A 5kva Automatic Transfer Switch With Overload, Short Circuit Protection And Generator Stop Functions

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***Abstract*—Automatic transfer switches (ATSs) are very necessary for the operation of electrical systems as they allow the transfer of loads between power sources without physical intervention. To ensure efficient and zero physical intervention in operation, the specific objectives of the present design are to achieve: automatic transfer switching, overload protection, short-circuit protection and generator stop functions. The design is implemented with solid state switching and programmable logic controlled by peripheral interface controller (PIC). TRIACs are used for the transfer switch giving a seamless and noiseless transfer. The necessary sensory units, isolated voltage sensor and isolated current sensor, are responsible for the overload and short circuit protection while the PIC, being the brain of the system, governs all operations. Testing of the implemented prototype shows fast switching time, accurate and stable generator shutdown, overload and short circuit protection; thus, the set objectives of this research are, therefore, achieved.**

Keywords: automatic transfer switch (ATS), peripheral interface controller (PIC), overload, short-circuit, voltage and current sensors

I. INTRODUCTION

For a country like Nigeria with incessant power outages, necessitating researches in alternative sources of power supply [I, 2], it is pertinent to have a device to transfer loads from utility supply to a generator or any other sources of power supply and vice versa in a seamless and timely manner without manual intervention. Beside this seamless transfer of loads between alternative sources of power, security of devices is also a source of concern in event of voltage surge or short circuit faults. An ideal transfer switch is, therefore, expected to be versatile in function [3].

For most purposes, ATSs are used to transfer load among several sources to ensure continuous operation of loads [4, 5]. It is reckoned as a very important component in electrical power systems at the consumers' end [6]. An effective way to improve the power quality and reliability of sensitive customers load is to use a static transfer switch [7].

Traditionally, relays have been used to transfer loads but unfortunately, the following demerits are observed: large switching losses, mechanical wears and tears, large sound due to mechanical movement, long switching time etc [8,9,10]. A typical case study is presented in [11]

From the literature, [12] used CMOS ICs to design an automatic power changeover Switch with emphasis only on power transfer between sources. An ATS using communication protocol in smart grids with emphasis on maintaining continuous power supply was presented in [13]. Again, [7] developed a model for a thyristor based automatic transfer switch presenting the complete analytical model for static transfer switches. Also, [14] developed an ATS with delay time of 0.3-0.8 seconds with focus on the protection of electrical devices by connecting through automatic switches between various sources and load to enable for smooth transition of power and causing very little interruption of supply to the load.

Considering the aforementioned inputs and limitations of the reviewed literature, the present ATS design aims to ensure efficient and zero physical intervention in operation. The specific objectives of the design are to achieve automatic transfer switching, overload protection, short-circuit protection and generator stop functions utilizing solid state switching between three power sources, the primary and two secondary sources. The switch will be built on solid state technology and will have a remote STOP feature to put OFF the secondary source when the mains supply is ON. It will also be menu driven, as it will be controlled by a PIC and will be very interactive with an LCD display showing such electrical characteristics as: voltage output, load conditions, and the source of power, whether mains or secondary sources.

II. DESIGN METHODOLOGY

The complete block diagram of the ATS as shown in Figure 1 is designed and successfully simulated in Proteus 8.1environment. This is followed by hardware implementation to realize the prototype. The sub-circuits of the system are explained in the following sub-sections:

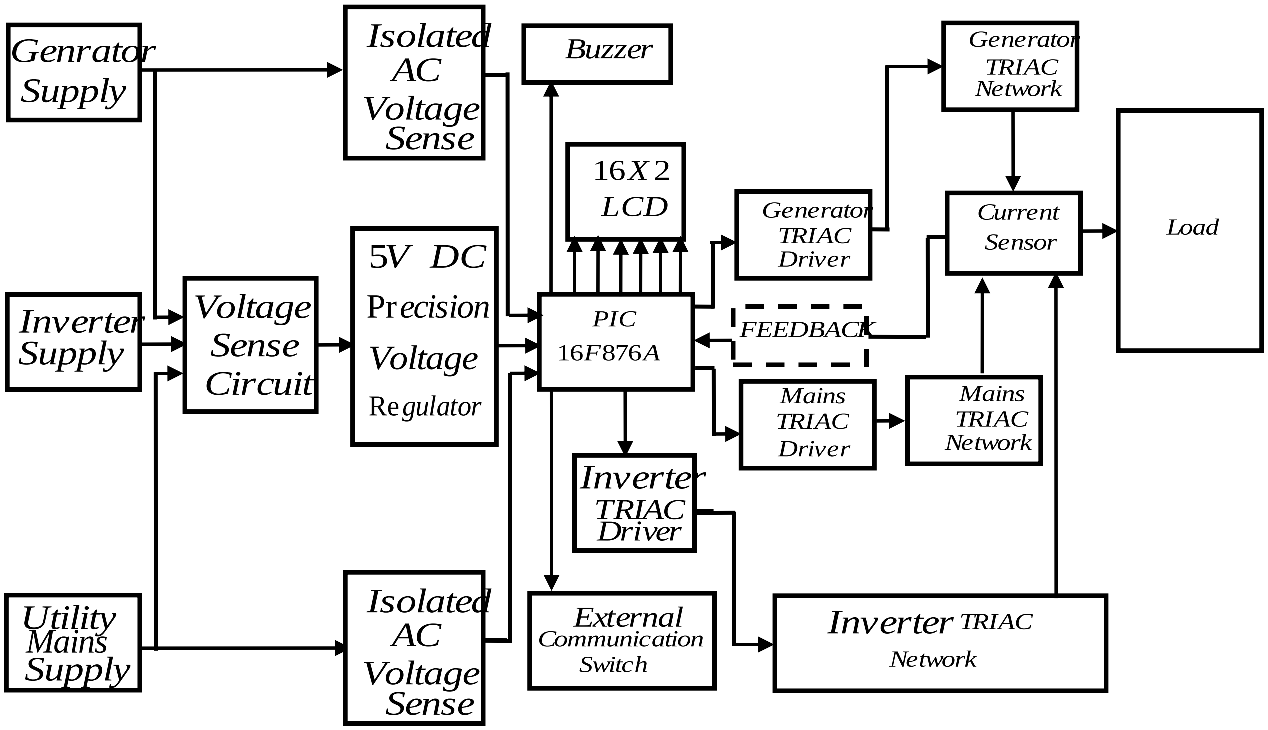

Figure 1. Detailed block diagram of the automatic transfer switch

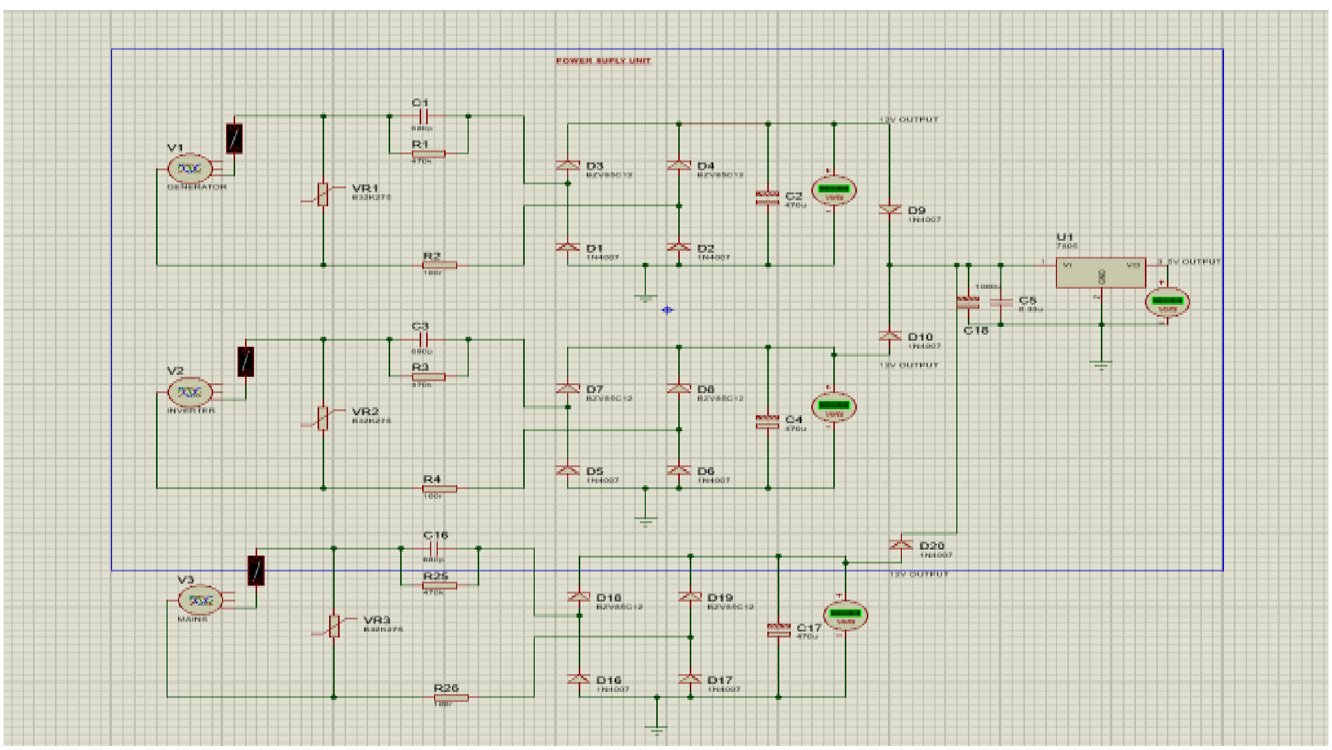

Figure 2. Power supply unit

A. *Power Supply Unit*

This unit is responsible for supplying the required voltage (12V) to the circuit and the necessary voltage to the PIC, irrespective of the source available (utility or secondary sources)

This includes the rectification stage which converts the AC supply to DC. It has the synchronization stage which synchronizes power from different sources. The full wave voltage rectification is done using 12V Zener diodes to ensure that the output voltage is not beyond 12V. The filtration stage which reduces the ripples from the DC signal is done by a 470µF as was selected to be a good enough capacitance to remove most of the ripples from the signal and the voltage regulation stage which regulates the supplied 12V DC to 5V DC which the PIC can operate with. The circuitry of the power supply unit is shown in Figure 2.

B. Isolated Voltage Sensor Circuit

This unit senses the presence of voltage at the power supply unit and passes on the voltage to the PIC which operates the system. This unit operates on isolated voltage because the PIC does not need any form of interference resulting from the direct conversion from AC to DC leading to undesirable stray signals which will affect the operation of the PIC. It makes use of operational amplifier (OP-AMP) configured in differential amplification mode. The circuit is shown in Figure 3.

For the circuit of Figure 3, the following obtains:

$$R_1 = R_{17} + R_{15} + R_{10} \quad (1)$$

$$R_1 = 1M\Omega + 1M\Omega + 22K\Omega = 2022K\Omega$$

$$R_f = 22K\Omega$$

$$Gain = \frac{R_f}{R_1} = \frac{22K\Omega}{2022K\Omega} = 0.011 \quad (2)$$

Output voltage

$$V_o = V_{in} * Gain \quad (3)$$

Where V_{in} is the input voltage of $220V$

$$V_0 = 220V * 0.011 = 2.42V \quad ac$$

Because the above voltage is ac, it is not suitable for the PIC due to the presence of negative half cycle. A constant DC voltage is supplied to the OP-AMP to ensure that a constant positive voltage is obtained and fed to the PIC. In this case, the constant positive voltage is 12V and the output will be determined as follows:

$$V_o = 12V \pm 2.42V = 14.42V \quad or \quad 9.58V \quad (4)$$

This implies that the PIC sees a constant positive voltage from between 9.58V and 14.42V for a standard 220V supply. This value will, however, change slightly when the AC input deviates from the above standard. It is this deviation that the system reads to know when voltage is healthy or not. The capacitances serve as filtration capacitors which serve to ensure that ripples are removed from the signal obtained from the input and fed to the PIC. The value of 0.33µF was used. The comparator used is the LM324N.

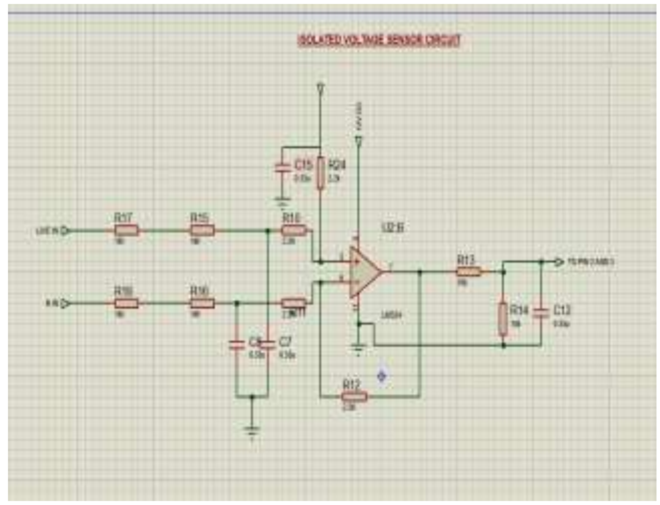

Figure 3. Isolated voltage sensor circuit

C. Isolated Current Sensor Circuit

This section is responsible for sensing the amount of current passing through the system as load is applied on it. This system converts the current observed into the power consumption of the building, by simply multiplying the current by the earlier sensed voltage.

Figure 4 shows the isolated current sensor circuit. It is still configured with the OP-AMP in a differential amplification mode as in the voltage sensor circuit.

D. Generator Remote Stop

This is the circuit that switches the generator off when it senses the presence of power from the mains. Figure 5 shows the necessary circuit of the generator remote stop.

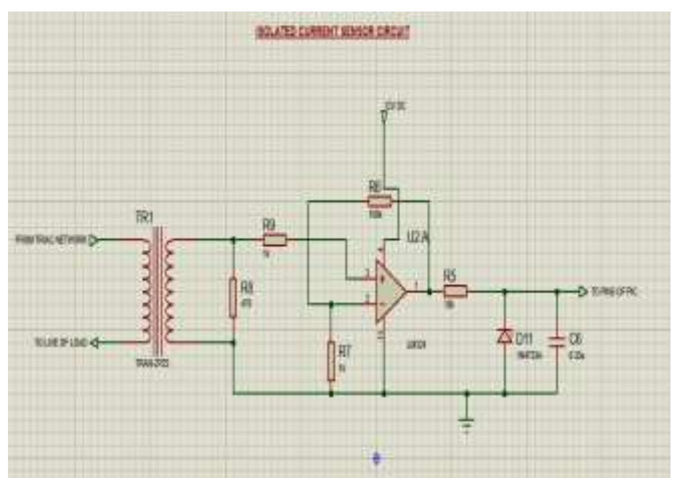

Figure 4. Isolated current sensor circuit

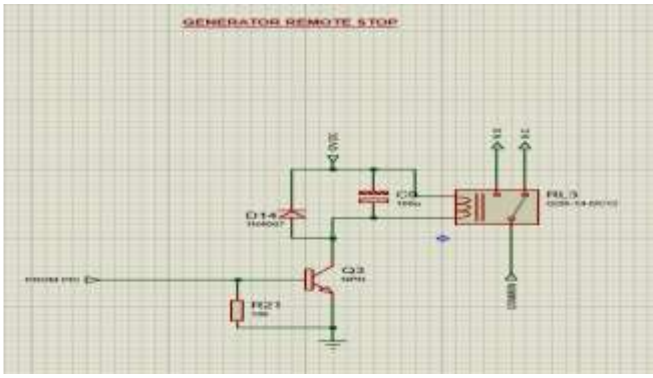

Figure 5. Generator remote stop circuit

E. LCD Driver Circuit

This circuit is responsible for interfacing with the user. The LCD tells the user what is going on in his building in terms of the condition of the AC input, the load consumption, and possible reasons for blackout in case the user was shut out due to faults observed by the system. The LCD driver circuit is shown in Figure 6.

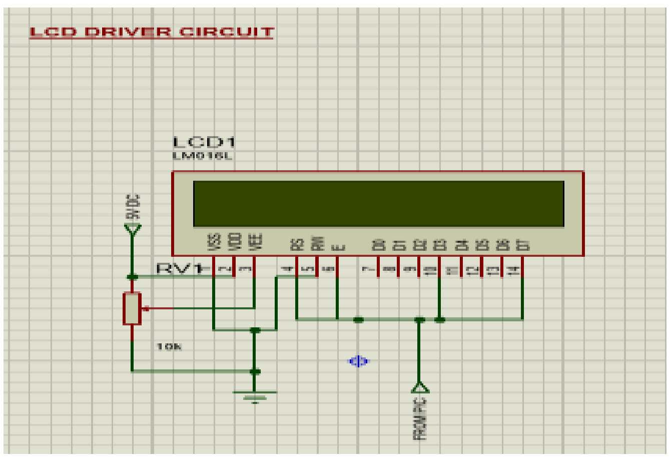

Figure 6. LCD driver circuit

F. Peripheral Interface Controller (PIC16F876A)

The PIC is the sole component which makes this ATS truly automatic and intelligent. The circuit connection of the PIC in the ATS is shown in Figure 7. Capacitors C13 and C14 serve as filtration capacitors which filter out ripples from the regulated DC waveforms derived from various modifications from the input AC. The PIC has a constant 5V DC supply which keeps it functioning. As can be seen, the various pins are for different functions which include signals for the remote stop, LCD, buzzer, and the signals that link the mains, and generator, and inverter sources of power.

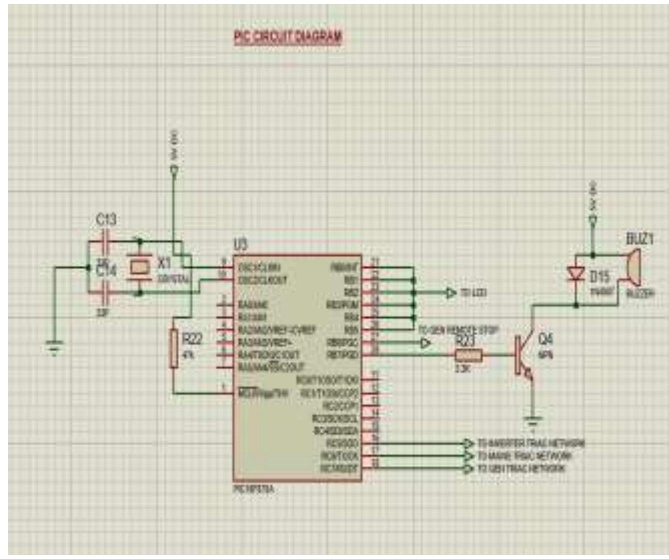

Figure 7. PIC circuit diagram

G. TRIAC Driver Network

This is the circuit which does the actual switching from mains to generator or to inverter depending on the signal from the PIC. The TRIAC driver circuit works like an opto-coupler. When the PIC sends 5V to the LED in MOC3041M, it allows the transistor to close, thereby allowing conduction of voltage through to the current transformer circuit and then to the load of the building. The circuit is shown in Figure 8. The TRIAC changes over without noise, hence the name solid state change over, as there are no moving parts in the system. Taking the mains line as an example, resistors R37, R28 and R29 are limiting resistors which help to limit the current intake of the system even when a fault occurs.

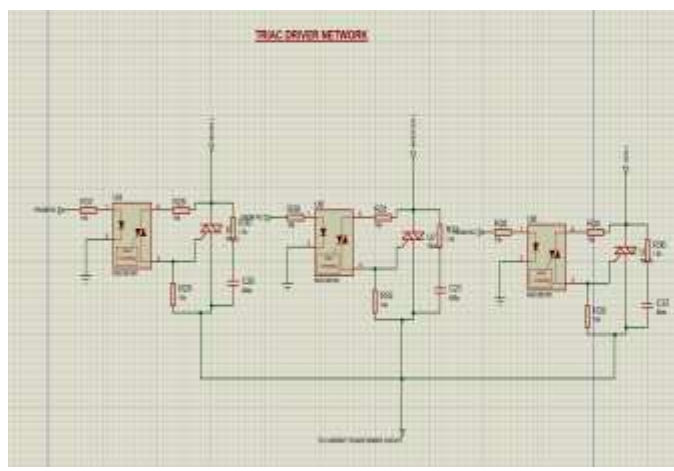

Figure 8. TRIAC driver network

III. TESTING AND RESULTS

Tests are carried-out on the implemented design shown in Figure 9 according to the research objectives.

Figure 9. Implemented prototype of the ATS

A. *Generator Stop Test*

The automatic transfer switch was connected to a typical building setting with power supplies from both the national grid and a standby generator. When the generator was ON, upon sensing voltage from the mains, after a delay of 30 seconds, the generator went OFF, automatically. Figure 10 shows the screen display message upon switching OFF the generator.

B. *Overload Protection Test*

Beyond a load of 2000W, for the above configured system, the system trips the output off. This function is very critical as it controls what load can be plugged to a certain output. This is a protective unit as it saves the electrical installation from electrical stress. Figure 11 shows the screen display when an overload occurs on the system.

C. *Short Circuit Protection Test*

As is common knowledge in electrical engineering, short circuit is a dangerous situation which can lead to unprecedented damage. Short circuit was simulated by connecting a wire between the life and neutral of the output. This led to a total shutdown of the load, as no power was transferred between the input and output. The system, because of this, does not allow the appliance at the load end to be damaged by the short circuit.

It is also noteworthy that when the short circuit is introduced to the system, the transfer switch goes off until a technician or engineer comes to reset the system. For now, there is an error message of overload, as already shown in Figure 11, upon the occurrence of short circuit.

D. *Transfer Switching*

To simulate this situation, the generator was put ON and utility supply was also put ON after a while. Upon sensing the presence of the utility supply, the generator was tripped OFF after a brief delay and transferred the load to the utility supply without any noticeable delay. Figures 12 and 13 show the various switching states of the ATS.

Figure 10. Screen display upon generator shutdown

Figure 11. ATS Screen Display Upon System Overload and Short Circuit

Figure 12. Screen display with the online inverter ON

Figure 13. Screen display when generator is ON and mains is off

Figure 14. Screen display upon occurrence of overvoltage

Figure 15. Screen display upon occurrence of low voltage

It was found that the switching between sources was noiseless because of the TRIACs used in the switching instead of mechanically driven relays. This was also found to switch faster with switching time of 0.1 milliseconds.

E. Over-voltage and under-voltage protection

The system has an inbuilt function which determines the presence of overvoltage and undervoltage and shuts the system down in event of such unhealthy voltages. Any voltage under 130V is considered critically low, and any voltage above 260V is seen as overvoltage. Figure 14 and 15 show the screen message upon occurrence of such phenomena.

IV. CONCLUSION AND REOMMENDATIONS

From the above tests on the ATS, the system was found to work perfectly well, switching automatically with a switching time of about 0.1 milli-seconds. The switching is solid state, and as such is noiseless, which is an improvement from already existing switches which are mechanically driven. The device was also very effective at turning OFF generators without recording any failure after 100 attempts.

Beside the very fast load switching between alternative sources owing to the use of TRIACs switches, the ATS has special features of overload protection; short-circuit protection and generator stop functions. Above all, zero physical intervention is required for the operation. The design is also found to be very interactive with an LCD display showing such electrical characteristics as: voltage output, load conditions, and the source of power, whether mains or secondary sources. These are enhancements to conventional ATSs available in literature.

It is therefore recommend that this device be further optimized for eventual mass producing and marketing. It will add desired values which include, but not limited to, increased convenience, greater power quality and improved protection of devices/appliances.

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