Ahmed R. Salihu, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 7, (Series-VII) July 2020, pp. 54-59

RESEARCH ARTICLE OPEN ACCESS

Automatic Transfer Switch with a Generator Cut off, Under voltage and Overvoltage Protection Device.

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ABSTRACT

Power supply (mains) from power generating stations and the alternative sources has become part of life especially in the developing countries such as Nigeria. The need to transfer services from mains supply to alternative power source such as generator set when mains fails can hardly be over emphasized. The incessant power outage from mains as well as unstable voltage and power surge of the mains which have destroyed numerous expensive loads in the system for the short time it is available have been addressed. The Automatic Transfer Switch (ATS) for a single phase electric power generator has been designed to enable automatic operation and power supply transfer between a public utility supply (mains) and a power generator. The automatic changeover switch designed, implemented and tested in this work is a single phase type that is compatible for single phase electrical generators. The main components were electromagnetic relays and integrated circuits. In addition to performing the switching operation between the mains and the generator in the presence or absence of power, the constructed device is also designed to switch when it senses an adverse incoming voltage to avoid too high voltages (above 249 V) or too low voltages (below 101 V). These voltage levels possess threat to sensitive electronic devices used in our homes or in any organization. The result of this designed ATS demonstrates its capability to automatically transfer the load from mains to generator when it senses these two extreme voltages.

Keywords: Automatic Transfer Switch (ATS), Generator Cut off, Overvoltage protection, Voltage sensing and Change over relay.

Date of Submission: 18-07-2020 Date of Acceptance: 02-08-2020

I. INTRODUCTION

The world today depends on stable electricity and instability of electricity supply in developing countries creates the needs to back up the existing supply. As a result of incessant power outage, developing countries like Nigeria faces slow growth in both private and public sectors of her economy, causing a setback in commercial and industrial activities in spite of the vast market made by the population. Introduction of alternative source of power supply assists in order to maintain a continuous supply of electricity to consumers.

A transfer switch is an electrical device that is capable of alternating and transferring a load from one source of power supply to another. The basic function of a transfer switch is to break and make from one source of power supply to another [1]. It can also serve to isolate power sources in the event of overvoltage and under-voltage, thus preventing power surge, voltages sags, and voltage surges and burnt. The voltage surges, sags and frequency are measured using a Digital Multimeter (DMM). These switches are designed to continue to monitor the condition of the utility power source until it is restored, and then it delays for some seconds to ensure that the utility line voltage is stable, after which it then sends a signal to shut down the alternative source while returning the load to the utility line [2]. This means that system also transfers load from mains power supply to other emergency power supply.

The static transfer switches have times of the order of 30ms. In order to further reduce this switching time, power semiconductor devices like Thyristors, MOSFET or IGBJT are being used. This system is designed using non-programmable components like microcontrollers. It enhances the complexity of the circuits. It helps in reduction of the troubleshooting complexity due to use of less number of components [3].

In [4], there is an improved idea of Automatic Transfer Switch (ATS) design that includes both hardware and software modules. It allows the control and monitoring of a generator from a remotely placed computer system, and is capable of monitoring fuel level, oil level, battery strength and next maintenance schedule as well as start and stop of the generator from computer system. However, it does not monitor the over voltage and under voltage situations for the load.

In [5], the automatic transfer switch system designed for 3-Ø 12KVA system is non-microcontroller based and consists of a 3-Ø relays, change over delay mechanism and utility phase detector circuits. When one of the phases is interrupted or all phases are interrupted, the changeover mechanism will shift the load from public utility to generator and then back to public utility supply on its restoration. It was developed to transfer the load from mains supply to generator in case of mains power failure. A single phase system was however not taken care of by this design.

In [6], an ATS system was designed for single phase 5kVA generator set. The control switch was designed without the use of microcontroller, while relay 555 timers, voltage regulators and other electronic components were used to design a low cost system. The function was to sense the mains supply and switch the load to generator on main supply failure. An over-voltage protection was also designed using comparator to disconnect the load on application of voltages higher than the safe limits or on arrival of surges in order to protect the load from being damaged. Also a full ATS circuit was designed using microcontroller. It included a power supply unit, delay circuit using 555 timers IC and over voltage protection circuit using comparator. Microcontroller was programmed to carry out numerous tasks for generator like its cool down timer, fail to start timer, warm up timer, crank timer and utility stabilization switch back timer. The delay circuit was used to produce delay for a certain pre-set time to ensure the voltage stability of utility line. This ATS design never incorporated a protection from an under voltage situation to ensure smooth operation of the appliances when the situation arises.

In [7], the design has to do with a Global System for Mobile (GSM) module connected to ATS to keep the user informed about the power supply situation and operations of ATS by sending him or her text messages through Short Message Service (SMS) provided by local mobile companies. Once there is power failure, the GSM module will send an SMS to user “POWER is OFF”. When ATS returns the load to mains power supply, an SMS is sent as “MAIN POWER is ON”. The generator can be controlled using GSM module. Many of the large industries, factories and educational institutions use generators as backup power source. Since these generators are placed in distant places, so man power is required to operate it with large delays. However, it takes sometimes to execute the transfer of load from one source to the other.

Other shortfall observed with the existing related designs: the cost of construction and the layout of such devices are only affordable by just big industries and companies owing to the fact that such devices might be expensive to purchase for domestic use. To overcome the identified lapses, a simple GSM based ATS that consists of a microcontroller which can detect the interruption in the supply very fast and turn ON the relay is proposed.

II. MATERIAL AND METHODS

A. Design and Components

Fig. 1 depicts the block diagram of the proposed design of the Automatic Transfer Switch with Generator Cut off and Protection Device.

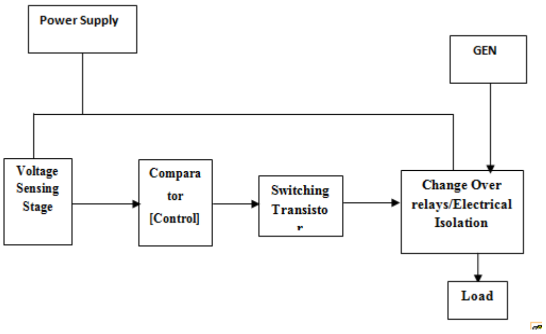


Fig 1: Block diagram of the Automatic Transfer Switch design with Generator Cut off and Protection Device.

The regulated power supply unit ensures a constant supply of 12V dc voltage to the electronic components in the circuit. In case of an over voltage supply by the utility source, the over voltage protection unit senses and arrests the over voltage from getting to the load, while the generator will continue supply power to the load. The control unit monitors the condition of the utility power supply. Once the utility voltage is normal, the delay unit will delay the voltage for a certain pre-set time to ensure that the utility line voltage is stable. It then sends signal that will cause the driver and switching unit to first de-energies the kick starter relay in the control unit, and cause the changeover unit to disconnect the generator then transfers the load to the utility power supply. Whenever there is power failure in the utility power source line, the control unit senses it, and sends signal to the changeover unit to disconnect the load from the utility power supply, then cause the kick starter to energies and start the generator automatically, thereby transfer the load to the generator.

B. Design and Specifications of the Power Supply Unit.

The power supply unit is made up of a step down transformer, diode rectifier circuit, filter circuit, power indicator, and IC voltage regulator as shown in Fig 2.

i. Transformer: The following specifications are considered in the selection of the transformer used in the design;

Input voltage: 220V
output voltage: 24V
ripple voltage: 2V
load current: 1A (max),

ii. Diode:

Diode forward voltage drop: 0.7V. Mathematically, $V_{max} = V_{out} + 2$ (diode forward voltage drop) where Peak voltage, $V_{max} = V_{rms} \times \sqrt{2}$, then,

$$24 \times \sqrt{2} = 33.94V$$

Also, the amplitude of the output voltage or the peak output voltage of the rectifier V_{out} , for a full wave bridge rectification is given as;

$$V_{out} = V_{max} - 2V_d$$

$$33.94 - 2(0.7) = 32.54V$$

where V_d is forward voltage drop across the diode. Average dc output voltage, i.e, the mean voltage appearing at the output of the rectifier circuit V_{out} is obtained.

Peak Inverse Voltage (PIV) is the maximum reverse voltage that a diode withstand without destroying the junction. For a full wave bridge rectifier, the peak inverse voltage of each diode is equal to the maximum secondary voltage of the transformer. That is;

$PIV = V_{max} = 33.94V$

Therefore, 1N4007 diode used in this design have the following specifications;

maximum current: 1A
bias voltage: 0.7V
peak inverse voltage: 1000V

iii. Capacitor

The design of the filter circuit is based on the choice of the capacitances of capacitor, and this can be obtained as:

$$C = \frac{I_{dc}}{4\sqrt{3} f \gamma V_{p2}}$$

where I_{dc} is the load current of the transformer =1A

f is the frequency of the ripple voltage = 50Hz

V_{p2} is the peak output voltage of the rectifier = 32.54V

and γ , the tolerable ripples voltage =0.02

$$C = \frac{1}{4\sqrt{3} \times 50 \times 0.02 \times 32.54} = 4441\mu F$$

Practically, the closest value of $4441\mu F$ is 4700 μF.

Variation in dc output voltage, due to the fluctuation in the input ac mains and load variations may cause inaccurate or erratic operation and even malfunctioning of the electronic circuit. Hence, the need for voltage regulation that will provide a constant dc output voltage to the electronic circuit . An NPN BJT transistor and reversed biased zener diode for voltage regulator were used for the regulation of power supply. It has a minimum and maximum input voltage of 14.6V and 35V respectively and produced 12V±5% outputs. This was suitable because the maximum peak of the rectified voltage calculated as 32.54V. The filtering capacitor will be fixed at the emitter of the transistor.

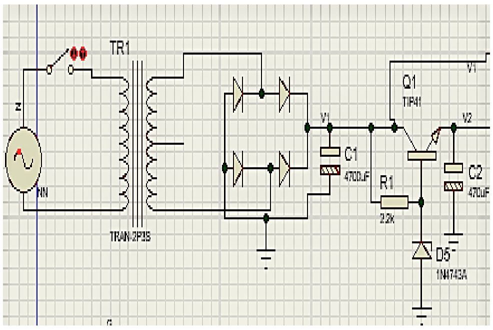


Fig 2: Power supply circuit

From the Fig 2, the V1 is the unregulated voltage respective to the main power supply while, V2 is the regulated voltage of constant 12V.

Calculations of Maximum and Minimum Voltage from Utility Power Supply

i. For a maximum voltage utility of 250V;

If 220V gives an output of 24V dc, then, 250V will give 27.3V

Therefore, $V_{max} = V_{rms} \times \sqrt{2}$

$$27.3 \times \sqrt{2} = 38.6V$$

ii. For a minimum voltage utility supply of 100V;

If 220V gives an output of 24V dc, then, 100V will give 10.9V

Therefore, $V_{min} = V_{rms} \times \sqrt{2}$

$$10.9 \times \sqrt{2} = 15.4V$$

C. Voltage Sensing

The comparator/voltage sensor compares two voltages, one voltage sampled from the unregulated voltage while the other is the regulated +5V voltage from the device power supply. If the two voltage levels are equal or the inverting voltage greater than the non-inverting, there will be no output from the sensor but if a reasonable discrepancy is experienced, an output will be obtained from the sensor. The comparator stage was used to sense when the public power supply voltage has dropped below a certain preset level. The input public power supply voltage is converted to d.c. voltage (by rectification) in the power supply stage and is regulated to 12V from the voltage regulator and 5V (ideal Voltage for LM324 comparator operates) for power supply needed in the circuit. The unregulated voltage varies as the public supply input varies.

i. Low voltage sensing for under voltage protection

Now considering the under-voltage condition as Fig 3 is the low voltage sensing circuit for under-voltage protection. When the line voltage equals or lesser than 100V, the voltage at the inverting terminal of operational amplifier U1:A will be greater than or equal to the voltage at its non-inverting terminal. Thus the output of operational amplifier U1:A goes off and de-energies the relay through transistor. The AC supply is disconnected from the load and electrical appliances turn off, thus the appliances are protected against under-voltage.

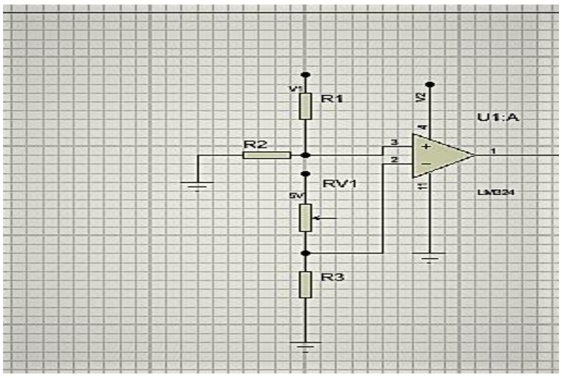


Fig 3: Low voltage sensing circuit

In Fig 3. , R1 and R2 form a potential divider to reduce the unregulated voltage to a low voltage of less than 5V at 100V a.c input. Remember, 100V a.c is single phase voltage to be rectified and compared with the regulated +5V d.c at pin 2 of the comparator. It is being taken as dangerously low voltage for appliances meant to operate with a nominal voltage of 220V a.c single-phase supply.

At the non-inverting terminal, assume R_2 as 3.3k

Apply voltage divider principle: $Vi \;= V_{in}[\frac{R_2}{R_1+R_2}]$, where Vi *is* the non-inverting terminal input voltage.

At an input voltage of 100V, the unregulated and rectified voltage is 15.4V

Vi = 5V, But $V_{in} = V_{min}$ =15.4V

$$5=15.4[\frac{3.3\times10^3}{3.3\times10^3+R_1}]$$

R_1=6.864kΩ

Practically, R_1= 6.8kΩ

For the inverting terminals, a pre-set resistor RV2 of 10 KΩ variable and R_3=10KΩ forms a potential difference to give a regulated voltage of 5V for comparison in Op-amp U1:A in voltage sensing at Under voltage conditions.

ii. High voltage sensing circuit design for overvoltage protection

Considering the under-voltage condition as high voltage sensing circuit is shown in Fig.4. When the line voltage is equals or greater than 250V, the voltage at the inverting terminal of operational amplifier U1:B is greater than or equal to the voltage at the non-inverting terminal. Thus the output of operational amplifier U1:B goes off and de-energies the relay through transistor. The AC supply is disconnected from the load and electrical appliances turn off. Thus the appliances are protected against over-voltage.

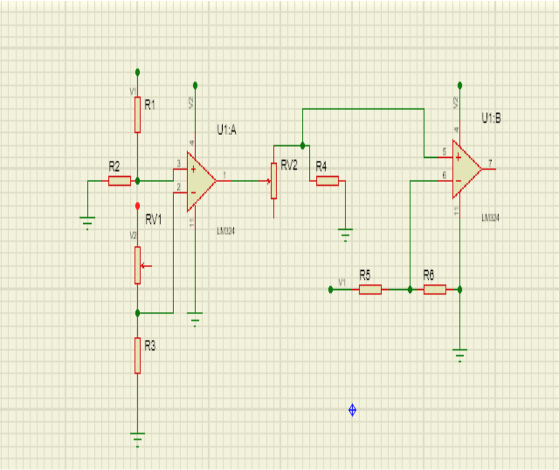


Fig 4: High voltage sensing circuit

The non-inverting terminal of the Op-amp U1:B is connected to the regulated output terminal of the low voltage sensor; after which the condition has been met. While the inverting terminal is connected to the Unregulated, a pre-set potential divider will be used to reduced and regulated the voltages at the output terminal for Op-amp U1:A to a regulated 5V for the non-inverting terminals. A designed potential divider will be used to regulate and reduced the unregulated voltage at 250V to a regulated voltage of 5V; which is the overvoltage condition.

Whenever the voltage at the non-inverting input terminal is lesser than or equals the inverting input terminal, the Op amp output will be at logic 0, thus making the Op-amp sensing an overvoltage.

Therefore, after voltage division, v_o=5v

At the inverting terminal, assume R_6 as 3.3kΩ

Apply voltage divider principle: $Vi \;= V_{in}[\frac{R_6}{R_5+R_6}]$, where Vi is the inverting terminal input voltage.

At an input voltage of 250V, the unregulated and rectified voltage is 38.6V.

Vi = 5V, But V_{in}= V_{max} =38.6V

$5=38.6[\frac{3.3\times10^3}{3.3\times10^3+R_5}]$; R_5= 22.18kΩ

But, practically; R_5 is 20kΩ.

NB: at R_5 = 20KΩ, the inverting terminal input Voltage Vi = 5.4V. This satisfies the condition at overvoltage that the inverting terminal input voltage should be either greater than or equals the non-inverting input voltage.

For the non-inverting terminals input terminals, a pre-set resistor R_{v2} of 10kΩ variable and R_4=10kΩ forms a potential difference to give a regulated voltage of 5V for comparison in Op-amp U1:B in voltage sensing.

Table 1: Variation of D.C Voltage against Input Supply Voltage (Calculated).

		U1:A		U1:B	
AC Input Voltage (V)	Unregulated (DC) Voltage (V)	Inverting Terminal Voltage(V)	Non-inverting terminal voltage(V)	Inverting terminal voltage(V)	Non-inverting terminal voltage(V)
280	43.14	5	14.00	5.59	5
250	38.52	5	12.50	5.00	5
220	33.90	5	11.00	4.39	5
190	29.65	5	9.50	3.79	5
160	24.65	5	8.00	3.19	5
130	20.03	5	6.50	2.59	5
100	15.40	5	5.00	1.99	5
70	10.78	5	3.50	1.40	5

D. Timing Circuit

This is the timing delay set for the system to switch or transfer to either the main supply or the auxiliary supply. The time delayed for the output of the Op-amp2 to send a signal after over-voltage condition is being passed to the next Op-amp, the time delayed for the transfer switching to occur and also the time delay for generator cut off.

T = $C_T \times R_T$

Let take T = 4seconds to set a delay for the aforementioned actions.

The capacitor required for the timing = 470μF/16V

$R_T = \frac{4}{470\times10^{-6}}$ = 8.2kΩ.

E. Transistor Switching Stage

The switching transistor switches the relay, which selects between the generator and public power supply. A base R_B resistor is required to ensure perfect switching of the transistor.

$R_B = \frac{V_{in}-V_{BE}}{I_B}$; V_{BE}= 0.7V (silicon); (0.3V-germanium) [4]

The input voltage; V_{in} = 5V

h_{fe}= 250 (from datasheet for BD135).

The base current; I_B is therefore calculated from current gain: $h_{fe} = \frac{I_C}{I_B}$

I_B=3.2mA

The collector current; I_c= 30mA

$V^+ = I_C R_C + V_{CE}$

The supply voltage; V^+ = 24V, collector resistor; R_C = 800Ω chosen with regard to the resistance of the relay coil, used in this work and the collector-emitter voltage V_{CE} = 0V (when transistor is ON). Therefore, R_B = 1.5k = 2.2k (preferred value).

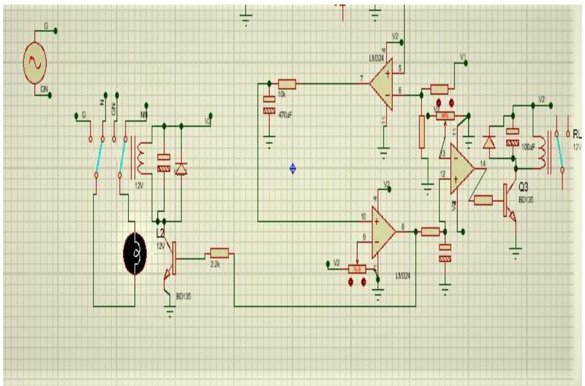


Fig 5: Transistor switching stage

F. Change-Over/Electrical Relay Isolation Stage

i. Coil Voltage: The relay coil voltage rating and resistance were taken into consideration.

ii. Coil Resistance: The circuit must be able to supply the current required by the relay coil.

From Ohm's law, relay coil current = $\frac{supply\ \ voltage}{coil\ resistance}$

Relay coil current = $\frac{V}{400\Omega}$ = $\frac{24}{400}$ = 60mA.

III. TEST, RESULTS AND DISCUSSION

PROTEUS RESULTS: Fig.6 is a circuit diagram of an automatic transfer switch on PROTEUS environment. The purpose of this circuit is to measure output voltage and the pulse width modulation waveform used in driving the MOSFET.

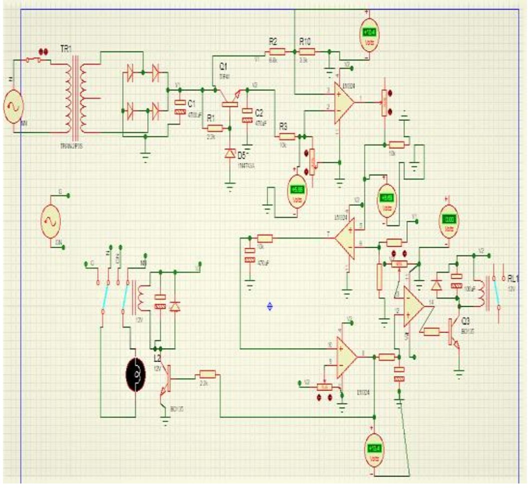


Fig 6: Proteus simulation results at 220V power supply

From the simulation of the ATS circuit, the ac voltage source 220Vof frequency 50Hz was used as single phase power supply. At the load side, a bulb was used as load for single phase supply. Voltmeters and ammeters were used at the places where it was necessary to take the voltage and current for analysis.

The simulation was done under three conditions as follows:

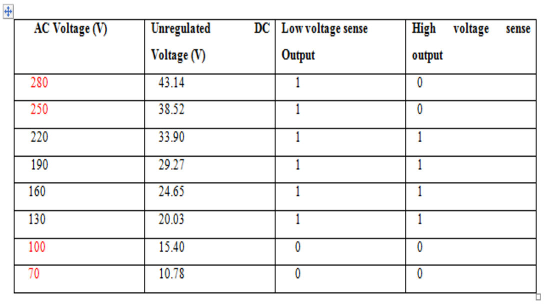
a) The single phases nominal voltage ratings (220V, 50 Hz).

b) The single phase ATS low voltage sensor that cuts of low voltages (≤100V, 50 Hz).

c) The single phase ATS high voltage sensor that cuts of high voltages (≥250V, 50 Hz).

In all the three conditions listed, loads must get correct level of voltages for their perfect operation.

Table 2: Logic Output



AC Voltage (V)	Unregulated DC Voltage (V)	Low voltage sense Output	High voltage sense output
280	43.14	1	0
250	38.52	1	0
220	33.90	1	1
190	29.27	1	1
160	24.65	1	1
130	20.03	1	1
100	15.40	0	0
70	10.78	0	0

A 220V supply, the comparator satisfied the condition, thus energized the relay at the N supply terminal and lightened the bulb.

When the mains supply is cut off, there is 8 seconds time delay before switching over to the auxiliary supply. During the time delay, the relay delays and switches to the G terminal. When the main power supply is restored, there is a time delay of 8 seconds again for the generator cut off at the relay 2 and return to mains.

IV. RECOMMEDATION

The main limitation of this work is that the issue of voltage fluctuation which will leads to intermittent starting of the generator could not be addressed. With this, I hereby recommend that such problem should be taken up in further research.

V. CONCLUSION

The exercise of designing the module is of great benefit due to the epileptic nature of our mains power supply. It is laudable to note that all goals are achieved within available resources and constraints. The exercise proved to be simple equipment while the systems could be conceived, designed and fabricated locally, thereby reducing the cost of production.

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