Journal of the Nigerian Association of Mathematical Physics
Volume26, (March, 2014), pp 433 – 440

Design and Development of an Automatic Generation Starter and Change over Circuit

Otasowie P. O.[1] and Omorowa H. N.[2]

Department of Electrical and Electronic Engineering, University of Benin, Benin City, Nigeria

Abstract

This paper presents a design and development of an automatic generator starter and change over circuit that starts a generator and change power to generator when there is power outage. The circuit can also automatically stop the generator and switch power back to the public power supply when the public power supply is restored.

The circuit consist of (i) a circuit that automatically starts the generator when the mains power fails (ii) a charging circuit (iii) a change over circuit (iv) automatic generator stop circuit (v) a control circuit and (vi) a generator stop circuit.

The circuit was designed, constructed and tested and found to perform satisfactorily. The circuit cost was N5,320 which is very affordable..

Keywords: Generator starter, change over, public power supply, power outage, switching

1.0 Justification for the Work

Power failure is on the increase in Nigeria, this has resulted in an astronomical increase in generators. Therefore, there is need to have a circuit that can start a generator and change over power to a generator when there is power failure and switch off the generator and switch power to the public power supply when the public power supply is restored. This circuit removes the stress of manually switching ON and OFF generator especially at night.

1.1 Introduction

A constant power supply is a critical component of every successful modern business and when power failure happen more often and will take longer time to fix, a reliable standby generator is really essential to power all the equipment and systems[1,2]. A reliable and uninterrupted power supply is a basic factor for the industrial and socio-economic development for any country. It is an obvious fact that unstable power supply is seriously confronting Nigeria as a nation. The influx of generators of wide range of power rating is an indication of unstable power supply in Nigeria. All institutions, public and private buildings in Nigeria have standby generators[3]. These generators normally operate alongside change over switches that switch from generator to the public power supply and vice versa when there is power outage.

There are three types of change over circuit. They are:

(i) Manual change over (ii) Electrical change over and (iii) Electrical/Electronic change over[4]

(i) Manual Change Over

The manual change over is the most popular change over switch in use. The contact is manually switched from mains terminal to the generator terminal and vice versa. The disadvantage of this process is that:

1) It consumes a lot of human labour and time
2) The mechanical part is as a result of continuous up and down wears which have to be replaced
3) The ceramic insulator can crack during switching and can lead to electric shock if the contact wire touches the metal casing

(ii) Electrical Change Over

The electrical change over uses ac relay for its operation. The circuit does not require a dc power pack or controlling board. The advantage of this circuit is that it is cheap and easily constructed. The only drawback is that at low mains voltage, the ac relay and some contractors start chattering, causing the output to be oscillating and this is dangerous to the equipment connected to the output.

Corresponding author: ***Otasowie P.O.***, E-mail: potasowie@yahoo.co.uk, Tel.: +2348037921371

(iii) Electrical/ Electronic Change Over Circuit

To overcome the shortcomings of the AC relay/contractors, DC relay was used. The DC relay is powered from a transformer power pack, whose stabilize voltage enable the relay worked to the design recommended voltage. This method is more efficient in that no chattering is possible because the control circuit shutdown and starts the generator to supply power to the load. The relays are switch ON and OFF by a transistor biased as a switch[5]

The electrical/electronic change over are of two types. The first type does not have a time delay in which it changes over immediately when the mains voltage is gone but the generator starter has a periodic delay to start the generator. After starting the feedback circuit from the generator side helps to deactivate the control circuit.

The second method has a delay before it changes over. The delay keep the generator running until the mains voltage is present for say 1 to 5 minutes before switching off the generator[5,6].

Previous Work

Ezema et al [7] in the work design of automatic change over switch with generator control mechanism concentrated on calculating the power for a three phase rating by determining the contractor rating and cable size. The work did not show the actual design that make up the generator change over switch with generator control mechanism. The cost of the change over switch was not also considered. Our design work will address these shortcomings.

2.0 Design Consideration and Analysis

The design of the circuit is in six stages which are (i) Automatic generator starter circuit. This is a circuit that automatically starts the generator when the mains power fails. This consists of a transformer, a bridge rectifier circuit (ii) A charging circuit. This consists of a regulator and a transistor (iii) A change over circuit. This consists of four relay in parallel (iv) Automatic generator stop circuit (v) A control circuit. This consist of a latch circuit (ON and OFF), RC cmos oscillator, a decade counter and an astable multivibrator circuit and (vi) A generator stop circuit.

2.1 Automatic Generator Starter Circuit

This is a circuit that automatically starts the generator when the mains power fails.

(i) Transformer

The transformer used for this work is step-down transformer with an output voltage of 15V and a current of 2amp.

Fuse Rating

The transformer specification:

Input voltage = 220-240volt

Input current = 2amp at 240volt

The fuse is designed to cut off at 230volt

$$V_{(cut)} = \frac{V_{main} + V_{rating}}{2} \qquad (1)$$

$$= \frac{220 + 240}{2} = 230V$$

Fuse Rating = I_{fuse}

$$= \frac{V_{main}}{V_{rating}} \, x \, I_{rated} \qquad (2)$$

$$I_{fuse} = \frac{220}{240} \, x \, 2 = 1.83amps$$

(ii) Rectification

The output of the secondary ac voltage from the transformer is converted to dc voltage/current by means of a bridge rectifier. In rectification, two diodes conduct D_2 and D_4 while the other two are off. In the reverse cycle D_1 and D_3 are ON while D_2 and D_4 are OFF. The output dc produce is given by

$$V_D = \sqrt{2}\, V_m \qquad (3)$$

The PIV (peak inverse voltage) of the diode is given by

$$PIV = V_m\sqrt{2} - 2V_{d(ON)} \qquad (4)$$

Where V_m is the peak secondary voltage from transformer

V_d (ON) is the diode forward drop and is given as 1volt typical in power supply rectification circuit.

$$PIV = 30\sqrt{2} - 2(1) = 40.42V$$

For good electronic design, the PIV to be computed should be greater say 3 times. This value

$$PIV_{(use)} = 3\, PIV_{cal} \qquad (5)$$

$= 3 \, x \, 40.42 = 121.26$V

Since the maximum current is 2Amp, the current rating of the diode should be 2-3 times the forward current. Therefore;

$$I_r(diode) = 2I_r\ of\ transformer \quad - \quad - \quad - \quad - \quad - \quad - \quad (6)$$
$$= 2x\ 2 = 4amps$$

The diode chosen has part number of KRJ1508G. The diode has a maximum input current of 4amp and a PIV of 1000volt.

From the approximate formula for ripple voltage analysis.

$$V_r = ripple\ voltage = \frac{I_o}{2fC} \quad - \quad - \quad - \quad - \quad - \quad - \quad -(7)$$

Where I_o = DC current from rectifier
f = mains frequency
C = capacitance in microfarad
Computation of I_o:
The backup battery needs 450mA for charging (10% of its maximum capacity)

Relay Consumption

Small relay = 90mA, Big relay = 282mA,
Circuit consumption = 50mA. Therefore,

$$Total\ current\ I_o = (450 + 90 + 282 + 50)mA$$
$$I_o = 872mA$$

If we assume

$$V_r = 6\%\ PIV \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (8)$$
$$V_r = \frac{6}{100}\ x\ 40.42 = 2.45V$$

Then from equation (5)

$$V_r = \frac{I_o}{2fC}$$
$$C = \frac{I_o}{2fV_r} = \frac{872\ x\ 10^{-3}}{2\ x\ 50\ x\ 2.425} = 3595.8\ x\ 10^{-6}F$$

3300μF (Nearest preferred value)

Voltage Rating

Since the capacitor is charged at alternate half cycle, the capacitor voltage should be 1.5 to 3 times the peak voltage.

$$V_{capacitor} = 1.5\ x\ PIV \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (9)$$
$$= 1.5\ x\ 40.42 = 60.63V$$

Because 60.63volts is not readily available, therefore 50volts was now chosen.

2.2 Charging Circuit

The charging circuit consists of a regulator LM7815, choke and D882 transistor.
The output voltage is given as:

$$V_{out} = V_{regulator} + V_{f(on)1} - V_{f(on)2} - V_{f(on)3} - V_{f(on)4} \quad - \quad - \quad - \quad (10)$$

Where V_{out} = voltage required to charge the battery
$V_{regulator}$ = output voltage from regulator
$V_{f(on)}$ = forward diode from of D_1, D_2, D_3 and D_4
V_{out} = 15 + 0.6 – 0.6 – 0.6 – 0.6
= 15 – 1.2 = 13.8volts

Since the charging current is 10% of the battery capacity.

$$V_{charge} = 10\%\ I_{max} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad -(11)$$
$$I_{charge} = 450mA$$

$I_{charge} = I_E$ where I_E is the emitter current of power transistor

From transistor equations,

$$\beta I_B = I_E$$
$$I_B + I_E = I_E \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (12)$$
$$I_B + \beta I_E = I_E \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad -(13)$$
$$I_B(1 + \beta) = I_E$$

$$I_B = \frac{I_E}{1+\beta} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (14)$$

Where β is the gain of the transistor

β = 12 for D882 from data book

$$\therefore I_B = \frac{450}{1+12} = 34.6mA \doteq 35mA$$

2.3 Change Over Circuit

The change over circuit consists of four (4) relay that are run parallel.

Parameter of relay:

Voltage rating = 12volt

Current rating (contact): Normally Open (NO) = 30amps

Normally closed (NC) = 20amp

Relay coil resistance = 170Ω measured

From Ohms law,

$$V = IR \Rightarrow I = {}^{V}/_{R} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (15)$$

Current rating of relay coil $I_{R1y} = \left(\frac{12}{170}\right) amp$

∴ Current rating for 4 relay

$$I_{R1y4} = \frac{12}{170} \, x \, 4 = 282mA$$

= 282mA

From equation (14),

$$I_B = \frac{282}{1+12} = 21.6mA \doteq 22mA \quad - \quad - \quad - \quad - \quad - \quad - \qquad (16)$$

2.4 Automatic Generator Stop Circuit

The automatic generator stop is activated from the voltage line via transistor relay.

Resistance of relay coil = 440Ω measured

Voltage of relay = 12volt

Current of relay = I_{R1y}

From Ohm's law

$$I_{R1y} = \frac{2V}{R} = \frac{12}{450} = 30mA \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (17)$$

Since the relay is driven by the transistor

$I_C = I_{R1y} = 30mA$

From transistor equation,

$$I_B = \frac{I_C}{1+hfe} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (18)$$

For C9014; hfe (minimum) chosen as 200

Then $\therefore I_B = \left(\frac{30}{200+1}\right) mA = \left(\frac{30}{200+1}\right) mA$

$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{15 - 0.6}{\left({}^{30}/_{201}\right)} \, x \, 10^3$$

From monostable formula, the period of oscillation is given by:

$$T = 1.1 \, R_t \, C_t \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (19)$$

R_t is usually taken as zero therefore equation reduced to

T = 1.1 x 0 x C_t = 0

T = 0 implies that when trigger ON it remain ON until the reset pin is used to reset it and when OFF it remain OFF until it is triggered.

RC CMOS Oscillator

The oscillator is design using CD4069.

The frequency of oscilltionis given as

$$f = \frac{1}{R_{BC}} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (20)$$

The base resistor R_B is chosen as 150KΩ for maximum turning.

The capacitor is chosen as 47μF

$$\therefore f = \frac{1}{R_{BC}}$$
$$= \frac{1}{150000\ x\ 47\ x\ 10^{-6}} = 0.142H_2$$

The time of oscillation, $T = \frac{1}{f}$

$$T = \frac{1}{f} = \frac{1}{0.142} = 7.0\ seconds$$

For minimum turning R_B is chosen as 10kΩ

The capacitor is chosen as 47μF

$$f = \frac{1}{10000\ x\ 47\ x\ 10^{-6}}$$

$f = 0.142H_2$ and

$$T = \frac{1}{f} = \frac{1}{0.47} \cong 2.12\ seconds$$

The timing can be set between 2.12 seconds to 7 seconds depending on the capacitor.

Decade Counter

The decade counter CD4017 is used in this work as a pulse stretcher.

Astable Circuit

The astable circuit is designed using the 555 timer circuit.

2.6 Generator Stop Circuit

The output of the generator is converted to dc by a 6volt transformer using bridge rectification.

The output dc voltage is

$$V_{dc} = V_m\sqrt{2} - 2V_{d(on)}$$
$$= 6 \text{ x } 1.414 - 2 = 8.5\text{volts}$$

The LED bias resistor is given as

$$R_{LED} = \frac{V_{CC} - V_f}{I_f} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (21)$$

Where

I_f is the minimum forward current

V_f is the forward voltage drop of the diode

V_{CC} is chosen as 8.5 volts

$I_{f(max)}$ is chosen as 25mA. Therefore If = 10% of 25mA = 2.5mA

V_f is chosen as 1volt, therefore;

$$R_{LED} = \frac{8.5 - 1}{2.5mA} = 3.3k\Omega$$

For the generator shut down, a low pass filter circuit is used to smoothen the wave. The cut off frequency is computed as;

$$f_{cut} = \frac{1}{2\pi fc} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (22)$$

$$f_{cut} = 30\%\ f_{mains} = \frac{30}{100}\ x\ 50 = 15H_2$$

Where f_{mains} is chosen as 50

The capacitor is computed as

$$C = \frac{1}{2\pi fR}$$

R is chosen as 1kΩ

$$C = \frac{1}{2\pi\ x\ 15\ x\ 1000} = 33\mu f$$

The capacitor used is 47μf nearest preferred value.

3.0 Principle of Operation

When the main is present, relay RL# is turned ON to stop the generator while transformer T_1 steps down the main voltage to 15volts. The 10Ω choke resistor R_1 slows down the input rushing current into IC1, LM7815. The regulator whose reference is buffered by diode D_1 (0.6v) produce an output voltage of 15.6volts. Current flows through diode D_1 to resistor R_2. Resistor R_2 forward biases transistor TR_1 (D882) which activate relay (RLY 4). The common contact of relay 4 is connected to the output while the No (normally open) and NC (normally close) contacts are connected to the mains and generator terminal respectively. Part of the current flow through diode D_2, resistor R_3 and variable resistor VR_1 to forward biase transistor TR_2 (D882) which is used to charge the backup battery via diode D_5. VR_1 is used to preset the charging current. Diode D_4 and resistor R_4 is used to forward biase transistor TR_3 which turns off IC3. With IC3 turn off, Relay, RLY_1 does not energize and IC5 are switch off. Thus, ensuring generator start is not possible. If the main goes off, current flows through the 10Ω 5watts resistor to IC2 whose reference has been buffered by two diode (IN4007). The output voltage drives IC3 which in turn energize relay RLY1 to come up. The contact of this relay feeds IC4 and IC5. IC4 is a CMOS not gate oscillator that provide the pulse delay and output the pulse. IC5 provides different sequential output which is used to forward biase transistor TR6. TR6 activate relay RL2 by switching its terminal to ground. The normally open (NO) contact close the generator switch for it to start. After three attempts, if the generator fails to start, pin 11 to IC5 triggers transistor TR7 via signal diode. If this happens IC6 (latch switch) is turned ON and its output is used to activate the blinker while the other part is used to reset IC3 which shut down the pulsing unit. IC3 can be reset so that the sequence can restart.

If the generator is activated, the feedback transformer T_2 send a shut down signal from its rectified DC output via a diode and resistor to forward biase transistor TR3. If TR_3 is forward biase (remain ON), pin 4 of IC3 is connected to ground via the collector of TR_3. This reset IC3, therefore RLY, is de-energized and IC4 and IC5 would not function since RLY, has been de-energized.

4.0 Construction

After calculation of the components values in design, the components were bought at the electronic store and tested with digital multimeter to ensure they are not bad/faulty.

The next stage was the construction of the power back up supply which was built directly on the veroboard while the control circuitry was first constructed and tested on the bread board and later transferred to a veroboard using 60 watts soldering iron. In soldering, the IC holders were used so as to prevent damage to the IC.

5.0 Testing and Result

Testing was carried out on both the control and change over circuit using a digital multimeter to read the various voltages at the terminal of the IC's. This is tabulated in Table 1.

Table 1: Test conducted on the generator starter and change over circuit

S/N	Test	Measured	Calculated
1.	Charging current of battery	350mA	450mA
2.	Base emitter voltage	0.64V	0.6V
3.	Output from regulator 7815	15.6V buffered by diode	15volt
4.	Output from regulator 7805 with reference diode	6.2V	6.2V
5.	Output from latch switch	5.6volt	-
6.	Output voltage of CD4069 peak-peak	2.7volt	-
7.	Output from counter CD4017	2.8 volt	-
8.	Pulse output (generator fail to start)	18 sec	-
9.	Pulse period from CD4069	1-5 sec	Variable

In the absent of generator Power Holding Company of Nigeria (PHCN) and generator socket outlet were both connected to wall socket in the laboratory. While the generator start and generator stop contacts were both connected to multimeter to check continuity.

When PHCN socket outlet was switched ON, generator start and generator stop contacts were found open.

Thereafter, PHCN socket outlet was switch off to simulate power failure. The generator start terminal was observed to be close three times for about six seconds which is enough to start the generator. At this point the generator socket outlet was switched ON to simulate that the generator has started and no further starting was observed. If however, the generator socket outlet was left OFF to simulate fail to start, error light will continue to flicker until a reset is done.

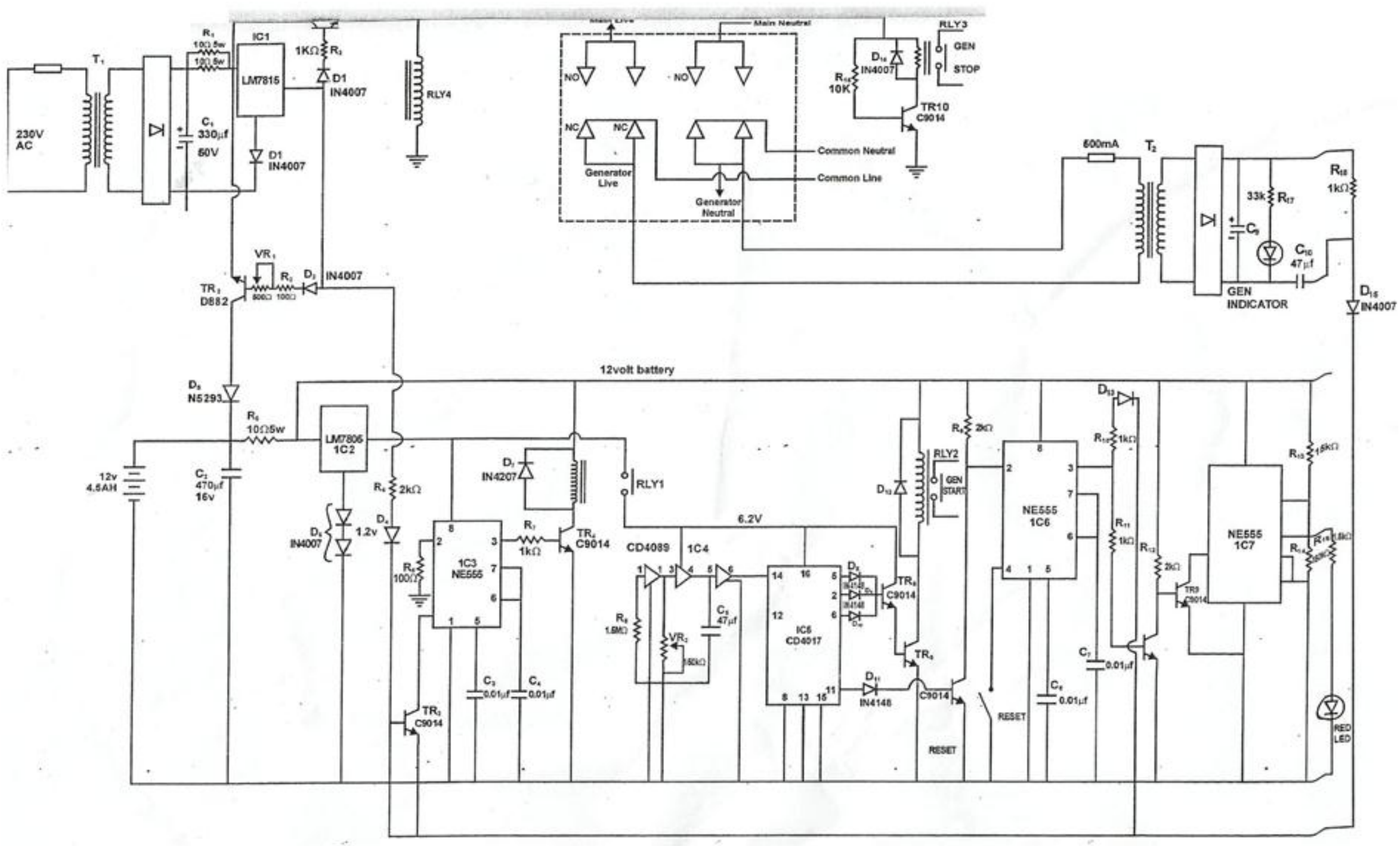

Fig 1: Complete circuit diagram of automatic generator starter and change over circuit

6.0 Bill of Quantities

Table 2: Bill of Quantities

S/N	Components	Quantity	Unit Price (N)	Total (N)
1.	15V, 3A transformer	1	450	450
2.	6V, 500MA transformer	1	180	180
3.	12V, 30A relay	4	180	720
4.	12V, 10A relay	3	40	120
5.	Choke resistor	3	10	30
6.	Bridge rectifier	1	40	40
7.	Diode FR604	1	10	10
8.	Diode IN4007	11	5	55
9.	Signal diode IN4148	4	40	160
10.	555 timer	3	40	120
11.	4-pin IC holder	3	10	30
12.	Not-gate (cmos) CD4069	1	80	80
13.	Decade counter CD4017	1	80	80
14.	8-pin IC holder	2	20	40
15.	Cable log	6	40	240
16.	Transistor	8	10	80
17.	Resistors	17	5	85
18.	LM7812 regulator	2	40	80
19.	Variable resistor	2	15	30
20.	Ceramic capacitor	3	5	15
21.	Electrolytic capacitor	6	10	60
22.	Small signal power	2	20	40
23.	50V, 3300μf electrolytic capacitor	1	50	50
24.	Nut and bolt	6	25	150
25.	Washer	13	5	65
26.	Battery	2	450	900
	Components	**Quantity**	**Unit Price (N)**	**Total (N)**
27.	Double lay Perspex casing	1	500	500
28.	Relay socket	12	50	600
29.	Voltmeter	3	50	150
30.	Veroboard	1	80	80
31.	LED bulb	4	10	40
32.	Power switch	1	40	40
	Total			**N5,320**

7.0 Conclusion

The various tests carried out and the result obtained demonstrated that the automatic change over circuit worked and achieved its designed aims. The automatic change over switch is relative affordable at a cost of N5,320.

References

[1] Pabia, A.S. (2003) "Electric Power Distribution." Fourth Edition. Tata McGraw Hill Publication Ltd, New Delhi, Pp 35-37.

[2] Gross, C.A. (1986) "Power System Analysis." Second Edition. John Wiley and Sons, New York, Pp 64-65.

[3] Ogunleye, I.O. and Ogunleye, J.M (2008) "Diversification of sources of power generation: The antidote to irregular power supply in Nigeria." Proceedings of 1st Nation Engineering Conference on Sustainable Energy Development in Nigeria Challenges and Prospects, Faculty of Engineering, University of Ado-Ekiti State, Nigeria, Pp 60-67.

[4] www.schneider-electric.com "Source changeover system". Accessed June 23rd 2012.

[5] www.cumminsonan.com "RV Generator Handbook". Accessed June 23rd 2012.

[6] Nagrath, I.J. and Kothari, I.D.P. (2000) "Power System Engineering". New Delhi, Tata McGraw Hill Publishing Company Ltd, Pp 220-240.

[7] Ezema, L.S., Peter, B.U. and Harris, O.O. (2012) "Design of automatic change over switch with generator control mechanism". Academic Research International Vol 3, No 3, Pp 125-130. www.savap.org.PK/journals