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DESIGN ANALYSIS OF A MICROCONTROLLER BASED CHANGE OVER SWITCH

Alexander Okandeji[1], Akpovi Ominike[2], Olumide Odeyinka[3] and Frank Onaifo[4]

[1]Department of Electrical and Electronic Engineering, University of Lagos, Akoka, Lagos State, Nigeria
[2]Department of Computer Science and Information Technology, Petroleum Training Institute, Warri, Delta State, Nigeria.
[3]Department of Systems Engineering, University of Lagos, Akoka, Lagos State, Nigeria
[4]Department of Electrical and Electronic Engineering, Olabisi Onabanjo University, Ogun State, Nigeria

Abstract

This paper investigates the design and implementation of a microcontroller-based single phase change-over system capable of controlling three power sources to solve the problems associated with manual mode of starting standby generators, change-over, and irregular power supply. In particular, this work considers the design and implementation of a microcontroller based 13KW, 230VAC change-over system for controlling three power sources. Results obtained showed that the proposed system eliminates the errors due to manual starting of generators, and eliminates unnecessary time delay in changeover of power supply. In addition, the system provides full automation for both the starting of the generator and the required changeover among the power sources (in this case, three sources), and also eliminates potential problems due to human inefficiency.

Keywords**:** single phase change-over system, microcontroller, change over, irregular power supply

1.0 Introduction

Power instability in developing countries creates a need for alternative sources of power as well as the automation of these power sources to cut down power failure. The automation became necessary as a result of time wasted in the process of manual changeovers, and load damage from human error leading to down time in commercial processes, and so much discomfort. To automate two or more power sources for a common load requires the creation of a closed loop system (self-supervisory system) for the power sources which is able to make logic decisions to select a source from available sources in a defined order of priority without human support to meet the user's need. The closed loop electrical control which does this is called automatic changeover system (sometimes called automatic changeover switch).

Before the advent of automatic changeover switch, manual change-over switches were in use and still in use today. A manual change-over switch consist of a manual change-over switch box, switch gear, and cut-out fuse or the connector fuse as described in [1]. This change-over switch box switches the load among the standby generator supply, public utility supply, and an additional supply (e.g. solar or inverter supply) for a manual change-over switch designed for three power sources. In a manual change-over system, when there is power supply outage from public utility, a user must change the line to inverter supply or standby generator and start the generator manually. Thus, when power supply is restored, such user has to put off the generator, and then change over from generator or solar/inverter to public utility supply. Problems associated with manual change over systems includes: Time delay in starting the generator and changeover, human inefficiency, errors in manual starting of generator, possibility of electric shock from close contact with parts of manual changeover not properly insulated [2].

In an automatic change-over system, the starting of the standby generator is done by a relay which switches the battery voltage to the kick starter motor of the generator within preset time. In this system, contactors or solid state relays are used to switch the load to public utility supply, inverter supply, solar supply, standby generator supply, etc. depending on which supply is available and the priority of supply in the system design. The system's interlock protects supplies from meeting at the load connection point.

The importance of an automatic change over system is attached to cases of operation in hospitals and airports in order to save life

Corresponding Author**:** Alexander O., Email: aokandeji@unilag.edu.ng, Tel: +2349039383220

as fast as possible. Also, the need for constant power supply in commercial and industrial environment necessitate the need for the design and implementation of an automatic change-over system which would solve the problems of human error and damages likely to be encountered in manual change-over system.
Accordingly, this work considers the design and construction of a closed loop control switch which has the ability to change the supply among three power sources namely public utility supply, a standby generator and an inverter. In particular, the proposed system is able to start and stop the standby generator automatically, and also provide supply for charging of inverter batteries on utility supply or standby generator supply. The areas of application of this automatic change-over system are homes, hospitals, airports, laboratories, commercial centers, offices, schools, and factories making use of single phase loads.

2.0 Theoretical Analysis

Automatic change-over system with generator start and stop control is a switching device capable of monitoring and controlling the changeovers of power supply and starting of a standby generator with no supervision from the users. It has inbuilt automatic interlock as a safety measure to prevent the supplies from meeting at the common load connection point. The two types of automatic change-over systems are:

1. Automatic changeover system with electromagnetic switching control;
2. Automatic changeover system with electronics control. This type is classified as programmable and non-programmable.

Both change-over systems are further divided into two groups based on the number of phases they are designed to handle [3]. They are:

1. Single phase automatic changeover system and
2. Three phase automatic changeover system.

This research work focuses on the design and implementation of microcontroller based single phase automatic changeover system for three power sources.

2.1 Microcontroller Based Automatic Change-Over System

A microcontroller based automatic change over system has two main circuits namely; Power circuit and Control circuit. The control circuit has two main parts which are hardware and software. The system consist of the following hardware parts; microcontroller IC, contactors, relays, cables, circuit breakers, ammeter, voltmeter, etc. The system is designed to handle three different power sources: Public utility supply, Inverter, and a standby generator. It makes provision for the inverter to be charged either by the public utility supply or by a standby generator via a separate change-over system different from the main change-over system. Incorporated in the design is the capability to start and stop a standby generator as required, software conditional interlock, hardware logic interlock, and voltage sensing stages. The power sources are arranged in their order of priority as follows: public utility supply, inverter, and standby generator. The design combines electronics and electromagnetic switching circuits to achieve its goal. The electromagnetic switching circuits are simply those of the contactors used and they are energized under the operations of the microcontroller via suitable relay interfaces on the microcontroller unit (MCU). The block diagram of the proposed system is shown in figure 1.

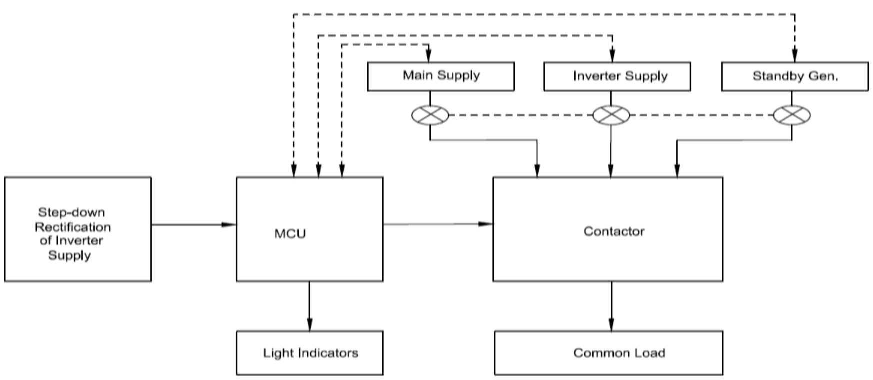

Fig:1 Block diagram of system

2.2 Principle of Operation

When the system is turned on by releasing the emergency switch and the inverter supply is present, the microcontroller unit (MCU) immediately checks the three power sources for presence of supply at its inputs via the optocouplers (U_1, U_2, and U_3) [4], [5] as shown in figure 2. If mains supply is present and it is within a safe range of 200VAC to 230VAC, the MCU will initiate a change over to the mains by sending signal to the mains contactor (KM_4) through interface relay RL_4. This action also initiates a change-over contactor (KM_1) for charging of inverter batteries on mains supply and switching on of a red indicator light showing that the supply is mains supply. The changeover to mains supply remains for as long as the supply is available and does not fall outside the range 200VAC to 230VAC. However, if mains supply is absent, or suddenly falls outside the safe range, the MCU initiates a changeover to the inverter supply by sending a signal to the inverter contactor (KM_3) through normally open contact (NO) of interface relay RL_5, and then send a signal to start the standby generator through normally open contact of interface relay RL_2. While the generator is yet to come on, the inverter feeds the common load. When the generator comes on, a voltage feedback is sent to the MCU via optocoupler U2. Then, the MCU waits for 10 seconds before initiating an action to allow the standby generator to run to full load speed. Afterwards, a signal is sent by the MCU to the generator contactor (KM_5) via normally open contact of interface relay RL_3. Contactor KM_5 energizes and power is changed over to the standby generator supply. This action by the MCU also initiates a change over from mains supply to generator supply for the charging of the inverter batteries through contactor KM_2. The changeover to generator supply will remain for an adjustable run time (one to eight hours). If during the run time of the standby generator, the mains supply is restored, a feedback would be sent to the MCU via optocoupler U_1, and after a voltage monitoring for an adjustable length of time (0 to 60 seconds), the MCU will initiate a change over to the mains supply. However, if there is no restoration of supply from the mains during the run time of the generator, the MCU will send a signal to interface relay RL_1, after generator run time of 8 hours, to stop the standby generator and immediately initiate a change over to the inverter supply through interface relay RL_5. It then remains on the inverter supply for a period of time which depends on the ampere hour(AH) of the inverter batteries till the mains supply is restored or the system is manually restarted by pressing and releasing the emergency switch. The MCU has three potentiometers for time adjustment: the potentiometer with a red nub is for setting the mains changeover delay time, the potentiometer with white nob is for setting inverter changeover delay time, and the potentiometer with blue nub is for adjusting the kick starter run time of the generator. The kick starter run time is set at 3 seconds. Some generators may take less or more than that. Based on design, the MCU is able to initiate a second starting trier if the generator does not come on after the first trier. If the generator still does not come on after the second trier, the changeover to power supply remains on the inverter supply until the mains supply is restored or the system is restarted. It is worth noting that the standby generator battery should be charged to avoid generator starting failure. In the power circuit, the mains circuit breaker is labeled Q_3, the generator circuit breaker is labeled Q_4, and the common load circuit breaker is labeled Q_6. Note that in MCU circuit, the transistors are labeled Q_1, Q_2, Q_3, Q_4, and Q_5.

3.0 Experimental Work

3.1 General Overview of the Section

The block diagram for the system as shown in figure 1 consists of eight blocks with arrow lines showing direction of communication/signal flow within the system. It is seen from figure 1 that the system comprises of power supply unit which powers the MCU, a microcontroller unit (MCU) which is essentially the brain of the system, electromechanical switching devices for change over (contactors), and interlock which rules out the possibility of two power sources meeting at any point. The light indicator block is an output block from the MCU. It indicates the current status of the system, (whether it is mains supply, inverter supply or standby generator supply).

3.2 Power Supply Design

The power supply unit as shown in figure 2 consists of 220/12VAC, 1A transformer, four diodes (IN4001) for full wave rectification of the 12VAC from transformer output, five filtering capacitors (C_8, C_3, C_4, C_5 and C_6), and two voltage regulators (7812 and 7805). The power supply unit gives two voltage output: 12VDC and 5VDC. The 5VDC is for biasing of the microcontroller, while the 12VDC is for powering of the interface relay coils.

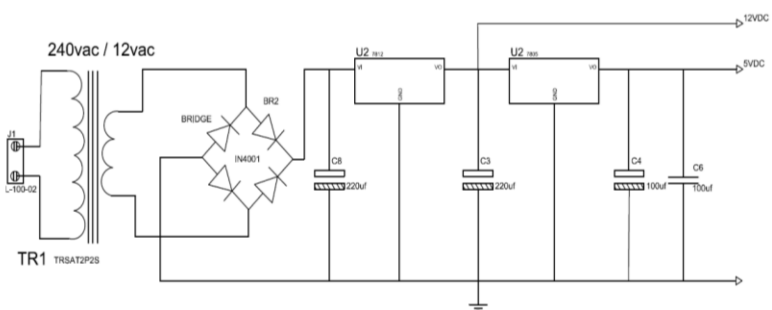

Fig 2: Power supply diagram

3.3 Section Design

The design analysis for the 13KW Single Phase Microcontroller-based Automatic Change-over System is as follow:

Power Capacity $= 12\text{kw} = 12{,}000\text{w}$.

Standard voltage selected = 230VAC; Power factor assumed = 0.87.

For a single phase, real power is given as $P = IV \cos\Phi$ [2] (1)

Thus, $I = P/V \cos\Phi$, where $\cos\Phi$ = Power factor; Φ = Phase angle between current and voltage; I = Maximum load current (A) that will flow through the main contacts of the contactors.

V = Single phase voltage selected (v); P = Real power (watt)

$$I = \frac{12{,}000}{230 \text{ X } 0.87} = 59.97 \text{ Amps} \quad (2)$$

Therefore, 60Amps is the maximum load current that flows through the load cables, circuit breakers, main contacts of contactors and ammeter. Thus, this value is used to select the current rating for the mentioned components.

Current required to energize each Schneider contactor coil is calculated as follows:

Coil resistance = 510Ω; Coil excitation voltage =230VAC

$$I = \frac{V}{R} = \frac{230}{510} = 0.45\text{Amps} \quad (3)$$

Apparent Power Consumed by each contactor coil [6] is expressed as

$$(S) = IV = 0.45 \times 230 = 103.5\text{VA} \quad (4)$$

For apparent power consumed by each light indicator (S);

Current rating (I) = 20mA

Voltage rating (V) = 230VAC

$$S = IV = 20 \text{ X } 0.001 \text{ X } 230 = 4.6\text{VA} \quad (5)$$

Current flowing through normally open contacts of interface relay RL_3, RL_4 and RL_5 are calculated as follows;

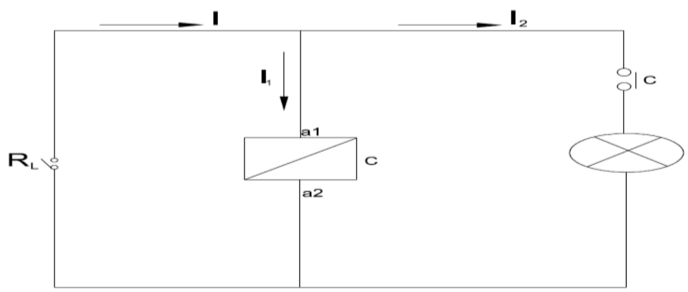

Fig. 3: Diagram showing how each contactor coil is interfaced by the MCU via low voltage relays

$$I = I1 + I2 = 0.45 + 20\text{Ma} = 0.47\text{A} \quad (6)$$

Apparent power consumed by RL_3, RL_4 and RL_5 circuit is given as:

$$S = IV = 0.47 \text{ X } 230 = 108\text{VA} \quad (7)$$

3.4 Generator Kick Starter

The MCU is interfaced with the generator kick starter with relay RL_2 (For starting of generator) and RL_1 (For stopping of generator).

For starting of Generator

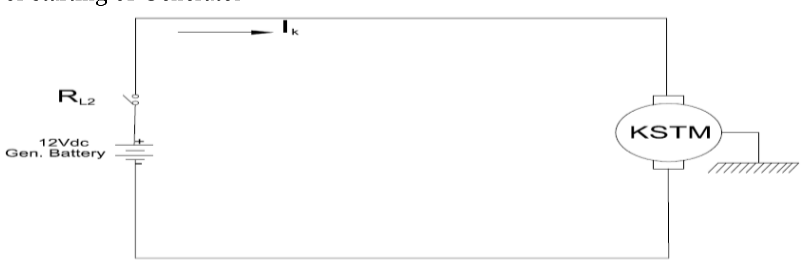

Fig.4: A section showing how the generator kick starter motor (KSTM) was interfaced with the MCU.

Power rating of KSTM = 100w = $I_k = \frac{P}{V} = \frac{100}{12} = 8.3$A. This is the current flowing through the normally open contactor relay RL_2 for starting the generator [7], [8].

3.5 Power Circuit Diagram

The power circuit diagram for the proposed system is shown in figure 5.

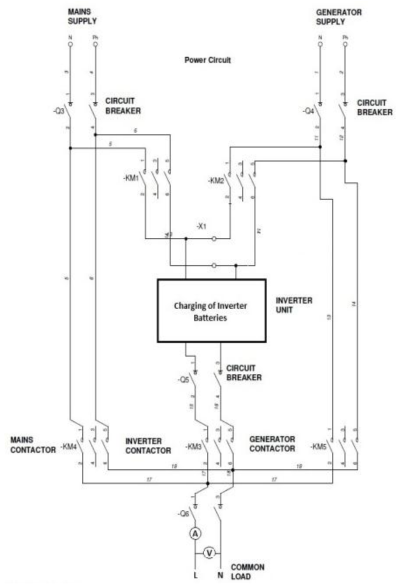

Fig.5: The Power Circuit

3.6 Control Circuit Diagram

The control circuit diagram (microcontroller circuit) for the proposed design is shown in figure 6.

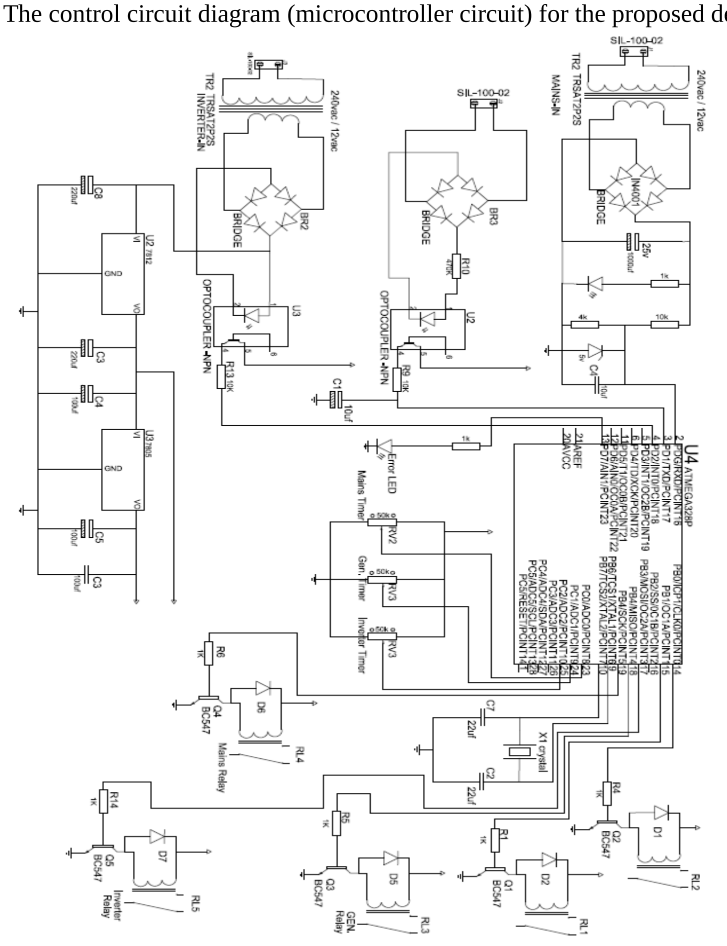

Fig. 6: Microcontroller circuit

4.0 Result and Discussions

4.1 Construction of the Microcontroller Unit (MCU)

The MCU was constructed using five 12VDC relays, one IC (ATMEGA328P), five BC547 transistors, three PC817 optocouplers, two voltage regulators, diodes, capacitors, resistors, connectors, control cables and a vero board as shown in figure 7. After construction, the MCU was connected and interfaced with the contactors for performance evaluation. All test results obtained were satisfactory. The photograph shown in figure 7 was taken during the test.

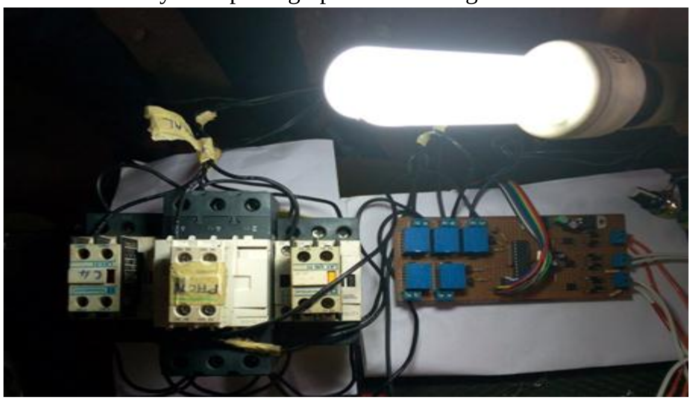

Fig.7: MCU interfaced with contactors for testing

4.2 Wiring and Testing

The construction of the hardware was done in five stages: marking out on the panel box, drilling of holes for all the necessary screw nails, fixing of D-rails and cable trucks, assembly of components, and wiring of assembled parts. The marking out and position of components on the panel cover and inside the panel box are shown in figure 8 and figure 9, respectively.

Fig. 8: Complete exterior of the proposed design

Fig.9: Complete interior of the proposed design

4.3 Installation

The block diagram in figure 10 shows how the microcontroller-based automatic changeover system should be installed with other power equipment.

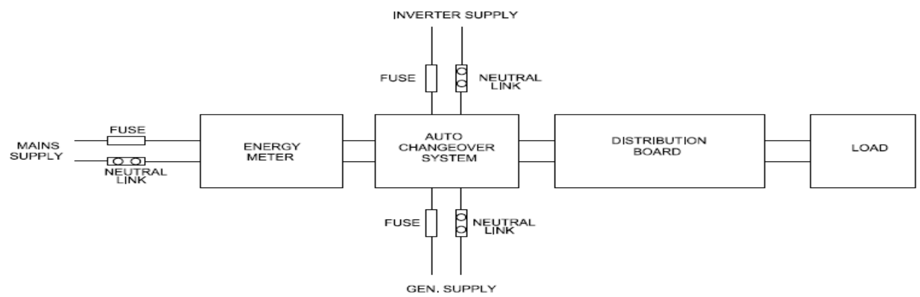

Fig. 10: Block diagram showing installation of system

The result from the continuity test of the proposed design in shown in Table 1.

Table 1: Continuity Test Result

S/N	TEST AREA	OBSERVATION	INFERENCE
1	Energizing coils	Low resistances were noted	The coils are in good working conditions
2	Normally open contacts	Infinite resistances were noted	Good
3	Normally closed contacts	Zero resistances were noted	Good

The result from the voltage signal test of the proposed design in shown in Table 2.

Table 2: Voltage Signal Test Result

S/N	TEST AREA	OBSERVATION	INFERENCE
1	Mains optocoupler output(controller inputs signal)	5VDC was recorded	Good
2	Inverter optocoupler output (controller inputs signal)	5VDC was recorded	Good
3	Generator optocoupler output (controller input signal)	5VDC was recorded	Good
4	Microcontroller integrated circuit output pins (ATMEGA328P)	Pin 19 – 5VDC Pin 14 – 5VDC Pin 15 – 5VDC Pin 17 – 5VDC Pin 18 – 5VDC These outputs were obtained as determined by the programme.	Good
5	Power supply	5VDC and 12VDC supply were obtained without over heating of the transformer or the other components after prolong use.	Good
6	Voltmeter	Deflected to measure the supply voltage across its terminals	Good

The result from the system operation test of the proposed design in shown in Table 3.

Table 3: System Operational Test Result

S/N	TEST AREA	OBSERVATION	INFERENCE
1.	Load change over and interlock	1.When mains is in, inverter and generator are out.	Good
		2. When mains is out inverter comes in while standby generator makes attempt to start .	Good
		3. IF no mains, and generator comes in, inverter goes out.	Good
		4. IF no mains, generator runs for maximum of 8 hours and goes out, inverter comes in.	Good
2.	Emergency switch	When emergency switch is pressed, the system goes OFF. When released, the system comes on and reset itself.	Good

5.0 Conclusion

In this work, the design analysis and implementation of a microcontroller based single phase automatic change over system was investigated. The various tests carried out and results obtained demonstrated that the microcontroller based single phase automatic change-over system achieved its design objectives. The system worked according to specification and very satisfactory. It is reliable, affordable, and easy to install. It eliminates problems associated with manual change over and unnecessary time delay.

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