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Microcontroller Based Electronic Distribution Board

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Abstract— This paper presents an electronic distribution board that overcomes the challenges of conventional distribution boards/circuit breakers such as arcing, contact bounce and slow response. The aim of the research work is to design a system that ensures reliable and secure power supply to a building. The system is built around PIC16F877A microcontroller, a Hall Effect current sensor and Solid State Relays (SSRs). When a fault occurs on any line, the current sensor sends data to the microcontroller to issue a command to the switching device (SSR) to switch off the faulty line. The system also incorporates a changeover circuitry with generator shutdown capability that switches power between mains and generator supplies. Empirical results show that the distribution board ensures a reliable and safe power supply to the building by switching off faulty lines when excessive load is sensed.

Index Terms – Changeover System, Electronic Distribution Board, Microcontroller, Over-current fault condition, Solid State Relay.

1 Introduction

Providing protection for electrical appliances in a building is essential for reliable and secure power supply. Distribution Boards (DBs) are protection devices used for connecting, protecting and controlling multiple branches of electrical circuits fed from a single primary circuit of wiring installation in a building [1]. DBs protect devices by allowing individual circuits to draw power from correctly rated breakers. They also ensure reliability of power supply by isolating faulty lines without disrupting the other segments of the power supply. The first generation of distribution boards include a number of fuses for protecting individual circuits. The fuse in these distribution boards must be replaced once it is blown by a fault condition such as short circuit, earth leakage, overload, etc. With the advent of circuit breakers, resettable distribution boards with higher load bearing capabilities became available. The circuit breakers used in conventional distribution boards are based on the principle of thermal bimetallic lever trip mechanism. The mechanism is slow and could take up to several minutes depending on the percentage of overload.

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The slow operation and sometimes, failure of circuit breakers to close or trip can be attributed to faulty lubrication of the circuit breaker operating mechanism [2]. These DBs are based on conventional circuit breakers and require human intervention to resume normal operation after a fault condition is cleared. In order to overcome the limitations of slow operation and the requirement of human intervention associated with electromechanical and electromagnetic circuit breakers, an electronic circuit breaker is proposed. An *electronic circuit breaker* uses solid state devices to operate when a load current exceeds a pre-set value. Solid state technology has resulted in circuit breakers that are free from arching and switch bounce, with correspondingly higher reliability and longer lifetime as well as faster switching times. A typical solid state circuit breaker is capable of switching off a faulty line in a matter of microseconds as opposed to milliseconds or even seconds for mechanical breakers [3]. The works in [4], [5] are based on electronic circuit breaker in which solid state relays are used as functional replacements for electromechanical relays to provide fast overload protection. The control system of the work in [5] consist of an Arduino microcontroller kit to control the circuit breaker according to the current sensor output. Under software control, the system collects the current sensor data, processes it and issues a trip command to the solid state relay in the event of overload.

The system described in this research work is similar to earlier works on electronic circuit breakers. Our major contribution in this work are two fold: first is the application of the principle of electronic circuit breakers in the development of intelligent distribution board, and second is the incorporation of multiple power source management task to the DB. This gives the system the capability of changing over from one power source to the other and the intelligence of distributing the power only to the loads that such source can accommodate. Early changeover systems known as automatic transfer switches (ATS) were employed in subway systems for illumination, signaling and telephoning central office buildings. The concept was extended for use in air traffic management and radar systems. With the development of life support and diagnostic medical equipment, automatic changeover systems (ACS) became an integral part of the emergency power units of hospitals. Manual changeover systems (MCS) are associated with loud noise and electrical sparks. The frequent changeover action also causes wear and tear coupled with the manual effort required. These limitations led to the development of electromechanical changeover system (ECS) which is automatic and faster but still faces the limitations of wear and tear, noise and arching which could sometimes result in fire outbreak. Solid state relays can be used in place of electromechanical relays to design a changeover system that eliminates the risks and limitations of conventional ones. Both the distribution board and changeover system in this work are controlled by a single microcontroller.

2 SYSTEM DESCRIPTION

Microcontroller based electronic distribution system consists of a PIC16F877A microcontroller, voltage and current sensors and actuators (solid state relays). The functional block diagram of the system is shown in fig. 1

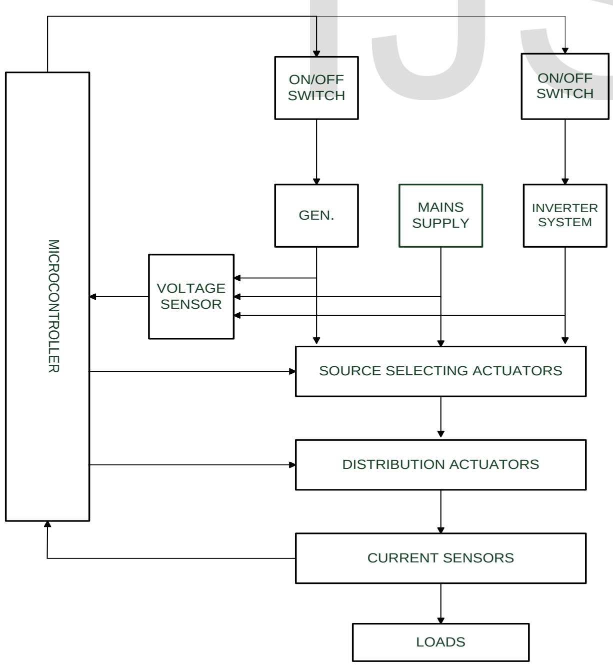

Fig.1 Functional block diagram of electronic distribution board with changeover system

Fault condition is monitored using an ACS758xCB Hall Effect sensor. The device consists of a precision, low-offset linear Hall sensor circuit with a copper conduction path located near the die. The thickness of the copper conductor allows survival of the device at high current conditions. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall Effect IC and converted into a proportional voltage [6]. The ACS758 outputs an analog signal, V_{out} that varies linearly with the uni- or bi-directional AC or DC primary sampled current, I_p, within the specified range [7]. The output is fed to the ADC pin of the microcontroller for converting the analog output to digital data. The primary sampled current here is the load current. Distribution actuators consist of a number of solid state relays used for disconnecting loads from the power supply when a fault condition is sensed. Each solid state relay is configured to trip off when the rated or pre-set current is exceeded.

The voltage sensing unit is used to sense the availability of power either from any of the multiple sources. A PC817 opto-coupler is used to provide voltage sensing. The source selector is realized using solid state relays which is used to connect the load to appropriate source. When two or more power sources are present, mains supply is selected as the default source. Power supply to the control unit is designed to use either of the sources and thus implemented as a binary OR logic. An electromechanical relay which is comparatively cheaper is used for switching off the generator or inverter.

3 HARDWARE DESIGN INTERFACE

This aspect deals with the detailed design and selection of the hardware components required in the design of the voltage sensing, current sensing and actuating unit of the system. Voltage transformer is used as the main component in the voltage sensing unit. A bridge rectifier circuit is used for converting the alternating current (AC) input from the transformer into a direct current (DC) output which supplies the optocoupler. The output of the optocoupler is fed to ADC of the microcontroller. Fig. 2 shows the diagram of Voltage sensing unit of the circuit.

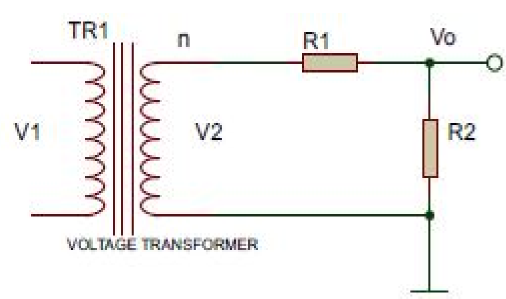

Fig. 2 Voltage Sensing Unit circuit

The following equations are used to derive the output voltage of the transformer TR1.

$$\frac{V1}{n} = V2 \qquad (1)$$

Where V1 is the transformer input voltage, V2 is the secondary voltage and n is the number of turns.

$$Vo = \frac{R2}{R1 + R2} V2 \qquad (2)$$

Where R1 and R2 are limiting resistors.

$$V1 = \frac{n(R1 + R2)}{R2} Vo \qquad (3)$$

$$V1 = KVo$$

Where $K = \frac{n(R1 + R2)}{R2}$

The current sensing element used in the system is a Hall Effect sensor (ACS758xCB). The copper conduction side of the sensor is connected to the load. The sensor outputs an analog signal, V_{OUT} that varies linearly with the uni - or bi-directional AC or DC primary sampled current, IP, within the specified range. The output of the device has a positive slope (>VCC / 2) when an increasing current flows through the primary copper conduction path [6]. The diagram of the current sensing circuit is shown in fig. 3.

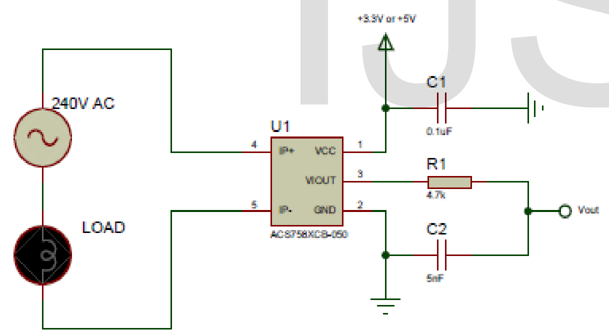

Fig. 3 Current sensing unit circuit

From the data sheet, the sensitivity of the Hall Effect current sensor in response to the application of load is given as 13.3mV/A and the offset voltage is Vcc/2 (2.5V). Using the given data, the equation relating to the measured current and the output voltage is obtained as given in equation (4).

$$V_{out} = mi + \frac{Vcc}{2} \qquad (4)$$

Where m is the sensitivity of the current sensor,
i is the load current and Vcc/2 is the offset voltage.

The actuating unit consist of a number of solid state relays (SSRs). It is used for switching (ON/OFF) the load. The relay is driven by a transistor (BC337) through a resistor connected to the port of a microcontroller as shown in fig. 4. A 5V supply is used as the input control signal. The secondary side is connected to a load.

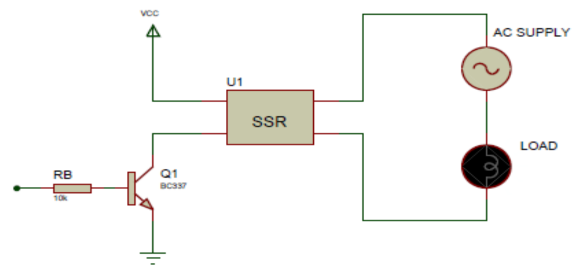

Fig. 4 Actuating unit circuit

The software program flowchart and the complete system schematic diagram are shown in fig. 5 and fig. 6 respectively. The diagrams of completed and packaged work are also shown in fig. 7 and fig. 8 respectively.

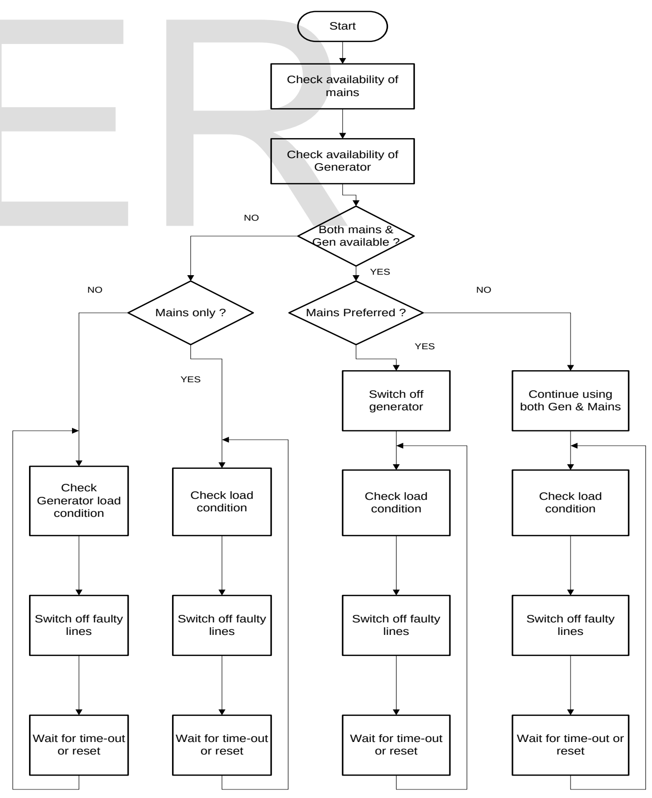

Fig. 5 Software Flowchart

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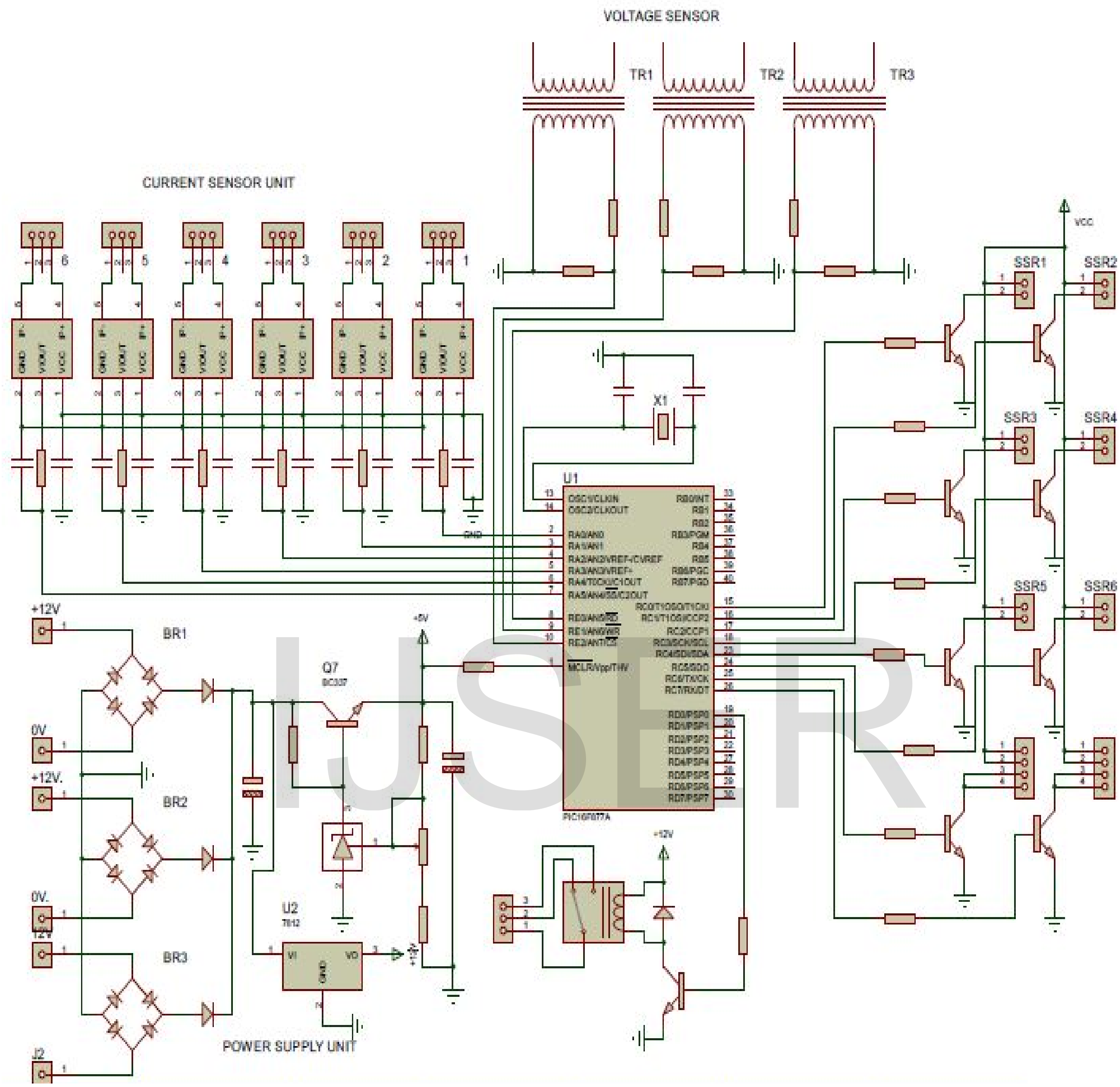

Fig. 6 Complete circuit diagram of Microcontroller based electronic distribution board

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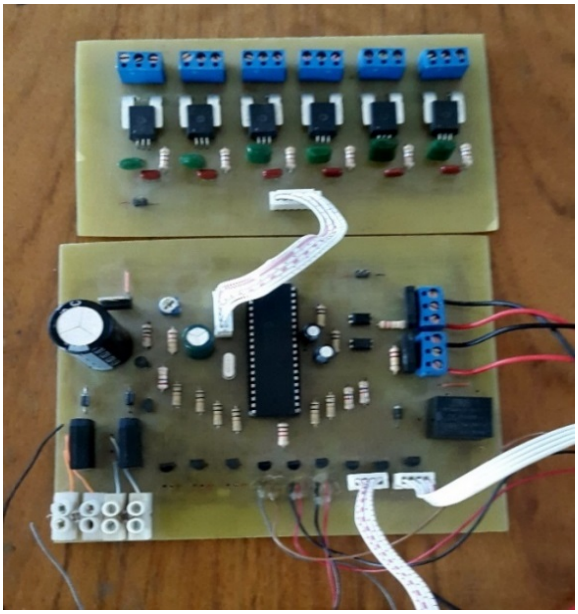

Fig. 7 Completed Work

Fig. 8 Packaged completed work

4 PERFORMANCE EVALUATION

The system is designed to provide protection against over-load and short circuit faults. It senses a fault when it occurs and trips off the switching device. It also has a changeover system in it which swaps over power between multiple power supplies. The graph below shows the characteristics of the Hall-effect current sensor in response to the application of load current. Table 1 shows the actual current ratings and the experimented load current applied to each rated circuit. For each load that is above the circuit rating, the breaker turns off the circuit as expected. The graph of Hall Effect characteristics in response to the application of load is shown in fig. 9.

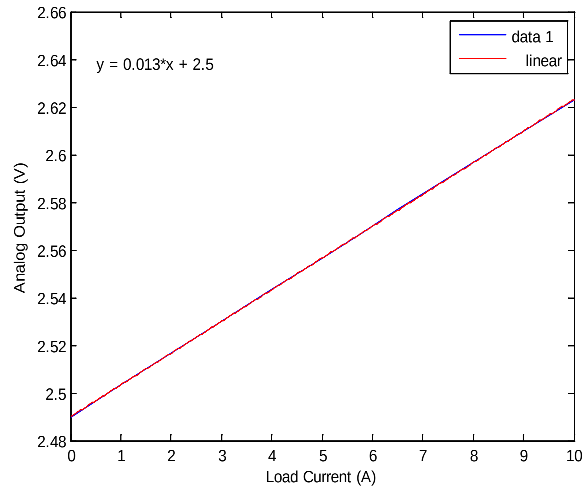

Fig. 9. Hall Effect characteristics in response to the application of load

From the graph above,

$$y = 0.013x + 2.5 \quad (5)$$

The linear equation (5) obtained from the graph verifies the equation (4) relating to the measured current with the output voltage earlier established in the hardware design.

TABLE 1
CIRCUIT BREAKER TEST CONDITION

S/N	Breaker Rating (A)	Load Current (A)	Breaker State
1	4	2.5	ON
		3.0	ON
		4.5	OFF
2	6	5.0	ON
		6.5	OFF
		7.0	OFF
3	8	6.0	ON
		8.5	OFF
		9.0	OFF
4	10	4.0	ON
		10.0	OFF
		11.5	OFF
5	12	8.0	ON
		9.5	ON
		12.0	OFF

5 CONCLUSION

This paper discussed the design and construction of an elec-

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tronic distribution board using a microcontroller interfaced to various sensors and actuators. The system overcomes the challenges of conventional circuit breakers which include slow response, arching, switch bounce and requirement for human intervention. Test results obtained show that the system trips off once the pre-set or rated current value is exceeded. Besides the system ability to offer protection against overload and short circuit, the system has an advantage of testing the load condition before supplying power to the various branch circuits thereby preventing any danger of fire accident due to any short circuit fault. Future works can consider the incorporation of human interface device such as a keypad to change some system parameters such as the current at which the load should be tripped off. Similarly, a WiFi (Wireless Fidelity) or Bluetooth module can be incorporated to enable a user control the system from a mobile device.

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