ≥ 42.42V and I_f ≥ 3A.

KBPC5010 diode having PIV = 1000V and I_f = 10A is used to ensure higher reliability of the circuit. Thus, KBPC5010 diode of the above rating is used throughout this work in order to achieve the same effect.

The capacitor (C_1) is a filtering capacitor to remove the ripple from the rectifier output. From datasheet, the voltage rating (V_C) of the capacitor should be at least twice the output voltage from the bridge rectifier (V_{br}) for better filtering. Also from Kirchhoff voltage law, the output voltage from the bridge rectifier is given by Eq. 5,

$$V_{br} = V_{s(\max)} - (2V_D) \qquad (5)$$

Where V_D is the forward bias voltage of the diode and is given as 0.7V.

$$\therefore V_{br} = 21.21 - 1.4 = 19.81V.$$

Thus, $V_c = 2 \times 19.81 = 39.62V$.

To realize the capacitance rating, the ripple voltage V_R should be 25% of V_{br}.

$$\therefore V_R = 0.25 \times 19.81 = 4.95V.$$

However, $V_R = \frac{I}{2fC}$ (6)

Where f is frequency at 50Hz, I is the maximum current from the bridge rectifier at 2A.

From Eq. (6),

$$\therefore C_1 = \frac{I}{2fV_R} = \frac{2}{2\times 50\times 4.95} = 4040\mu F.$$

A standard value of 4700µF was selected and used in this design. Diod**e** (**(**D_5) does stop the back flow of current when the AC source is not present. It is selected using the procedures used in selecting $D_1 – D_4$. Fixed voltage regulators from the LM78XX series were used in the design. They are LM7805 and LM7812 supply 5V and 12V respectively where needed.

The current limiting resistor R_1 to the LED is obtained using Eq. (7).

$$R_1 = \frac{V_s - V_d}{I_d} \qquad (7)$$

Where V_s is the supply voltage of 5V,V_d is the voltage drop across the LED of 2V and I_d is the current through the LED of 10mA-20mA. However, a current of 10mA was used in the design.

$$R_1 = \frac{5-2}{0.01} = 300\Omega.$$

Thus, a standard resistor value of 330Ω is used.

2.3 Phase Indicator Unit

The phase indicator unit indicates the status of the phases. A transformer of rating 220V/12V at 300mA was chosen in this design. Using Eq. (3), Eq. (2) and Eq. (4), we get

$$V_{s(max)} = \sqrt{2} \times 12 = 16.97V \qquad (8)$$

$$PIV \geq 2V_{s(max)} = 2 \times 16.97 = 33.94V \qquad (9)$$

$$I_f \geq 1.5 I_{tf} = 1.5 \times 300mA = 450mA \qquad (10)$$

Base on the values obtained above, the full wave rectifier diodes D_6-D_9 used were of the type KBPC5010 having PIV = 1000V and I_f = 10A.

The filtering capacitor C_2 is calculated for. From Eq. (5) and Eq. (8) with V_D given as 0.7V,

$$\therefore V_{br} = 16.97 - 1.4 = 15.57V.$$

$$V_R = 0.25 \times 15.57 = 3.89V.$$

From Eq. (6),

$$\therefore C_2 = \frac{I}{2fV_R} = \frac{0.3}{2\times 50\times 3.89} = 771.2\mu F.$$

However, a capacitor value of 4700µF was chosen due to availability and to ensure increased reliability through over rating of components.

From Eq. (7), a limiting resistor R_2 was realized thus

$$\therefore R_2 = \frac{12-2}{0.01} = 1k\Omega.$$

A standard resistor value of 1kΩ was selected for R_2 in the design. This design is used for the three phase indicators.

2.4 Generator Indicator Unit

The generator indicator unit shows when there is availability of supply from the generator. The generator supplies 220V through the limiting resistor R_3, which reduces the current in the supply to a minimum that will not damage the diodes D_{10}-D_{13} which rectify the $220V_{ac}$ to $220V_{dc}$ that powers the LED in the opto coupler that serves as the base current to the photo transistor which then allows the 5V supply in the collector to flow into the emitter. The emitter sends the signal into the NOT gate that takes a zero signal to the microcontroller. Thus, the microcontroller sees a zero (0) as the presence of supply and a one (1) as the absence of supply [13]. From the diode datasheet, I_{tf} for the diode is 1mA.

$$V = IR_3 \quad (11)$$

For V=220V, I=1mA, then

$$\therefore R_3 = \frac{220}{0.001} = 220k\Omega.$$

A standard resistor value of 220kΩ was selected for the design. The resistor R_4 is a pull down resistor that ensures that the input of the NOT gate is always zero when there is no supply from the generator. From the data sheet, R_4 has values in the range 470Ω - 47kΩ and a value of 10kΩ was selected for the design.

From Eq. (3), Eq. (2) and Eq. (4), we get

$$V_{s(max)} = \sqrt{2} \times 220 = 311.08V \quad (12)$$

$$PIV \geq 2V_{s(max)} = 2 \times 311.08 = 622.16V \quad (13)$$

$$I_f \geq 1.5I_{tf} = 1.5 \times 1mA = 1.5mA \quad (14)$$

Base on the values obtained above, the full wave rectifier diodes D_{10}-D_{13} used were of the type KBPC5010 having PIV = 1000V and I_f = 10A. The opto coupler IC used for the design is the 4N35 general purpose.

2.5 Alarm Circuit

This unit controls an audio-visual indicator in the system. It is activated when the system requires the user's attention such as abnormal situations like when the generator refuses to start or stop. The alarm is designed using a 555 timer connected in astable mode. The frequency of the 555 timer in the as table mode is given as by Eq. (15).

$$= \frac{1.44}{(2R_6+R_5)C_4} \quad (15)$$

The timer is activated or deactivated using an active low or an active high signal respectively. For a signal duration of 1sec operating at 50% duty cycle, then T = (50/100) x 1 = 0.5sec. This gives a frequency of 2Hz. Taking C_4 = 100 µF and R_5 = 1kΩ,

$$\therefore R_6 = \frac{1.44}{2fC_4} - \frac{R_5}{2} = \frac{1.44}{0.0004} - 500 = 3.1k\Omega$$

Thus, a standard value of 3.1kΩ was selected for R_6. From the data sheet, C_5 is given as 0.01µF.

The transistor serves to control the ON and OFF of the LED and buzzer. When IC_1 sends a signal of 1 through R_7 to the base of the transistor, the transistor is closed and the LED and buzzer are ON while when IC_1 doesn't send any output, the transistor is open and the buzzer and LED are off. Using Eq. (7), where V_s = 5V, V_d = 2V, and I_d = 10mA.

$$R_8 = \frac{5-2}{0.01} = 300\Omega.$$

A standard resistor value of 330Ω was selected for R_8. However, R_7 helps to ensure a 100% return at the collector from the base and is given as

$$R_7 = 10R_8 = 3.3k\Omega.$$

A standard resistor value of 3.3kΩ was selected for R_7.

2.6 Voltage Monitor Circuit

This circuit monitors the voltage output from each phase. It is designed to send an output signal only when the voltage level is within a certain range and does not send any output when the generator fails or when the input is higher than the higher reference or is lower than the lower reference. To ensure a reliable circuit, the value of R_{10} is made three times smaller than R_9 in order to make the voltage in the circuit not to exceed 5V.

Using voltage divider formula,

$$V_{out} = \left(\frac{R_{10}}{R_9+R_{10}}\right)V_s \quad (16)$$

Where R_{10} = 3.9kΩ, R9=1.2kΩ and V_S = 5V

$$\therefore V_{out} = \left(\frac{3.9}{1.2+3.9}\right)5 = 3.82V.$$

This shows that the output voltage is less than 5V. The AND gate used is a CD4081 model and the OP-AMP is LM324 because they are compatible with each other and the microcontroller. This same design is used for all the phases.

2.7 Power Control Circuit

This circuit controls the power flow in the system. The system uses the circuit to select any of the phases (i.e. red, yellow and blue phases) and the generator. R_{15} is a pull up resistor in the range of 470Ω – 47kΩ. For this design, R_{15} of 1kΩ is selected based on data sheet information. Using Eq. (7), where V_S=5V, V_d= 2, I_d= 10mA,

$$\therefore R_{13} = \frac{5-2}{10mA} = 300\Omega$$

A standard resistor value of 330Ω was selected for R_{13}. However, R_{14} helps to ensure a 100% return at the collector from the base and is given as

$$R_{14} = 10R_{13} = 3.3k\Omega.$$

A standard resistor value of 3.3kΩ was selected for R_7.

2.8 Input Circuit

The keypad sends input signal to the microcontroller – which it uses to set the clock and the ON or OFF time of the generator. R_p is the pull down resistor within the range of 470Ω – 47kΩ.

2.9 Generator Control

This is the circuit that the system uses to control the generator (ON or OFF). The impedance of the coils of the relay is 400Ω. From datasheet, using the hard saturation formula, R_B= $10R_c$, where R_c= impedance of the coil of the relay,

R_B=R_{16}= 4kΩ. A standard resistor of 4.7kΩ was selected.

2.10 Display Unit

The system uses this circuit to communicate with the user. The Liquid Crystal Display (LCD) L044 was used as the display unit and is a 20 x 4 character display interfaced with the microcontroller AT89C52. The resistor R_o is contrast resistor (used to alternate the brightness or dullness of the words displayed. R_o is given as 1kΩ in the data sheet. Limiting resistor R_{17} is obtained from Eq. (7) as

$$R_{17} = \frac{5-2}{10mA} = 300\Omega.$$

A standard resistor value of 330Ω was selected.

The complete circuit diagram of the automatic changeover switch is as presented in Figure 2.

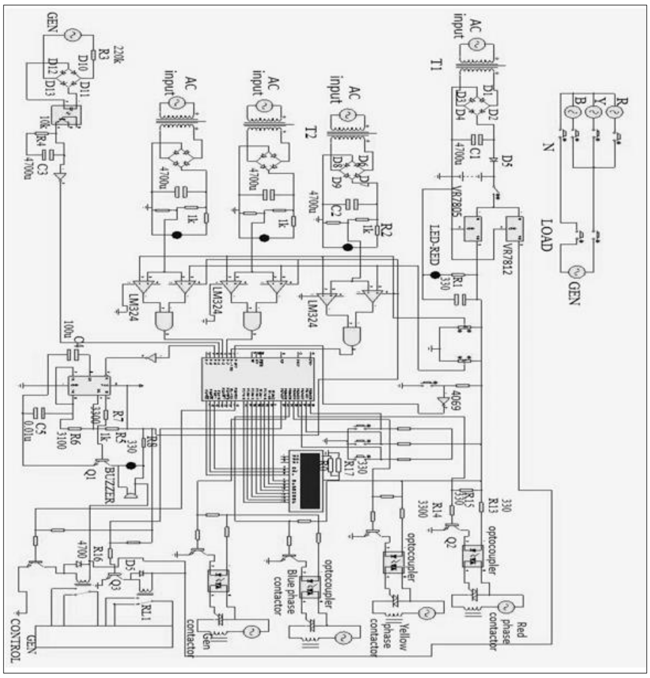

Fig 2: Circuit diagram of the automatic changeover switch with timer

3. Principle of Operation of the System

The system is set to automatically run phase checks of all three phases upon power failure for five seconds and if there is power in any of the phases (say red phase at 240/220V_{AC}), it compares it with the reference voltage and if it normal, the transformer T_2 steps down this voltage to 12V_{AC}. The arrangement of diodes D_6-D_9 in bridge arrangement serves as the rectifier of the circuit that converts the AC to DC power, the capacitor C_1 then filters the rectified voltage to ensure the removal of ripple in the dc voltage. The op-amps and AND gate are arranged to serve as the "comparators" of the circuit that sends signals to the microcontroller about the level of the supply voltage and this happens for all the phases. Otherwise, if the phase voltage is either above or below the reference voltage, the Generator control having a relay tries to start the generator. After it has started, the generator indicator circuit which also has diodes serving as the rectifier converts it to DC power and the capacitor C_2 filters it. The NOT gate is set to send a signal to the microprocessor depending on the voltage availability of generator supply. The alarm system contains a buzzer and an LED that is set to come ON whenever the user's attention is needed. The input circuit is used to input the generator ON or OFF time and set the clock of the day. It also displays the present state of the circuit. When the load is connected to the generator and BEDC (public utility) comes back on, the circuit does a transient check on the BEDC supply for 15 seconds before it turns off the generator and connects back to the utility. Figure 3 shows the flowchart for the automatic changeover switch showing the sequence of operation.

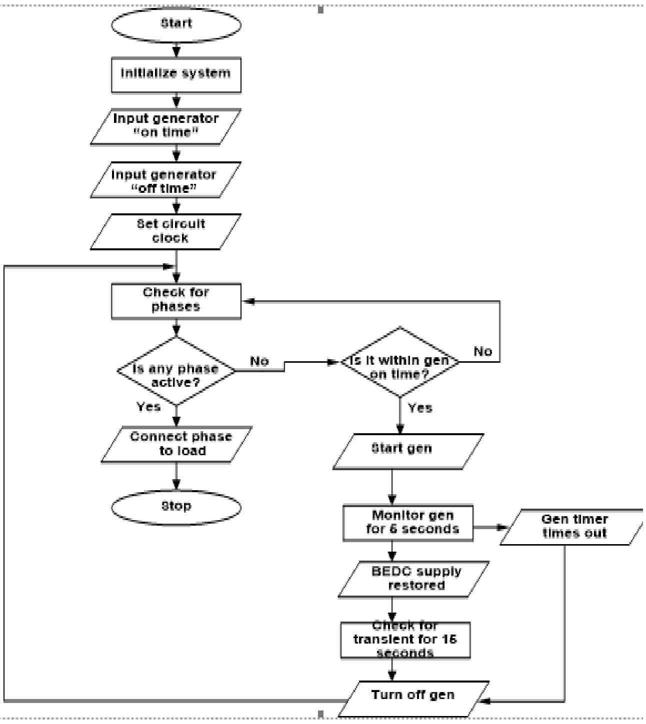

Fig 3: Flowchart of the automatic changeover switch

4. Simulation

After the system was designed, simulation was done with Proteus 8 software. The circuit involves AT89C52 microcontroller (MCU) which was programmed with M-ICU studio that has emulator of emul8051 (TS control emulator 8051 v.1.0) which works with assembly language. When the play button is clicked on the simulation, the LED display asks the user to set the generator ON/OFF time. When that is set, it then check if any of the phases in the circuit is closed or open, if closed it displays the phase that is on and the particular phase indicator comes on. If all the three phases are ON the red phase takes priority followed by yellow phase. If all the phases are out, the buzzer alarm beeps notifying that there is no more power from all the phases and it then switches ON the generator. However, the initial time limit that was set is still being monitored by the MCU, the generator comes ON and power is restored. But if in the process of turning ON within its delaying time, it displays switching not successful and the alarm buzzes, which means that there is fault with the generator that needs to be fixed. There is a switch that is used to demonstrate this fault condition in this simulation. When the switching ON time of the generator has elapsed and no power supply, it displays "set ON/OFF time" again. On the other hand, if power comes on in any of the phases, it then displays "power is available on the available phase". Also a switch is used in the simulation to control the power output from all the phases in the sense that the MCU has been programmed in such a way that it accepts a particular range of voltage input. This switch is used to set the required voltage. This is the general operation of the automatic changeover switch simulation.

5. Development

The designed circuit of the automatic changeover switch presented in Figure 2 was wired and a model developed as shown in Figure 4.

Fig 4: Developed model of the automatic changeover switch with a 5kVA generator

6. Test

Various tests were carried out on the system to check its functionality. Figures 5-10 show the display out for each scenario.

Fig 5: Display during normal operation with public utility available

Fig 6: Display during power failure from public utility

Fig 7: Display during changeover from public utility to generator

Fig 8: Display during generator stabilization

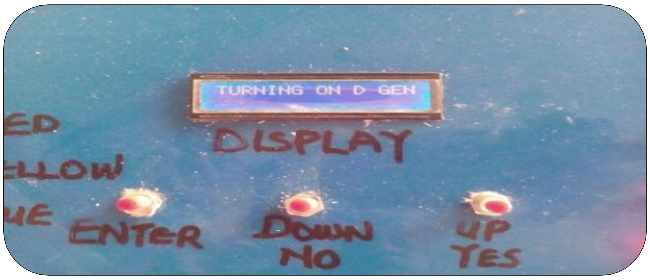

Fig 9: Display during generator turn on

Fig 10: Display after any successful operation

7. Results and Discussion

From the test results carried out on the developed system, it can be confirmed that the system performed satisfactorily. The work follows closely systems designed using AT89C52 microcontroller [14, 15]. However, the methodology adapted in this paper is different from others. The modifications to existing works include among others phase indicators, phase voltage monitors, uniquely connected contactors, keypad and display, backup battery and alarm system. A phase indicator is attached to each phase (see figure. 1) and the generator. Microprocessor is programmed to first of all do an overview between phases before taking any action on the generator.

The phase voltage monitors check whether the amount of voltage that is released to the load is either above or below its range in order to take it as zero. This helps to avoid the oversupply or under supply to the load as this can lead to damage of sensitive equipment due to power surge. Likewise, the contactors are connected to the microprocessor in such a way that when a phase is needed for operation the contactor for that particular phase closes and the same goes for the generator contactor. The keypad is a unit that allows the user to input the specific time duration he/she wants the generator to run. This feature is designed in such a way that the timing can be altered and set with the clock. The display unit shows the various operations that are being performed by the system, e.g. Display of time counting, display of the phase that is ON/OFF. The battery is connected in such a way that whenever the load is being powered, it recharges. The alarm system is set to come on whenever there is an abnormal situation or when the system requires the attention of the user. These are added advantages as compared to other changeover switches which were previously designed. The turning on of the generator is dependent on high level of fuel in the generator tank, absence of power in all three phase of utility suply. However, the system will be much more efficient if a choke less generator is available

8. Conclusion

In this paper, an automatic changeover switched with timer circuit was designed and a prototype was developed. The system also has an over-current and voltage protection incorporated into it. From the test carried out, the system worked satisfactorily. This system was designed to help curb incessant attack on users of generators at night, which has resulted in death of some individuals. This system is strongly recommended for users of generators at night when utility supply is not available, as the generator will automatically be switched off after the time set has elapsed.

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