Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 1 Issue 4, November - 2014

Design and development of a low cost automatic transfer switch (ATS) with an over-voltage protection

Lanre Olatomiwa, Rasheed Olufadi
Department of Electrical and Electronics Engineering,
Federal University of Technology, Minna PMB 65, Niger State, Nigeria
Corresponding author: olatomiwa.l@futminna.edu.ng

Abstract- Erratic power supply owing to inability of public power supply utilities to meet the demands of the populace has necessitates the need for an alternative or emergency source of power supply (such as generator set). In this case, transfer switch is usually used to transfer different sources of power to the load. Manual transfer switch involves the use of manpower in operating the generator set and then changing the supply from utility line to generator, when there is power failure, and vice-versa, this often wastes time and sometimes unreliable. Hence, the needs for an automatic transfer switch. The objectives on the design centers on sensing of the primary/main source of power supply when restored, startup the secondary source (generator) when main power fails, shutdown the generator when the main source is power restored as well as automatic transfer of load to the available power source, thereby making the entire process easy and reliable. In order to achieve the objectives, the utility power supply (main source) considered in this the study is single phase power supply and the device it made to operate on a 5KVA single phase (key operated) generator set.

The main design was carried out with a low cost solid state electronic component such as; contactor, transformer, relays, Op-amp, 555 timer, voltage regulator, transistors, resistors, capacitors, diodes and so on. The entire work was implemented with hardware, tested working and perfectly functional.

Keywords-*Automatic transfer switch; over-voltage protection; generator; public utility supply*

I. INTRODUCTION

A transfer switch is an electrical device that is capable of alternating and transferring a load from one source of power supply to another [1]. The basic function of a transfer switch is to make and break from one source of power supply to another. It can also serve to isolate power sources in the event of overvoltage, thus preventing power surge. A manual operation of transfer switch requires the availability of electrical personnel to operate the switch. Thus, it cannot be used in some industrial and commercial applications where absence of power for a certain period of time could have serious implications in terms of life and financial losses due to loss of production, data storage and products. In order to eliminate the time delay between changing over from one source to another, there is therefore a need for an automatic transfer switch.

Automatic transfer switch (ATS) serves as an interface between power sources in order to maintain a continuous supply of electricity to the load [2]. The switch automatically senses power failure on the power utility line, sends signal to the generator for startup. At the moment the generator attained it nominal speed, the automatic switch disconnect the utility line and then transfer the load to the generator, thereby restoring power to the load. The switch will continue to monitor the condition of the utility power source until it is restored, and then it will delay for some seconds to ensure that the utility line voltage is stable, after this, it then send signal to shut down the generator and then retransfer the load back to the utility line.

Over the years, some research works have been carried out to improve the design of ATS so as to achieve reliability and flexibility. These works includes the development of a pre-integrated digital power switching system which is efficient, flexible and user's friendly [3]. Loren *et al* [4], designed an ATS for residential and small industrial load. This work comprises of a power supply, a charger, microcontroller (MC), LEDs, LCD, input keyboard and switches. The MC is configured to monitor the total elapsed running time of the generator, total elapsed time since last maintenance, and also to provide at least one alarm to an operator to provide maintenance of the generator after a predetermine time elapse. The MC comprises of a display and input panel to enable an operator to input programmable memory instructions for the control parameter. Peter and Walter [5], also invented an improved actuator based transfer switch. This work relates a method of actuating ATS to alternate the power supply to an electric load. The transfer switch comprises of output contacts, primary input contact, secondary input contacts, a toggle mechanism consisting of crossbars and actuator that rotates the crossbar to alternately engage a first set of moving contact with the output contact and primary input contact, it also relate the second crossbar to alternately engage a second set of moving contact with the output contacts and the secondary input contact. A user oriented ATS was developed in [6]. The ATS includes a power circuit, transformer, solenoid driver circuit and a controller. The controller uses an embedded microcontroller to monitor utility and generator voltages which are interfaced to a user interface for operator instructions at the operator interface. The controller is configured with generator cool down timer, generator warm up timer, loss of power delay timer, generator fail to start timer, generator crank timer and utility stabilization switch back timer. More so, the controller includes configuration section which contains plurality of user selectable jumper to facilitate the control operation of the controller. The controller solves problems such as external relay transformer boxes separated from the controller, a need for an external exerciser clock.

In view of this, there is a need to design an ATS that will have high power capability, efficiency, as well as cost effectiveness. The previous works mentioned above do not take into consideration the effect of an over voltage on the load. An over-voltage circuit protection is incorporated in this work to mitigate the effect of over-voltage on the load output.

II. Material and Method

Modular approach is employed in the circuit design of the automatic transfer switch and this consists of six (6) major units namely; the regulated power supply unit, over-voltage protection unit, time delay unit, driver and switching unit, control unit and changeover unit. Fig. 1.0 shows the block diagram of the modular design.

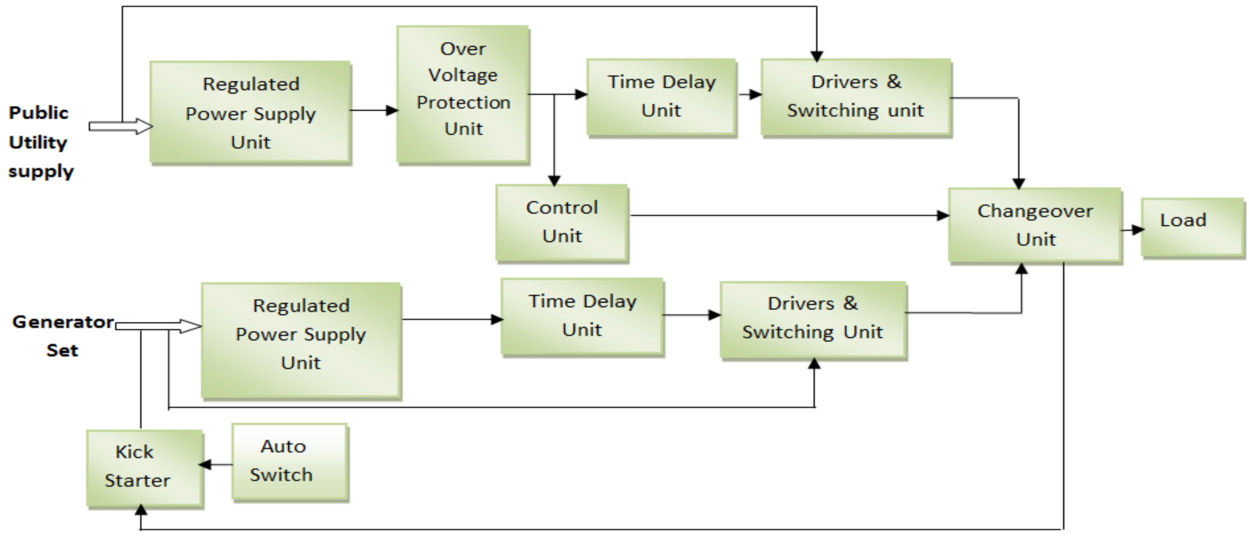


Fig.1. Block Diagram of the modular design.

The regulated power supply unit ensures a constant supply of 12V dc voltage to the electronic components in the circuit and in case over voltage is supply by the utility source, the over voltage protection units 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 preset time to ensure that the utility line voltage is stable, then sends signal that will cause the driver and switching unit to first de-energies the kick starter relay in the control unit, and then cause the changeover unit to disconnect the generator and transfer 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.

A. Design of 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 figure 2. The following specifications are considered in the selection of the transformer used in the design; output voltage: 12V (min), ripple voltage: 2V, load current: 1A (max), diode forward voltage drop: 0.7V according to the following equations [7];

$$V_{\max} = V_{out} + 2\ (\text{diode forward voltage drop}). \quad (1)$$

Peak voltage, $V_p = V_{rms} \times \sqrt{2}$ (2)

Also, the amplitude of the output voltage or the peak output voltage of the rectifier V_{P2}, for a full wave bridge rectification is given as [7];

$$V_{p2} = V_p - 2V_d \quad (3)$$

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 is obtained by [8]:

$$V_{dc} = 2V_p/\pi \quad (4)$$

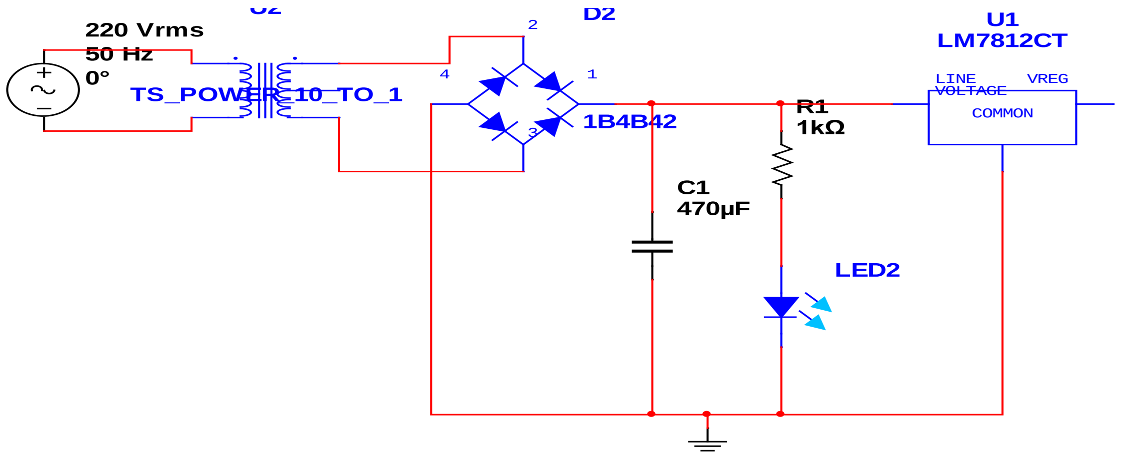


Fig. 2 Power supply unit

Peak Inverse Voltage (PIV) is the maximum reverse voltage that a diode can 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 [8]. That is;

$$PIV = V_p \quad (5)$$

Therefore, 1N4007 diode used in deign have the following specifications; maximum current: 1A, bias voltage: 0.7, and peak reverse voltage: 1000V [11]. The design of the filter circuit is based on the choice of the capacitances of capacitor, and this can be obtained from [9, 14];

$$C = \frac{I_{dc}}{4\sqrt{3}f\gamma V_{p2}} \quad (6)$$

where I_{dc} is the load current of the transformer ,C is the capacitance of the capacitor, V_{p2} is the peak output voltage of the rectifier and γ , the tolerable ripples voltage (2%).

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 [8]. A LM7812 fixed positive voltage regulator is used for the regulation of power supply [17]. It has a minimum and maximum input voltage of 14.6V and 35V respectively and produced 12V$\pm$5% outputs. This is suitable because the maximum peak of the rectified voltage is calculated as 15.6V.

B. Design of over voltage protection unit

The non-inverting terminal of the Op-amp is connected to the unregulated input terminal (V_{unreg}) of the voltage regulator (figure 3) which varies with the input mains. Thus making the Op-amp to be able to monitor and sense over-voltage. Whenever the voltage at the non-inverting input terminal (V_{in}) is greater than the inverting (V_{ref}) input terminal, the Op amp output (V_{out}) will be at logic HIGH, otherwise, the will be at logic LOW [9,15].

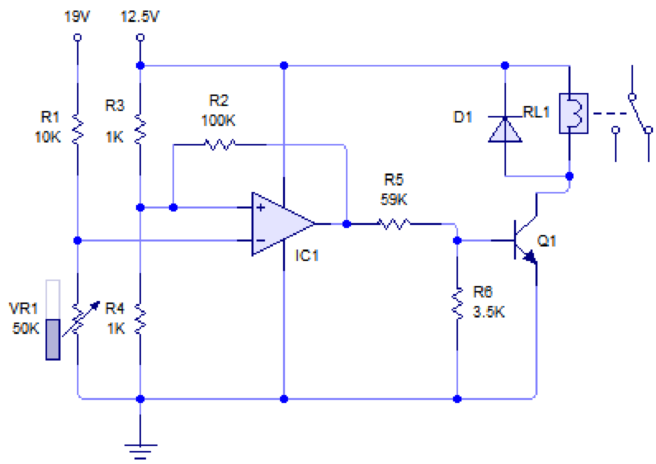


Fig. 3: Over Voltage Protection Unit

Assuming, the voltage drop across the resistor, V_{R1} beyond 240V ac input voltage is 6.1V and the average dc voltage (V_{dc}) is 19V. This implies that the variable resistor, V_{R1} is preset to 4.7K (as calculated from eqn. 7) in order to obtain a voltage drop of 6.1V that will cause the Op-amp output to go LOW, since the V_{ref} is chosen to be 6V.

$$V_{R1} = \frac{V_{unreg} \times R_1}{R_1 \times R_2} \quad (7)$$

The output voltage of the Op amp (V_{out}) is given as [7];

$$V_{out} = \frac{R_4}{R_3}(V_{R1} - V_{ref}) \quad (8)$$

C. Design of the driver and switching circuit

The switching transistor operates the relay (RLY_1) which prevents over-voltage from going to the output load. The output of the over-voltage protection circuit serves as the input voltage (V_{in}) to the biasing arrangement of the transistor Q1. In this work, C1815 transistor was selected as the switch. From the manufactural data sheet[10], the following specification were obtained; V_{BE} (0.7V), V_{CE} (6V), I_C (2mA) and the h_{fe} gain (100). From these, the base current of the transistor (I_B) is obtained from eqn. (9) [8];

$$I_B = I_c/h_{fe} \qquad (9)$$

Other parameters considered include the resistance of the relay coil (400Ω), while resistance values of the resistor R_1 and R_2 are calculated as 3.5K Ω and 56.5KΩ respectively. The design is as shown in Fig 4.

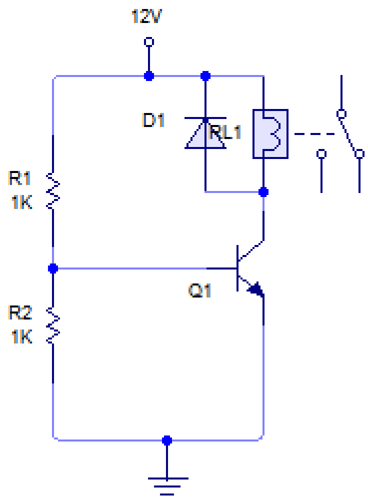


Fig. 4: Driver and Switching Circuit

D. Design of the delay circuit

From figure 5, the time constant for the delay unit is given as [7];

$$T = 1.1R_8C_3 \qquad (10)$$

Resistor, R_7 and capacitor, C_2 are used to generate the input clock pulse to pin 2 of IC 555 timer to triggers its operation. The value of the capacitor, C_4 is chosen so to be able to control the output voltage from oscillation [16]. Thus the IC 555 timer output (pin 3) will remain HIGH for the preset time. This is also applicable to the delay unit found in the generator section (Fig 6).

The ignition coil of a generator operates step-up transformer by principle of electromagnetic induction. When the auto switch, SW_2, is operated, the battery voltage is transferred to the primary winding of the ignition coil while cranking the generator and creates magnetic field which also surrounds the secondary windings. After the preset time elapses (5secs), the RLY_4 de-energizes and the voltage applied to the primary winding is cut-off, thus causing the magnetic field stored in the relay coil to collapse suddenly.

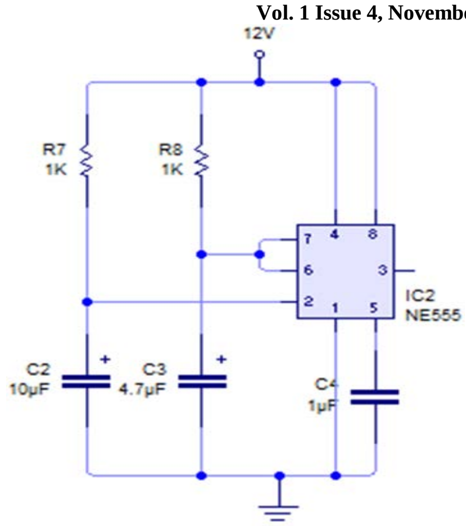


Fig. 5 Delay circuit for primary source (public utility)

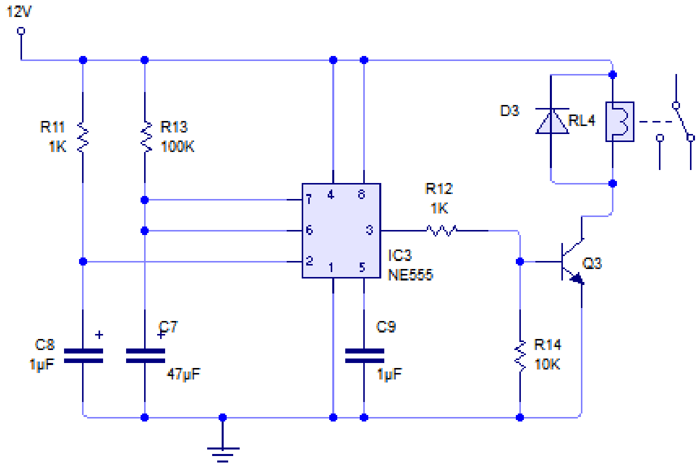


Fig. 6 Delay circuit for secondary source (generator)

The rapidly changing magnetic field produced by this effect is transferred to a high wound secondary winding as current. The secondary winding thereby creates a high voltage spike required for sparking the plugs for generator operation [3].

E. Design of the changeover/contactor Unit

This design is intended for 5kW load. The full load current can be obtained from [11];

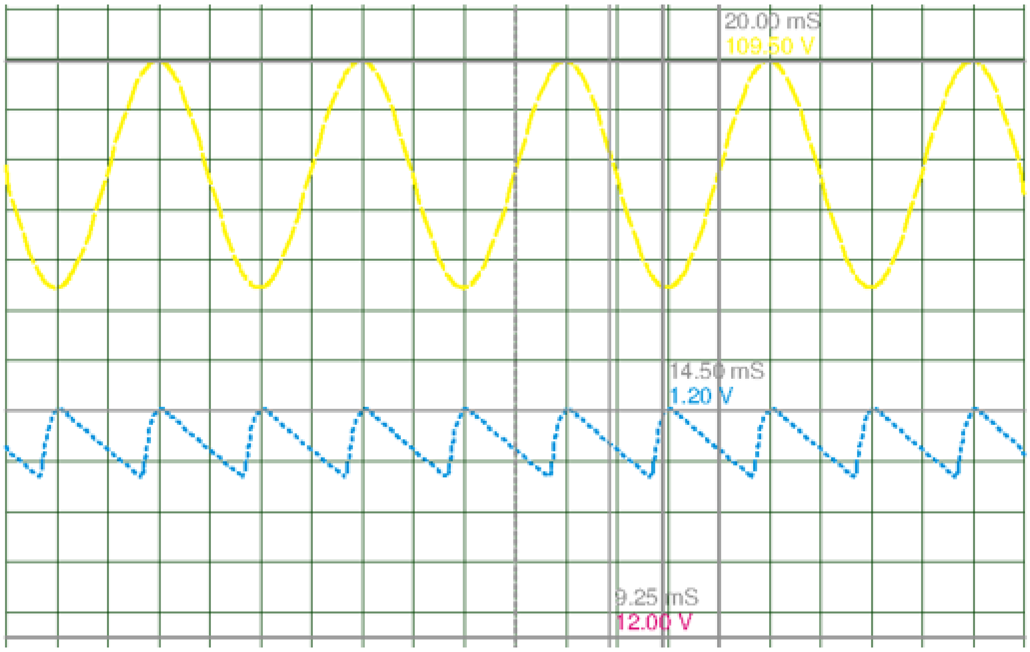
$$I = \frac{P}{\sqrt{3}\times VIcos\varphi} \qquad (11)$$

where P is the load power, V is the mains supply voltage and $cos\varphi$ is the power factor (0.8). The running current is considered while selecting the contactor rating for the designs. Since the full load current is calculated as 16.4A (from eqn.11), a higher value 40A contactor was selected for the mains and the generator operation in order to ensure reliable operation and also for future extension purpose. Relays with dc rating (10A/12V) and ac rating (5A/220V) where selected to meet up with the design specification.

III. RESULTS AND DISCUSSIONS

After the necessary calculation of the entire design parameters, and component values, the designed circuit was first simulated with Proteus 7.8 (electronic simulation package) [13], before final implementation of the hardware. The results of the simulation confirmed good workability of the entire design.

Fig. 6 shows both the input and output waveforms of the power supply section of the design, from this figure, it can be observed that the input ac signal is well regulated to produce a near perfect dc regulated voltage that supply the various electronics components in the circuit. The regulated power supply unit is designed to produce a constant 12V dc voltage at the V_{CC} terminal. Table 1 also presents the results obtained at the input and output of the voltage regulator, LM7812, as the input mains supply varies. It is observed that the output of the voltage regulator is maintained at 12V±5% when the mains power supply is $\geq 180V$, which is within the range needed for the electronic circuit.



	Channel A	Channel B	Channel C	Channel D
V/Div	48.67 V	2.00 V	5.00 V	5.00 V
Offset	360.13 V	-6.40 V	-79.00 V	-60.00 V
Invert	Normal	Normal	Normal	Normal
Coupling	AC	AC	DC	Off

Fig. 6 Simulation result of the power supply module

Table 1: Input and Output of a Voltage Regulator.

Ac mains voltage(V)	Regulator input (V)	Regulator output (V)
180	11.85	11.58
220	13.67	11.95
230	14.90	12.45

The over voltage unit is designed to sense and arrest overvoltage when it is supplied by the primary source. A variac, which is an electrical devices that have a ranges of output voltages was used in presetting the over voltage circuit. The results shown in Table 2 were obtained when the reference voltage at the non-inverting terminal (pin 3) of the Op amp is 6V.

A critical look at Table 2, shows that whenever the mains supply is within the desired voltage range, the non-inverting (V_{in}) input terminal of the Op amp is always greater than the inverting (V_{ref}) terminal. As such the output of the Op amp remains high. But when the mains supply voltage is 240V and above, the V_{in} will be less than the V_{ref}. And as such, the Op amp output, V_{out}, goes low (0V), thereby de-energize the relay and disconnect such voltage from getting to the output load. Thus, protects the load from overvoltage.

Table 2: Output of overvoltage protection circuit with varying input voltage

AC main voltage (V)	Inverting input voltage (V)	Op-Amp output voltage (V)
220	5.82	10.23
230	5.94	10.23
245	6.09	0.00

The delay unit, at the primary source, is designed to hold the incoming power supply for a preset time while generator is shutting down unlike the delay unit at the secondary source that is used for disconnecting the battery terminals, which start the generator, after the preset time elapses. Table 3 shows the outcome of the time delay for various input voltage.

Table 3: Variation of delay with input voltage

AC mains source voltage (volts)	Time (secs.)
180	5.75
220	5.03
230	4.85

The driver and switching unit is designed to isolate the generator output from the load when the utility supply is restored and also to operate the control unit to start/shutdown the generator depending on the situation of the mains source. Initially, the resistance of the relay coil was measured to be 400Ω. A digital multimeter, with its knob set to the dc voltage range, was used to measure the V_{cc} voltage and the relay voltage as the mains source voltage varies. Table 4 present the results obtained. Actually, a 400Ω resistance coil is needed to give the relay good excitation when current flows through it. Whenever the delay output goes HIGH, the driver generates the required voltage to energize the relay for isolating the generator live output and for operating the control unit.

Table 4: Variation of relay coil voltage and Vcc with changes in ac mains supply

AC mains voltage (V)	V_{CC} (V)	Relay coil voltage (V)
180	11.58	11.23
220	12.45	12.05
240	13.50	0.00

Finally, the changeover unit was tested to determine the voltage at which the contactor operates to transfer power to the load. ON and OFF were used to denote when the contactor energizes/inactive as shown in Table 5. This shows that for the contactor to energize the resistance of the coil must be within the range of 500-700Ω and the supply voltage must be $\geq 170V$.

Table 5: Status of contactor operation as the mains supply varies.

Ac mains voltage (V)	Operation
120	OFF
150	OFF
170	ON
220	ON

IV. Conclusion

The work presented in this paper center on the design and development an automatic transfer switch (ATS) with the capacity to transfer power between two sources of power supply to the load. The public utility supply is considered the primary source, while a key-operated ignition generator is the secondary source. The ATS works to transfer the public utility line to generator line when there is failure on the line and to also switch over to primary source and shut down the secondary source when the main source is restored. Moreover, the design also has the capability of taking care of over-voltages whenever it occurs, thus protecting the output load from damage. The simulation results of series of test carried out on the design ant its hardware confirm the workability of the entire setup.

All the materials and components utilized in this work are sourced locally; they are low cost and also readily available. Hence, this design is recommended for homes, schools, offices, hospital, data centers and any other applications where constant supply of electricity is of paramount importance.

References

1. Mokhtari, H., Dewan, S. B., & Travani, M. R. (2000). Performance evaluation of thyristor based static transfer switch. Power Delivery, IEEE Transactions on, 15(3), 960-966.
2. Eaton, Zane C., Anthony J. Hackbarth, and George C. Henegar. "Automatic transfers switch system capable of governing the supply of power from more than two power sources to a load." U.S. Patent No. 7,005,760. 28 Feb. 2006.
3. Cummins Power Generation Inc. Transfer Switch for optimum reliability and efficiency, available at www.cumminspower.com accessed on February 20, 2013.
4. Loren, L.R and Larry D.H (2003) Transfer Switch with Improved Actuator United State Patent, US 6,765,157 pp 5-7

5. Peter J.R and Walter Payack (2004). ATS System and controller. United State Patent, US 6,876,103 pp1-3.
6. Ashour, H. (2004, June). Automatic transfer switch (ATS) using programmable logic controller (PLC). In Mechatronics, 2004. ICM'04. Proceedings of the IEEE International Conference on (pp. 531-535). IEEE.
7. Horowitz, P., Hill, W., and Hayes, T.C. (1989). The art of electronics (vol.2, p.658). Cambridge: Cambridge university press. Pp: 140-143.
8. Gupta, J.B. (2009). Rectifier: Electronic Devices and Circuit. (3rd Edition, pp 656-659).New Delhi: S.K Kataria and Sons.
9. Theraja, B.L and Theraja, A.K (2012). Working Principle of Transformer: A Textbook of Electrical Technology. (11th Edition, pp2148). New Delhi: S. Chand.
10. Futurlec semiconductor (2013). Transistor Datasheet. Available at http://www.futurlec.com/Transistors/C1815.shtml
11. Futurlec semiconductor (2013). Diode Datasheet. Available at http://www.futurlec.com/Diodes/1N4007.shtml
12. Gómez-Expósito, A., Conejo, A. J., & Cañizares, C. (Eds.). (2008). Electric energy systems: analysis and operation. CRC Press.
13. Labcenter Electronics Ltd. Proteus Electronic simulation software. Available at http://www.labcenter.com/products/pcb/schematic_intro.cfm
14. Miomir, F.D. (2007). Capacitor: *Understanding Electronics Components [Online Textbook]*. www.mikroe.com/ MikroElektronika.
15. Gupta, J.B. (2009). Operational amplifier: Electronic Devices and circuit. (3rd Edition, pp656- 659). New Delhi: S.K Kataria and Sons.
16. Gupta, J.B. (2009). 555 timers: Electronic Devices and Circuit. (3rd Edition, pp 656-659).New Delhi: S.K Kataria and Sons.
17. Gupta, J.B. (2009). Voltage Regulator: Electronic Devices and Circuit. (3rd Edition, pp 656-659).New Delhi: S.K Kataria and Sons.