Design and Analysis of an Automatic Power Changeover with Backup

Patrick Effraim, Mr. Napoleon Addison, Mr. Abayemah Alphonus Bayor
Electrical and Electronics Engineering, Department Accra Institute Of Technology Accra, Ghana

***Abstract*: The stability of the power supply in Ghana and another part of Africa is a major concern to the community and shop owners. The need for alternative power supply support and switching of load between two power sources. The system will eliminate the need for manual intervention by sensing the main gridline supply and switching to a backup source. Automation charger over to the backup source will eliminate the delay and provide efficiency in production. The system will automatically switch back when main gridline power is restored back. the system uses a microcontroller as the main automatic changing over the process and other component consists of a power supply circuit consisting of a step-down transformer, rectifier, filter capacitor, voltage regulator, and sg3525 which perform the oscillation convention from DC to AC Renewable energy sources generating direct current will require inverters to produce the alternating current necessary for domestic and industrial use The design, construction, testing of this circuit, is satisfactorily in switching from mains supply to generator/renewable energy source(s) and vice versa.**

***Keywords:* gridline supply, battery, microcontroller, rectifier, regulator, changeover, inverter.**

I. INTRODUCTION

Power generation, which plays a major role in the economic development of this great nation (Ghana), forms the basis of this thesis, with interests in human, infrastructural, and economic development. In most developing and underdeveloped parts of the world, the supply of electricity for industrial, commercial, and domestic use is highly unstable. The main aim of any electric power supply in the world is to provide an uninterrupted power supply at all times to all its consumers. Nevertheless, in developing countries, the electric power generated to meet the demands of the growing consumers of electricity is insufficient, hence resulting in power instability and outage [1].

Automatic changeover switches find a wide scope of application wherever the reliability of electrical supply from the utilities is low and it is used wherever continuity of supply is necessary, for switching to an alternative source from the main supply and vice versa.

An inverter changes direct current (DC) power from a battery into conventional alternating current (AC) power that can be used to operate all kinds of devices.

This project is aimed at designing an automatic power changeover switch with a backup supply using a battery bank and a self-designed inverter. This means that when there is mains failure, the device will automatically switch to an alternative power supply (Battery bank), and back to the main supply when it is restored.

1.1 The Research Problem

In most of the developing world, the supply of electricity to industrial, commercial, and domestic are highly unstable, especially during the rainy season not that only Ghana has experienced a power shortage crisis which has also contributed to this problem. This has problem effects on the consumers of the electricity and the equipment that is operated from the main sources of electricity supply. This gave rise to the frequent use of alternative sources of power supply to meet up with the energy demands such as generators which have been incorporated into manual power changeover switches. This is, however, quite expensive, especially from the point of maintenance and reliability coupled with noise pollution and unhealthy emissions. These conventional systems are operated or switched on or off manually. This is time-consuming and stressful. Most times manual switching creates sparks which can cause arch flash, as well as the wearing out of the device[1][2].

As a result, we presented an automatic power changeover that switches the power supply from the national gridline to the battery bank once there is a national gridline supply outage and back to the national gridline when it comes up.

II. LITERATURE REVIEW

Sequential Logic-Controlled (SLC) Changeover System

In sequential logic control of power selection, sequential digital circuits are used to effect detection and control of the supplied power. The sequential logic control approach involves only an automatic violation of the public power source in the event of a power failure but the generator activation to supply alternative power is done manually [8].

Mbaocha and Constance (2015) designed a field programmable gate array power changeover system. The major aim of this work was to exploit the advanced programmable logic device (PLD) facilities in bringing about automation of changeover process. Taking advantage of hardware parallelism, FPGAs exceed the computing power of digital signal processors (DSPs) by breaking the paradigm of sequential execution and accomplishing more per clock cycle[8][9].

This type of automatic changeover system for industrial applications was designed using FPGA. Field Programmable Gate Array (FPGA) is a recent breakthrough in the family of semiconductor devices. It can be reconfigured by the consumer to perform a desired task. FPGA is generically described as a programmable device with an internal array of logic blocks, surrounded by a ring of programmable input/output blocks, connected via programma able interconnect. FPGA can be thought of as a two-layered device by **Dhaher (2004)** involves the design and construction of an automatic transfer switch which thatts the sequential controlled changeover system. The prototype of the system worked according to specification and quite swas atisfactory. The automatic phase change-over switch is relatively affordable and reliable. It is easy to operate, and it provides a high level the of power supply when there are power outages. Finally, it reduces stress associated with manual change-over. However, for future work on this project,recommendedmending that an actuator for mechanical movement of the choke lever should be included for cases single-phase phase generators without automatic choke controllers are used for testing operations.

Horowitz and Winfield (nd) achieved a state of the art changeover switch with electromechanical relays where a relay is an electromagnetic device that is activated by varying its input to get a desiredtheoutput. Relays are of two types, the nory closed and normally open.

In this system, the electromechanical relay was implemented with another component to implement automatic changeover such as logic gates, transistors, onto-coupler, microcontroller, etc. Most of these components make use of 5v since they are Transistor Logic (TTL) based. The control system of the design was properly isolated from the relay as shown in figure 2.9 to avoid the flow back of AC signal into the control electronics

III. MATERIALS /METHODS

The design tools/instruments to be used in achieving the proposed automatic changeover with backup using a battery bank and self-designed inverter are as follows:

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller.[13][14]

The microcontroller is the main and integral part of an inverter. The main work of the microcontroller is to control the switching of signals according to the requirements. A single microcontroller can perform multiple functions (e.g.) generating PWM for switching, controlling the protection systems, etc. There are various types and families of microcontrollers available in the market, for example:

- PIC family
- AVRs (ATMEGA series)
- Atmel
- Arduino
- FPGA (etc.)

Depending on the design specifications, any microcontroller can be used.

3.1.1 Transformer

A transformer is a static device that transfers electrical energy (power) from one voltage level to another voltage level. A transformer is used to step up or step down the electrical voltages. Unlike in rotating machines, there is no energy conversion. The transfer of energy takes place through the magnetic field [3]. A transformer is made up of primary and secondary windings

3.1.2 Diodes:

A diode is an electrical device allowing current to move through it in one direction with far greater ease than in the other. The most common type of diode in modern circuit design is the semiconductor diode, although other diode technologies exist [5].

3.1.3 Transistors:

Transistors are active components and are found everywhere in electronic circuits [8]. They are used as amplifiers and switching devices. As amplifiers, they are used in high and low-frequency stages, oscillators, modulators, detectors, and in any circuit needing to perform a function. In digital circuit,s they are used as switches[6].

3.1.4 Solid State Relays

A typical solid-state relay consists of a light emitting diode (LED) optically coupled to a photovoltaic device such as a Field Effect Transistor (FET)[5][6]. Light from the LED creates a voltage across the photovoltaic array and activates the output FET. FET is the preferred switching element in a solid-state relay because it presents comparatively less electric resistant when it is in a conductive state than a triac in the same state and therefore, generates less heat. As a result of this, FET requires smaller heat dissipating fans and can reduce the overall size of the solid-state relay.

The input circuit is deactivated when the voltage applied is less than the specified minimum dropout voltage of the relay. The voltage ranges of 3V DC to 32V DC, commonly used with most solid-state relays, makes it useful for most electronic circuits. The control circuit is the part of the relay that determines when the output component is energized or de-energized. The control circuit functions as the coupling between the input and output circuits. In electromechanical relays, the coil accomplishes this function. A relay output circuit is the portion of the relay that switches on the load and performs the same function as the mechanical contacts of electromechanical relays.

3.2 System Design

The proposed system is an automatic power change-over switch with self-battery backup using a battery bank and self-designed inverter which is based on Arduino ATMEGA328p microcontroller to control the enteral system. The system is controlled by a software program embedded in the Arduino microcontroller chip.

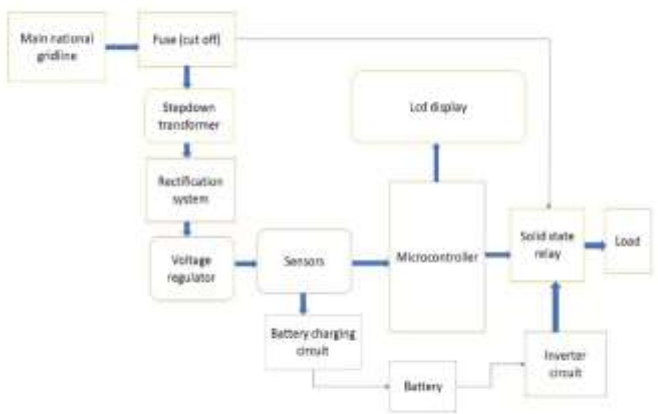


Figure 1 shows the system block diagram

The circuit is made-up of the following part the power supply stage, battery charging stage sensors stage, microcontroller section, and inverter. The heart inverter is the oscillator circuit which is done using SG3526N. figure 2.0 show below the entire circuit of the inverter, when 12V power is applied to the circuit, Diode D3 will be forward biased, and the current will then flow through Resistor, R12, to the power pin of IC, U2. Capacitor, C1, is a decoupling capacitor that serves as a power backup for U2.

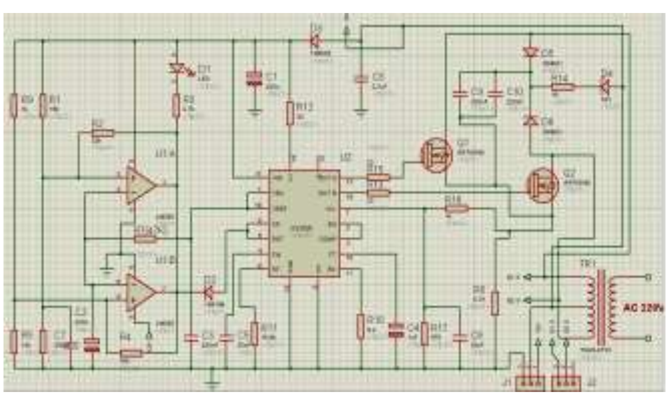


Figure 2 inverter system

The output of the inverter circuit has the characteristics of switches i.e., it will be causing voltage drops in the supply voltage when it is turned ON and OFF. This voltage drop will cause malfunctioning of U2 hence the need for Diode, D3, in the Circuit. The diode, D3, in addition to maintaining a constant supply voltage to U2, also protects the IC from getting damaged in case the supply voltage is mistakenly connected in the reverse form.

When power is applied to the oscillator circuit, the IC (sg3525) starts generating rectangular waves at its outputs pin13 and pin 16 at a frequency determined by the value of the resistor, R11, R11 which can also be substituted with a variable resistor for frequency variation, and capacitor, C4, connected on pin 9(RST) and 10(CT) respectively. This frequency, as usual, is 50Hz which corresponds to the frequency used in Ghana to obtain the 220v and 240v alternative current. The output waveform coming from pin13 and 16 which is oscillation behaving switches the output MOSFET transistor, Q1, and Q2, at a frequency of 50Hz and a Phase difference of 180, the switch of the transistor is done with the help of resistors, R13 and R15, whichever as biasing resistors for the two transistors which feed to the transformer steps the voltage up,

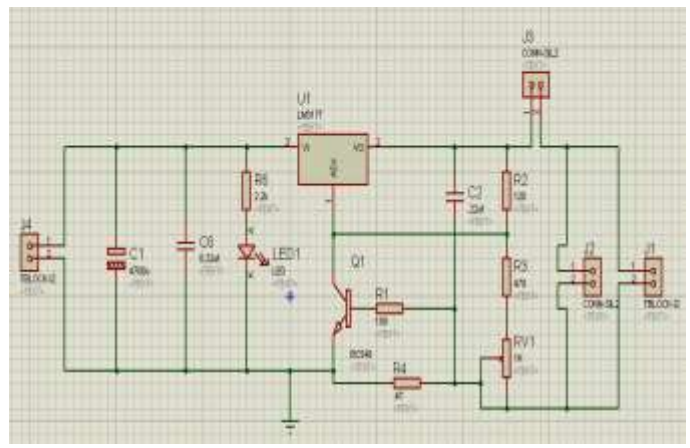


Figure 3 show is battery charging unite

Figure 3 takes about the charger unit which uses IC LM317 as a voltage driver to provide the desired voltage to charge the battery. A battery must be charged with 12-Volt-21-Ah. The charging current for the battery is controlled by the ransistor with help of the, R1, R,4 and RVA potentiometerter, RV1, can be used to set the charging current. The When battery is fully the charged, charger circuit reduces the charging current and this mode is called trickle charging mode.

The power supply for the whole circuit is taken from a 12 volts battery so the system will not affect when then the main gridline is off.

The ATmega328p requires a regulated 5volt supply voltage. The IC, LM7805, voltage regulator was used to provide voltage regulation. The circuit shown in Figure 4.4 converts an unregulated supply of 12V volts to 5 volts for use by the microcontroller.

The following calculations aided us to determine whether the voltage regulator lm7805 needs a heat sink.

Data

Input Voltage (V_{in}) = 12V
Output Voltage (V_{ought}) = 5V
Current measurements from loads = 300mA

Power dissipation by line regulator is given as$P = IV = I(V_{in} - V_{out})P = (300 \times 10^{-3})(12 - 5)$

$P = 2.1W$

From the calculation, power dissipation is small therefore the voltage regulator will not need a heat sink.

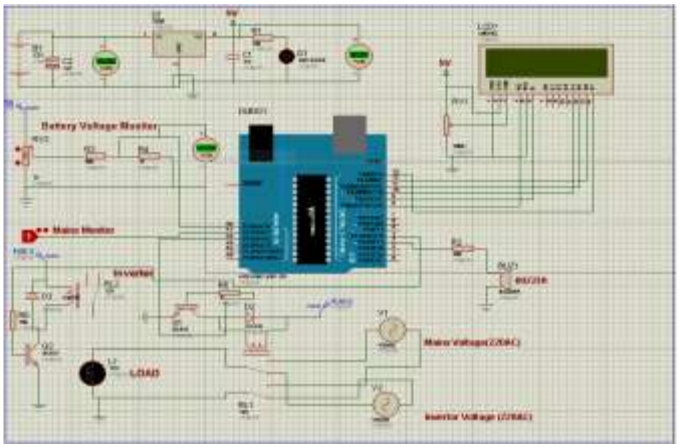


Figure 4.: Change over control circuit

The changeover control circuit is the backbone of the proposed system. The heart of this circuit is an Atmel microcontroller, ATmega328p; it listens to input devices such as mains monitor and battery monitor sensors and tdecidesto control the output devices such as changeover relay by the help of a user program stored in its flash memory.

When the system detects mains failure by the help of the mains monitor sensor connected to pin A1, it turns output pin A2 low. This low signal

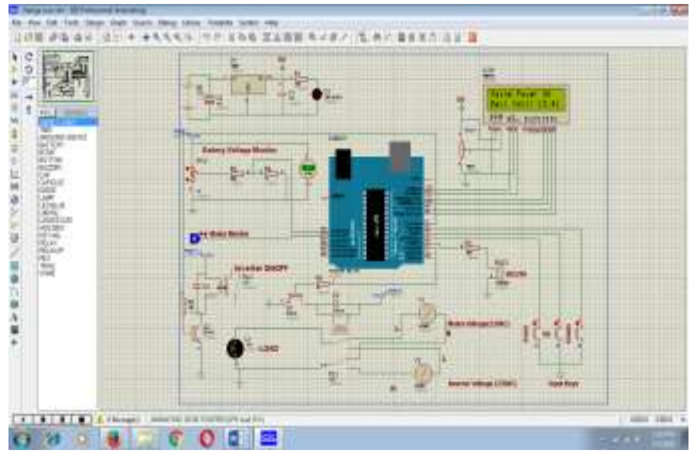
biases transistor, Q1, through base resistor, R5, which de-energizes relay, RL1, which in turn switches load from mains to inverter. Pin 4 is also turned ON, biasing transistor, Q2, through a resistor, R6, and the transistor is switched on energizing relay, RL2, this relay turns the inverter circuit ON to supply power to the load.

Diodes, D2 and D3, are protective diodes which prevents the transistors from getting damaged by back e.m.f. generated when the relays switch Off. The system status information is periodically displayed on the LCD connected to the controller from pin 13 to 8. The buzzer gives edible sound during any status change and it gives this sound when mains power fails or when its presents and good enough to use.

IV. RESULT AND DISCUSSION

In this case, the relay can be seen in its normally closed position where the load forms a closed circuit with an inverter, and the mains supply portion forming the normally open part of the relay. As seen above, there is no power supply to the load since the simulation is off.

Figure 5 Figure is the simulation of when the system is turned ON (Mains ON)



When the simulation is turned on, the entire components are activated with lights turned on indicating the system is activated as seen in the diagram (orange and blue lights). The LCD comes on and shows that the mains is turned on and also shows the level of the battery. The mains are ON when the mains monitor displays “0” and the load switches from the inverter to the mains supply changing the position of the switch thereby providing power to the load from the mains supply as shown in the diagram.

Figurea 6. show When the Main gridline is turned OFF

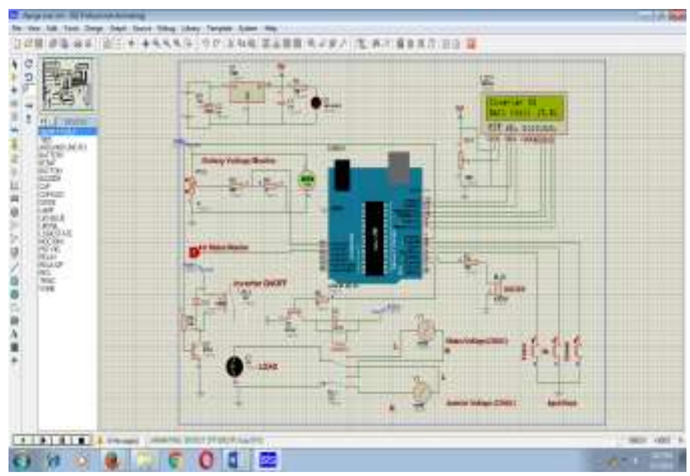
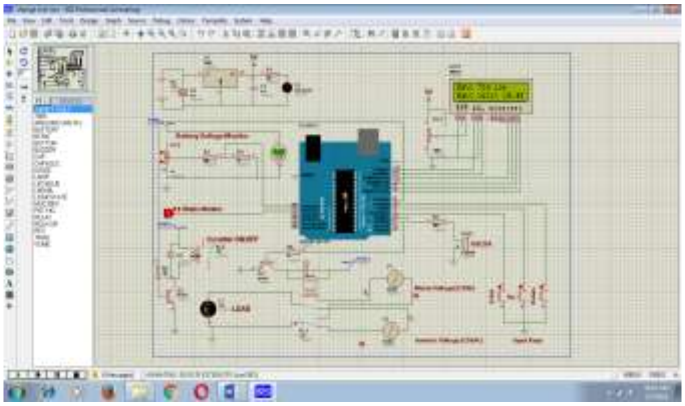


Figure 5.3: Simulation circuit wh turned off

When the mains supply is turned OFF, the LCDs “Mains OFF” and “inverter ON” and also shows the level of the battery, automatically. The mains monitor changes from “0” to “1” indicating that the ther no mains supply and the inverter is turned ON automatically (with the help of a relay, RL2) and with another relay switching the load from the mains to the inverter. Thus, the load receives a constant power supply as it is switched from the mains to the inverter.

Figure 7 represents When the battery of the system reaches it LOW limit



When the battery is low, the LCD "Battery too low" also displays the battery level. In this case of low battery, the inverter automatically switches off; this switching is done by relay 2 (RL2) as shown in the diagram above thereby switching off the load to avoid damage to the battery. The mains monitor still displays one indicating the load is still on the inverter since there is no mains supply.

4. 1. Inverter Circuit Testing and Result

The inverter circuit was tested and a rectangular waveform with a power of 24 watts was obtained as the outputs of the inverter circuit as depicted below:

An analog (single channel) oscilloscope was used in obtaining the output waveform of the inverter circuit where the ground pin from the oscilloscope was connected to the ground of the system and the input positive pin from the oscilloscope was connected to the base of the N-channel MOSFET to obtain the true output waveform of the inverter.

4.2. Analysis of the Results from the Inverter Circuit

1. The inverter circuit was tested for different input voltage values and different output voltage values were obtained. The different input voltage values resulted from different voltage levels of the 12V battery as it is charged or drained at different times. The values are shown thus:

Table 1: Input and Output values of the inverter

INPUT VOLTAGE (DCV)	OUTPUT VOLTAGE (ACV)
11.5	172.4
12.0	184.0
12.5	195.4
13.0	204.3
13.5	213.0
14.0	221.5

From the table above, it can be deduced that the lower the input voltage values, the lower the output voltage values from the inverter and the higher the input voltage values, the higher the output voltage values from the inverter.

2. The output power of the inverter is approximately 24 watts and is obtained mathematically as thus:

$$P = I \times V$$

$$where\ = 2A(Max\ current that\ is\ drawn\ by\ the\ transformer)$$

$$V = 12V(Voltage\ rating\ of\ the\ battery)$$

$$P = 2\ \times 12 = 24\ watts$$

Hence, the system can be used on loads with low power such as electric bulbs. It is important to state the N-channel MOSFET used for the inverter circuit design can handle 81amps at room temperature as indicated in its datasheet. Hence, to obtain a higher output from this system, a larger transformer can be used whose secondary windings produce currents as large as 80 amps. The output of the system can also be increased by using a battery with a higher voltage rating.

The battery charger circuit was tested and confirmed to operate as intended by using an IC called LM317 to control the charging of the battery. However, since this IC LM317 dissipates a lot of heat as indicated in its datasheet, measures and calculations were made to construct a heat sink for the battery charger circuit. The area of heat sink used was obtained by using the formula

$$:A_{HS} \cong \frac{1}{0.0025R_{th,\ HS-A}}$$

$$where\ R_{th,\ HS-A} = Thermal\ resistance, Heat\ sink\ to\ Ambient = 25\ K/W$$

$$A_{HS} = Area\ of\ Heat\ sink$$

$$A_{HS} \cong \frac{1}{0.0025 \times 25} = 16cm^2$$

The above calculated area of the heat sink enabled us to cut out and use the size of heat sink as is seen to be attached to the IC LM317 of the battery charger circuit.

The thermal resistance, heat sink to ambient was gotten from

$$R_{th,\ HS-A} = value\ is\ gotten\ from\ data\ sheet\ of\ LM317 - (R_{th,\ J-C} + R_{th,\ C-HS})$$

$$where\ R_{eq} = Total\ resistance\ of\ series - connected\ resistors = 84\ \ K/W$$

$$R_{th,\ J-C} = Thermal\ resistance, Junction\ to\ Case = 5\ K/W\ (value\ is\ gotten\ from\ data\ sheet\ of\ LM317$$

$$R_{th,\ C-HS} = Thermal\ resistance, Case\ to\ Heat\ sink = 54\ K/W\ (value\ i\ from\ data\ sheet\ of\ LM317$$

Similarly, the total resistance is obtained from:

$$R_{eq} = \frac{H}{T}$$

$$where\ H = Heat\ flow = 1.7857W$$

$$T = Temperature\ rise = \ T_J - T_A = 423 - 298 = 125K$$

$$T_J = Operating\ Junction\ Temperature\ Range = 323K - 423K$$

$T_A = Ambient\ Temperature = 298K$

The heat flow was obtained with the assumption that there was no heat sink and hence leaving the temperature rise and the thermal resistance (junction to ambient) as the only parameters needed to obtain the heat flow.

When the mains supply is on, the battery charges automatically and the level of the battery is displayed on the LCD indicating the level of the battery as shown above. However, when the battery is fully charged, the battery charger circuit then enables the trickle charging mode to allow small amounts of voltage to the battery.

When the mains go off, the inverter is automatically switched on and powered by the battery within a twinkle of an eye as well as load being transferred to the inverter supply and when the mains supply comes back, the inverter automatically goes off, switching the load to the mains supply.

In addition, the LCD displays the status of the system by indicating when the mains supply or is on or off as well as the voltage level of the battery

The system worked as proposed and according to its stated specific objectives and some data and analysis were taken.

V. RESULT AND ANALYSIS OF THE SYSTEM

The efficiency of the system was derived from

$$\eta = \frac{P_o}{P_i} \times 100$$

$where\ P_o = Output\ power\ of\ inverter = 24W$

$P_i = I \times V$

$$where\ I = 5A = \frac{Energy\ stored\ in\ battery}{Time} = \frac{5Ah}{1h}$$

$V = 12V(Voltage\ rating\ of\ battery)$

Therefore,

$P_i = 5 \times 12 = 60W$

Hence, efficiency of the system with respect to the inverter is

$$\eta = \frac{24W}{60W} \times 100 = 40\%$$

VI. CONCLUSION

After the design and construction of the automatic switching mechanism, it was able to perform the following operations:

- Automatically transferred power from the inverter and backup battery, in the case of power failure in the mains supply, to the connected loads.
- Automatically detects when power has been restored to the mains supply and returns the load to this source while turning off the inverter and automatically commence the charging of the battery.
- Enabled the continuous flow of power (of about 24 watts) with an efficiency of about 40% from the inverter system. As a result, such power cannot be used for sensitive equipment due to the generation of harmonics present in the rectangular waves from the output of the inverter
- Eliminated the stress of manually switching to the inverter when there is public power failure.
- Made use of microcontroller facilities (ATMEGA328p) in bringing about automation of the changeover process and hence, decrease power consumption and space.

This project is not only applicable to home lighting system with few modifications but also can be used to drive other DC loads like a DC motor of any electronic equipment and largely, in industrial applications.

It is worthy to note that this project is subject to scrutiny and further development especially in obtaining a pure sine wave as the output waveform of the inverter. Included in the design is a liquid crystal display unit for user friendliness. The cost of the system is approximately 500 Ghana cedi to construct. This system thus offers considerable operational advantages and cost saving over the manual system currently used by many companies in Africa other developing and under developed parts of the world.

REFERENCE

[1] Amuzuvi, C. K. and Addo, E. (2015), "A Microcontroller-Based Automatic Transfer Switching System for a Standby Electric Generator", Ghana Mining Journal, Vol. 15, No. 1, pp. 85 - 92. https://dspace.mit.edu/handle/1721.1/122096

[2] Jerry C. Whitaker (ND). Electronic Handbook. (Cyclic Redundancy checks, CRC Press/Institute of Electronics Engineering, IEEE Press) page 1030 – 1031.

[3] Jonathan Gana Kolo (2007). Design and Construction of an Automatic Power Changeover Switch. AUJ. T. II (2): 113 – 118 (October 2007).

[4] M. A. Mazidi and J. G. Mazidi (2000). The 8051 Microcontroller and Embedded System: Prentice Hall Inc.

[5] Paul Horowitz and Winfield Hill (ND). The art of electronics, Cambridge university press, second edition.

[6] Ogbugo Arinze, (Jan. 2009). "Changeover with Automatic Transfer Switch", Academic Research International Journal vol 1. No. 3

[7] Theraja B.L. and Theraja A.K. (2000). Electrical technology. S. Chand and Company Limited
[8] David E. Johnson, John L. Hillburn, Johnny R. Johnson, Peter D. Scott (ND). Basic electronics circuit analysis. John Wiley and son sons, Inc. Fifth edition.
[9] Mano, M. Morris and Kime, Charles R., (2004) "Logic and Computer Design Fundamentals, 3rd Edition'', Pearson Prentice-Hall.
[10] Hyde, Daniel C., (1997) "CSCI 320 Computer Architecture Handbook on Verilog Hdl".
[11] Brown, Stephen and Vranesic, Zvonko, "Fundamentals of Digital Logic with Verilog Design", McGraw-Hill.
[12] Ciletti, Michael D., (2003) "Advanced Digital Design with Verilog Hdl", Prentice Hall.
[13] Thompson, (2012) "Introduction to FPGA Technology: Top 5 Benefits", National Instruments, USA.
[14] A. H. G. Al-Dhaher, (2004) "Manual Changeover Switch Box" Int. J. Engng Ed. Vol. 20, No. 1, pp. 52±60
[15] Ezema L.S, Peter B.U, Harris O.O, "Design of Automatic Change-over Switch with Generator Control Mechanism", Part-1: Natural and Applied Sciences, ISSN-L: 2223-9553, ISSN: 2223-9944, Vol. 3, No. 3, November 2012.
[16] Christian C Mbaocha and Kalu Constance, (2015)" Field Programmable Gate Array Power Changeover System" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol. 4, Issue 08, August-2015