A Microcontroller-Based Automatic Transfer Switching System for a Standby Electric Generator*

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Abstract

Unreliability in electric power supply has occasioned the proliferation of standby generators especially in developing countries. However, the methods and equipment employed to effect power supply changeover remain fraught with challenges ranging from inefficiency to cost. Most industries still employ the manual method of power supply changeover, which is beset by a myriad of setbacks including: time wastage, strenuous operation, susceptibility to fire outbreak and high maintenance frequency. This paper presents a Microcontroller-Based Automatic Transfer Switching System (MBATSS), which eliminates the challenges of a manual changeover system. A voltage sensing circuit, a Hall Effect current sensor, relays, LEDs and an LCD were all coordinated using a PIC16F877A microcontroller. A system flow chart was developed for the firmware and the microcontroller programmed using GCG BASIC programming software. The simulation of the designed circuitry was conducted using proteus design suit software. The simulation results vindicated the method used, thus, confirming the workability of the proposed design. Duration analysis yielded excellent results, as approximately 20 seconds elapses during the entire process of power supply changeover. The timely restoration of power and ease of operation are some of the advantages attributable to the design.

Keywords: Standby generator, Changeover, Microcontroller, Firmware, Automatic.

1 Introduction

Reliable and secure uninterruptible power supply is a *sine qua non* for virtually all industrial operations. The reality, however, especially in most developing countries, is that energy resources are simply inadequate. Most manufacturing industries and firms have to contend with insecure and unreliable power supply coupled with its attendant negative impacts on productivity and cost of production.

The quest for secure and reliable power supply remains a dream yet to be attained, especially in most developing countries. This is as a result of population growth, industrialisation and urbanisation (Aguinaga, 2008; Akparibo, 2011; Fuller, 2007; Kolo, 2007) and improper planning by service providers and governments. Most manufacturing industries, firms and institutions such as hospitals and healthcare facilities, financial institutions, data centres and airports to mention but a few require constant power supply all year round. Power instability generally retards development in public and private sectors of any economy (Kolo, 2007; Anon., 2010; Chukwubuikem, 2012). Any instance of power failure could lead to prohibitive consequences ranging from loss of huge amounts of money to life casualties (Aguinaga, 2008). The spate of frequent power outages without an effective back-up system is truly a disincentive to investors in any developing economy like Ghana (Kolo, 2007).

Indeed, the ravages of power instability have equally necessitated automation of the switching system between national grid energy system and standby generators used as backup. In the last decade, different equipment and configurations have been used in order to cope with this problem (Aguinaga, 2008). An automatic changeover system makes use of sensors and transducers to realise the changeover in a shorter time while eliminating human interference and its attendant errors (Chukwubuikem, 2012).

The main problems associated with a manual switching system are as follows: interrupted power supply, device damage due to frequent commutations, possible causes of fire outbreak due to switching sparks and frequent high maintenance cost due to changeover action and wear and tear of mechanical parts. In this paper, we demonstrate how to surmount these problems by the design of a Microcontroller-Based Automatic Transfer Switching System (MBATSS). We have also performed a simulation to test the workability of the controller using appropriate simulation software.

2 Materials and Methods Used

The materials and methods used to integrate the electric generator as an alternative power source to the grid is very important in determining how secure and reliable the power supply to load can be. The switching system could be manual, where a

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person switches the generator set on when the grid supply is lost and switches the generator off when the grid power is restored or alternatively, automatic switching, where the electric generator switches on and off when the grid is restored (Chukwubuikem, 2012).

2.1 Mechanism of Operation of Electric Power Generators

Electric power generators could produce Direct Current (DC) or Alternating Current (AC). AC power generators consist of armature windings placed in stator slots into which an AC voltage is induced, and a rotor coupled to a prime mover. Mechanical rotation of the prime mover cuts the magnetic flux produced in the stator field by an exciter. This induces an alternating electromotive force in the stator windings. Any load connected to the stator windings completes the external circuit and current flows through the load. Fig. 1 shows a schematic diagram of a practical three-phase alternator.

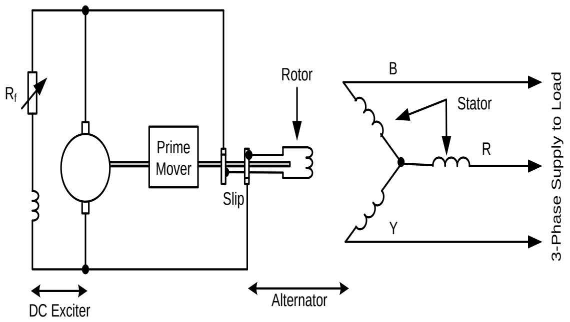

Fig. 1 A Practical Three-Phase Alternator

2.2 Standby Generators

Standby generators Anon. (2011) also known as backup or alternate generators, are secondary sources of electric power usually kept at the premises of consumers to provide electrical power in the event of failure of power supply from a power service provider. Standby generators are installed at the consumer's premises and run in parallel with the utility power supply in order to augment the utility supply, when power is lost Anon. (2012a).

There are other electric generator switching automation systems using electromechanical relays, contactors and timers which comes with some shortcomings, notably: poor sensing ability to fluctuations due to the fact that relays do not function optimally at very low voltages; and slow switching time in the event of mains power supply outage because switching is effected on the basis of energising and de-energising of the relay coils.

2.3 Transfer Switches

Transfer switches**,** also known as changeover switches, are electrical devices designed to power an electric load from multiple sources. They are mainly used with generator sets in applications where the loads need, if not a fully continuous, at least a steady supply of electric power (Aguinaga, 2008). Transfer switches could be manually or automatically operated. A manual transfer switch box separates the utility supply from the standby generator. Whenever there is power failure, changeover is done manually by humans and the same happens when the public utility power is restored and this is usually accompanied with loud noise and electrical sparks (Chukwubuikem, 2012). An Automatic Transfer Switch (ATS) is used with standby systems. It includes a control circuit that senses mains voltage. When mains power is interrupted, the control circuit starts up the generator set, disconnects the load from the utility and connects it to the generator set. It then continues to monitor the mains status. When mains power is restored, it commutes the load from the generator back to the utility within a threshold time Anon. (2012a).

When the generator is disconnected, it goes through a cool-down process and then automatically shuts down (Chukwubuikem, 2012). Fig. 2 shows a schematic diagram of a typical transfer switch. Transfer switches could be installed between two generators, a generator and a utility supply or between alternate utility providers Anon. (2012b).

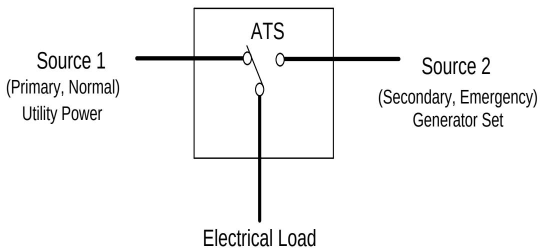

Fig. 2 Schematic Diagram of a Typical Transfer Switch

2.4 The Proposed Switching System

In general, a switch control mechanism could be done electromechanically or solid state-based. Both methods come with corresponding trade-offs ranging from efficiency to cost. The methods of switching on standby generators can also be categorised mainly into two modes: Open

Transition (OT) mode and Closed Transition (CT) mode Anon. (2013a).

An ATS is an electrical device for transferring power sources to an electrical load. The switch should have the ability to sense the loss or fluctuation of power from the main source and based on that stimulus, initiate and execute the process of transfer of source to the load. Normally, the sensing circuits are connected to the power sources through relays. Transfer switching systems have been studied by numerous researchers with different applications usually aimed at reducing component count and minimising power consumed by the control circuitry (Aguinaga, 2008), (Kolo, 2007), (Chukwubuikem, 2012), Anon. (2013a). The ATS is able to monitor all the sources consistently for over/under voltage and current conditions or total loss of power and issue an appropriate command for the transfer of load to an alternate power source.

This paper reports on the design of an efficient microcontroller-based ATS making use of relays, voltage and current sensing circuitry, a display unit and an alarm unit in order to reduce the circuit's power consumption, operate fast, reduce component count and considerably reduce cost. Fig. 3 and Fig. 4 show a block diagram of the overall system design and the block diagram of the ATS respectively (Anderson, 2003).

The system hardware consists mainly of a Transfer Switch (TS) microcontroller serving as the main controlling device to which all other devices are connected. The AC voltage sensing circuits sense the status of the AC power from the mains and generator and communicate it to the TS microcontroller.

A Hall Effect current sensor feeds the load current to the TS controller. A source change relay acts as switchgear to switch power sources between mains and generator to the load.

Fuel flow and starter relays are used to start the fuel flow pump and engine respectively. All the relays are driven by a relay driver (ULN2003A). The TS microcontroller monitors the charging state of a battery that supplies power to the entire control circuitry.

Voltage Sensing Circuits

Two AC voltage sensing circuits continuously monitor the state of the utility supply, generator and communicate it to the TS microcontroller. The voltage sensor, as shown in the circuit diagram in Fig. 5, is made up of a 240/3.4 V step down transformer, two resistors, a diode and a capacitor. To ensure that 5 V TTL requirement of the microcontroller is not violated, a voltage divider circuit, consisting of R_1 and R_2 is used to output about 5 V to the controller. This is achieved by setting the ratio of R_1 to R_2 to be 10 is to 5. The values of R_1 and R_2 are deliberately selected in the kilo ohm range in order to limit the sink current to the microcontroller. The diode and capacitor C_1 are used to give a unidirectional DC to the respective input pin of the microcontroller. An AC sensor (ACS712-05B-T); is used to monitor the load for over- and under-current conditions.

The change breaker relay, OMIH-SH-105D, was selected to commute the power source from utility to generator and vice versa. This is necessary in order to avoid both sources being connected at the same time, otherwise the generator could "back feed" into the utility lines. This is an unhealthy condition since personnel working on the line could be electrocuted. This calculation is done for a typical company in Tarkwa.

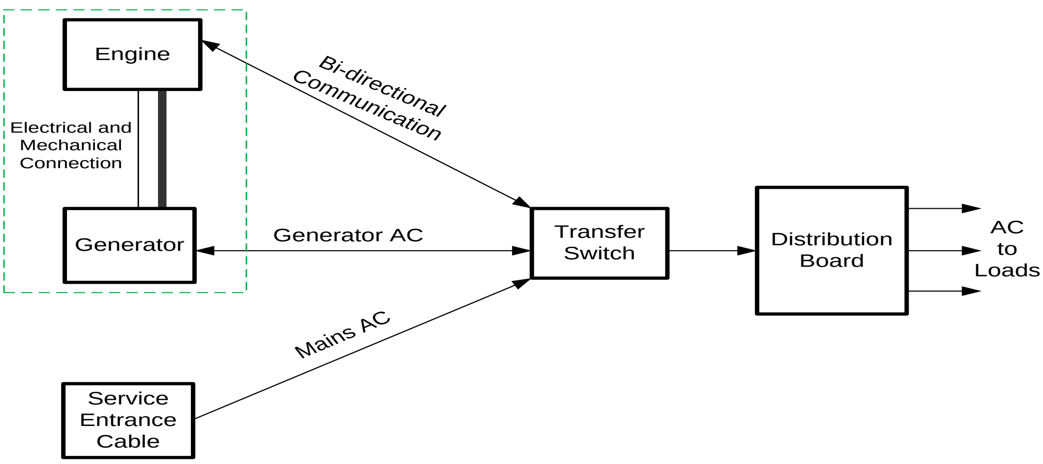

Fig. 3 Block Diagram of the Overall System Design

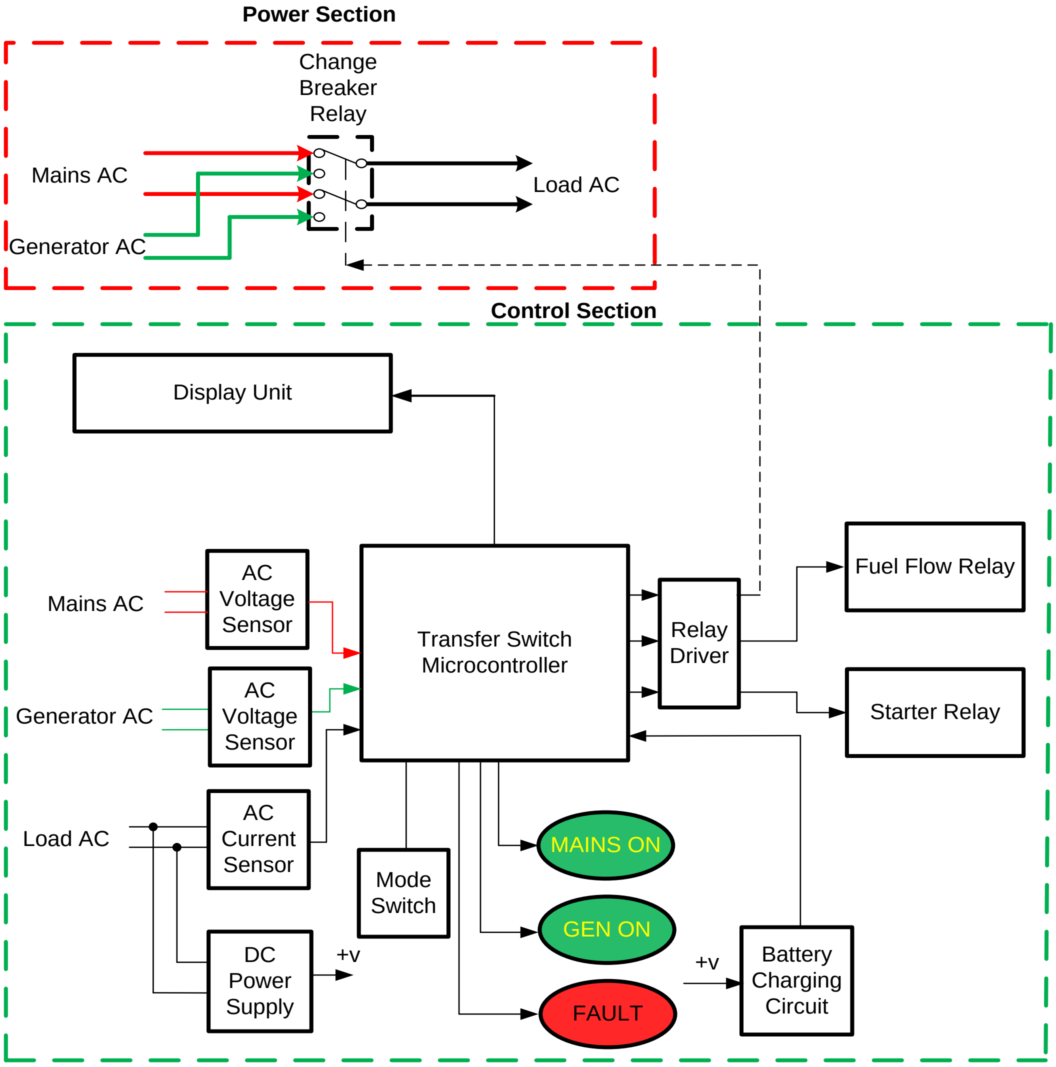

Fig. 4 Block Diagram of Automatic Transfer Switch

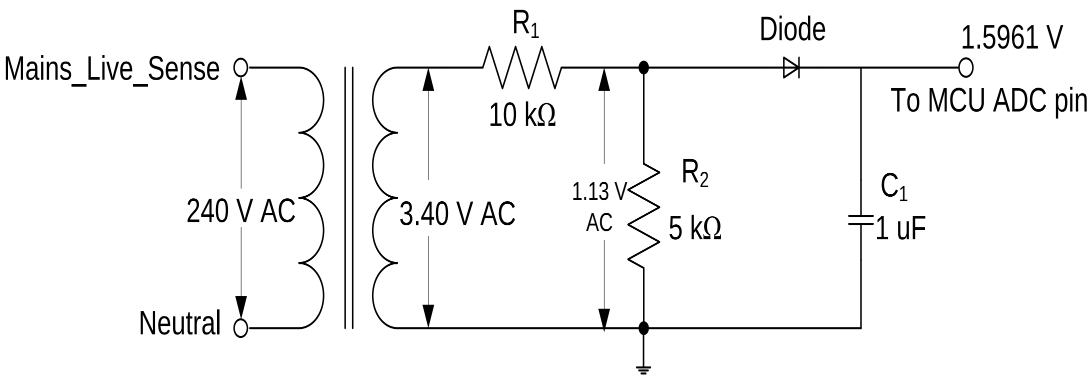

Fig. 5 Schematic Diagram of AC Voltage Sensing Circuit

Schematic Diagram of the Hardware Design

The circuit diagram of the hardware design of the ATS is shown in Fig. 6. The microcontroller receives its power from a MAX610 AC to DC converter through a 10 kΩ resistor. Evenly spaced pulses coming from the oscillator enable harmonic and synchronous operation of all circuits of the microcontroller. The oscillator module is usually configured to use quartz crystal or ceramic resonator for frequency stabilisation.

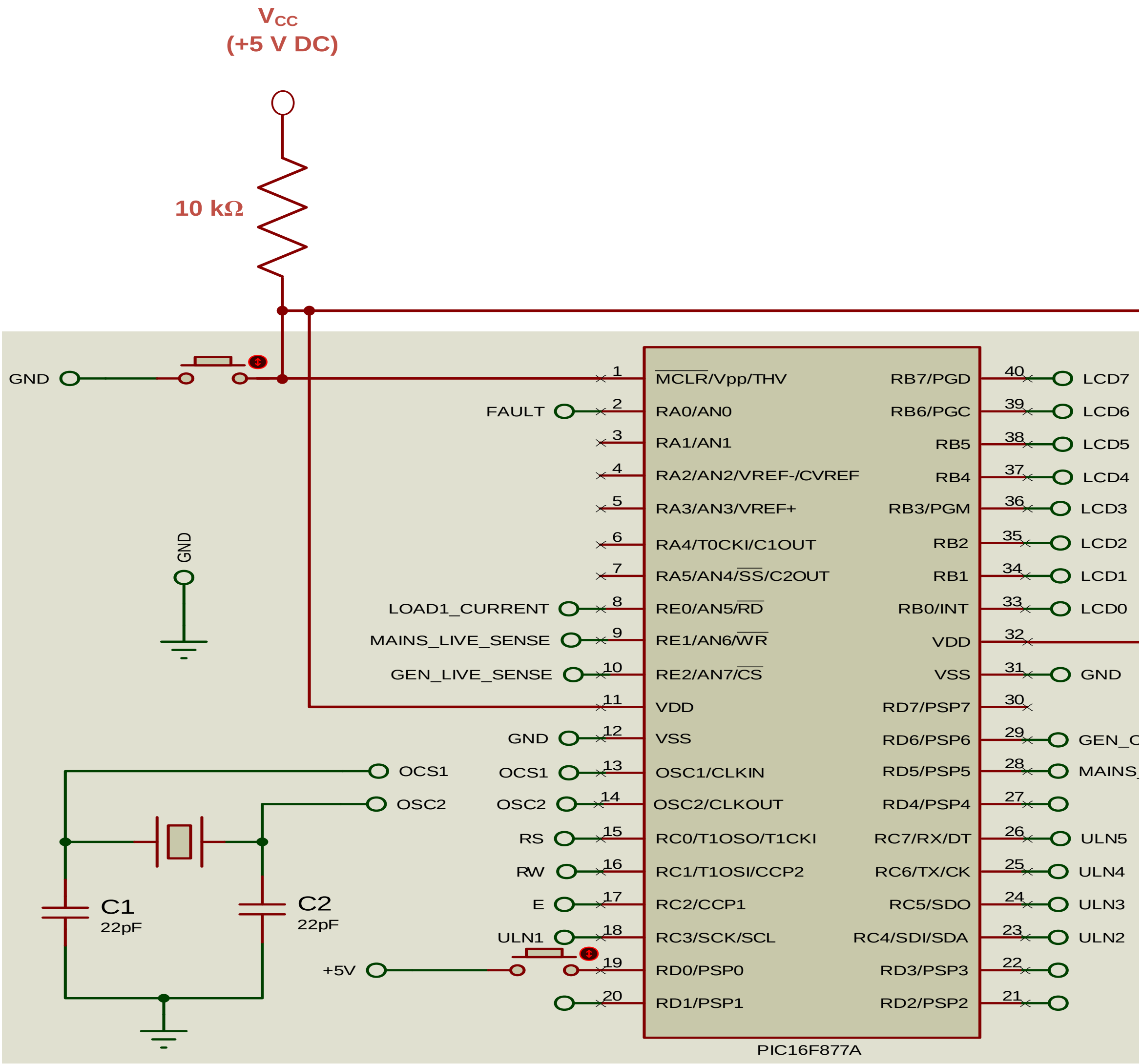

Fig. 6 Circuit Diagram of Hardware Design of the Automatic Transfer Switch

Proteus Design Suit

The Proteus design suit is a professional printed circuit board (PCB) design software with integrated shape based auto-router. It was used for the circuit simulation, schematic capture, and the PCB design. It is developed by Labcenter Electronics Anon. (2013b). The method adopted in this paper cover the system flow chart, programming the microcontroller and simulation of the circuitry of the proposed design.

System Flow Chart

The flow chart for the firmware development is presented in Fig. 7.

3 Results and Discussion

The results are based on the system flow chart developed, the corresponding hardware programming and the simulation outcome. The programming of the hardware was done using GCG Basic programming software. The proposed circuit was successfully simulated using the proteus design suite software. This was done to ascertain the workability of the proposed design. The results indicated that, the ATS responded appropriately to power outages, voltage dips and swells, over and under-current conditions and restorations. A screen shot of the simulated designed circuit is as shown in Fig. 8. The power source changeover was initialised once the utility source became unavailable or experienced a voltage dip or swell or dangerous a surge in current. Fig. 9 (a), (b), (c) and (d) respectively show the system responses indicated.

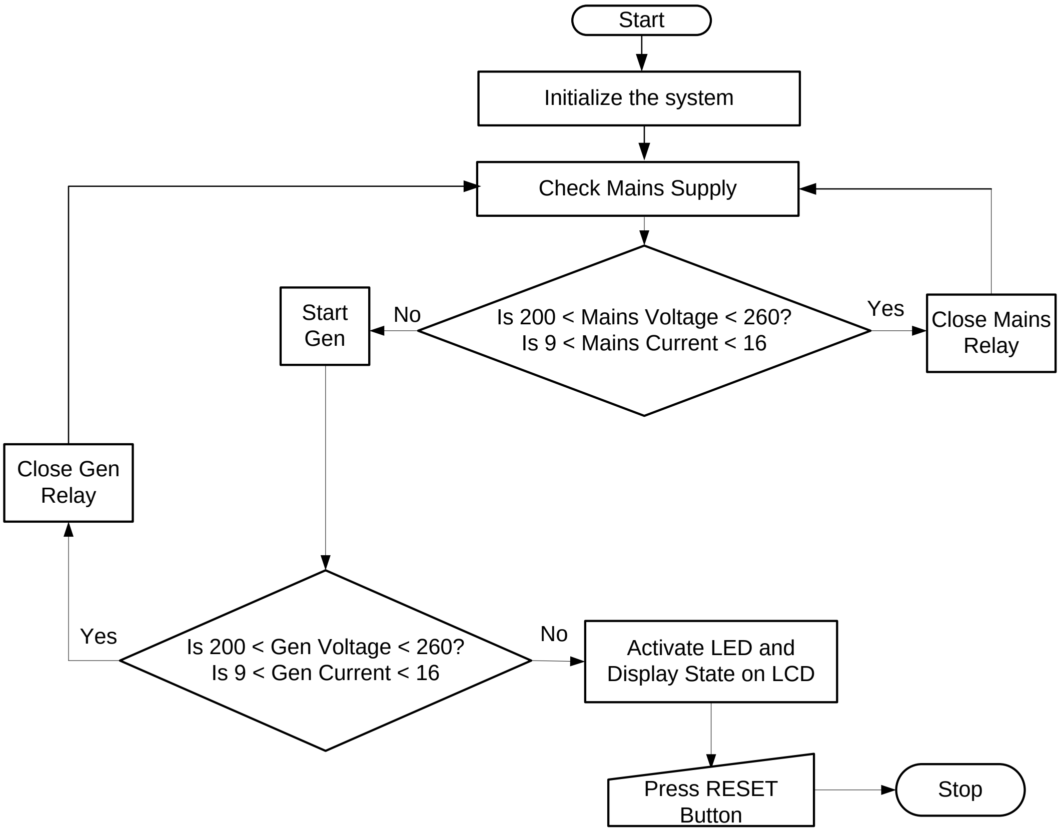

Fig.7 Flow Chart for Firmware Development

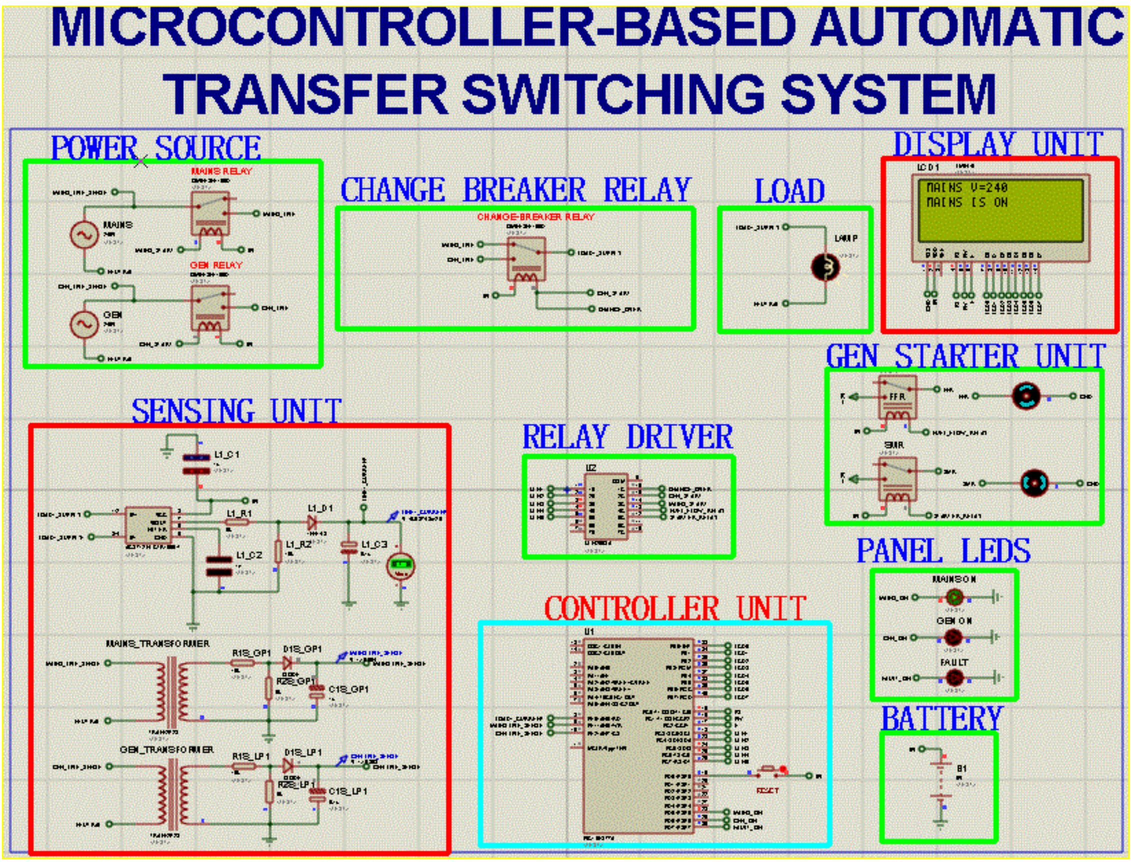

Fig. 8 Screen Shot of Simulation of Designed Circuit

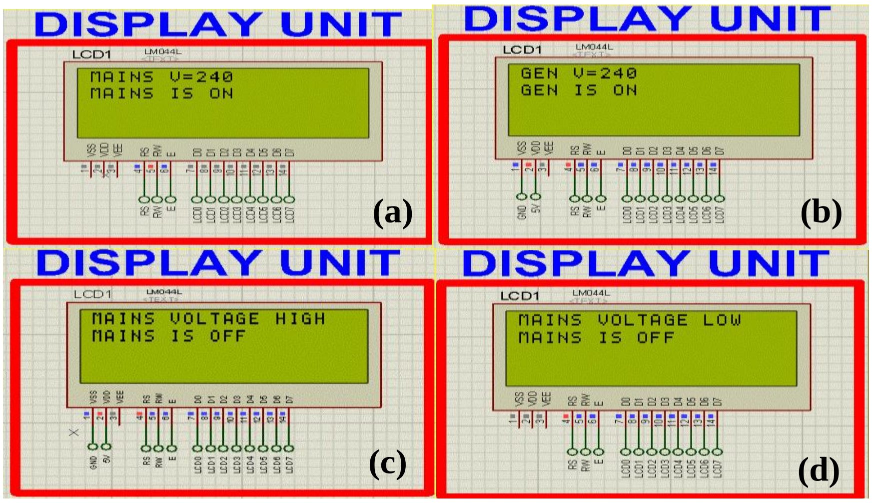

Fig. 9 System Response to Power Outages and Restorations: (a) Mains Supply Normal, (b) Supply from Generator, (c) Voltage Surge on Mains and (d) Loss of Mains Supply

To ensure an almost seamless transfer of power supply, it is required that minimum time is spent for the entire process of supply changeover. The generator, per the program run on the controller, is expected to start within 10 seconds of utility power outage, and when rated voltage is sensed by the generator AC sensor, the controller immediately pulses the changeover relay to change the power source. Thus, on average, approximately 20 seconds is expected to elapse during the interruption of power supply to the load.

Cost Analysis

An estimated cost of GH₵ 992.61 (approx. 330.87 USD) is required for the implementation of the design. Comparatively, this amount is a little higher than the cost of a manual system, but the advantages of convenience, reliability and efficiency of this system far outweigh that for the manual system. Table 1 presents the summary of the detailed components cost of the system Anon. (2013b), Anon. (2013c), Anon.

Table 1 Cost Analysis

Components	**Quantity**	**Cost (GH₵)**	**Total Cost (GH₵)**
Power Supply (MAX610)	1	2.60	2.60
PIC16F877A Microcontroller	1	8.73	8.73
Current Sensor (ACS712-05B-T)	1	4.97	4.97
Transformer (TRAN-2P2S)	2	30.90	61.80
Liquid Crystal Display (LM044L)	1	4.98	4.98
Relay Driver (ULN2003A)	1	1.50	1.50
Relays (5 V)	3	1.20	3.60
Crystal Oscillator	1	2.33	2.33
Resistors (10 kΩ, 5 kΩ)	7	0.30	2.10
Transfer Switch Box	1	900.00	900.00
TOTAL			**992.61**

4 Conclusions and Recommendations

4.1 Conclusions

This paper has presented the design of an efficient, cost effective and reliable Microcontroller-Based Automatic Transfer Switching System (MATSS), which has the ability to accurately monitor the power supply from the utility company and respond appropriately upon a power outage by starting an on-site generator to supply power. Upon the restoration of utility power, the system commutes the load back to utility and shuts down the generator. Included in the design is an over-voltage/over-current protection unit. This enables the system to automatically changeover when the voltage or current rises above its rating, to protect equipment from damage. The cost of the MBATSS is approximately 330.87 USD to construct and install. This new system thus offers considerable operational advantages and cost saving over the manual system currently used by many companies in Ghana. The switch transition mode used (open transition mode) eliminates the problem of standby power generators "back-feeding" into the utility lines.

4.2 Recommendation

It is recommended that hospitals, financial institutions, internet service providers, mining and allied companies in Ghana, which require constant power supply should use the MBATSS.

Acknowledgements

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