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Microcontroller Based Solid State Residual Current Circuit Breaker Using Thyristors for LT Applications

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Abstract: Residual current circuit breaker is the necessary element in a wiring system to protect an individual from electrocution and from the risk of electric shock. The speed of operation and reliability is the most important part of circuit breaker design. Limitations of mechanical circuit breakers used in domestic as well as industrial applications led to the development of solid-state circuit breakers. Solid state circuit breakers use solid state devices for switching and isolation. The response of solid-state circuit breaker to a fault is very quick. In the case of an earth fault, the response of circuit breaker to a fault is very important because the fast acting of circuit breaker may save a life from electrocution. In this paper a microcontroller based static residual current circuit breaker using thyristor is proposed which offers protection from earth faults and leakage currents. After a brief introduction and presentation, the design of microcontroller based static residual current circuit breaker is described.

Keywords: Core Balanced Current Transformer; Microcontroller; Solid State Circuit Breakers

I. INTRODUCTION

Residual current circuit breakers protect an individual from electrical shocks, electrocution and fires that are caused due to earth faults and faulty wiring [1]. The fundamental principle behind the operation of RCCB is that in ideal situations the current flowing into the circuit through live wire should be equal as that of the current returning from the neutral [1]. The current flows to earth through accidental means, in the case of an earth fault. As a result, the neutral current is reduced. RCCB is designed such a way that it continuously measures and compares the difference in current flow through the live and neutral wires. Any small change in the current value in live and neutral wires would trigger the RCCB to trip the circuit. Nowadays the mechanical RCCBs are widely used for this purpose.

The mechanical RCCB has a very small conducting resistance whereas it has a long turn-off time (60-100ms) and limited number of operation due to arc occurrence [2]. The properties of mechanical circuit breakers, also varies with ageing. Tripping circuit which is used in mechanical circuit breakers should be able to differentiate the fault within this electromagnetic environment. This may sometimes, leads to nuisance tripping of circuit breaker.

Solid state circuit breakers are more efficient when compared to mechanical circuit breakers. They offer more reliability, life and speed of interruption to a continues current without arching [2]. Due to the absence of mechanical tripping mechanism the complex electromagnetic environment is eliminated. Thus, the nuisance tripping can be minimized. The drawbacks of using a power electronic switch as a switching device in circuit breaker are the cost of material, on-state losses, flow of leakage current during off state and the absence of complete isolation [3].

II. DESIGN AND WORKING

Aiming at the reliable and fastest operation of residual current circuit breakers, the parts of the protective device integrates the functions of sensing, measuring, and controlling of the supply. The design of microcontroller based static residual current circuit breaker using thyristors includes both hardware and software design. The software design includes the triggering and breaker program. The triggering program is to switch thyristors in desired points and the breaker program evaluates the fault condition and necessary actions are taken. The hardware of the breaker is divided into six according to their functions. They are core balanced current transformer, the circuit to detect leakage current, test/manual trip circuit, microcontroller, power electronic switches used for isolation and a power supply unit. In normal operation of circuit breaker, the zero-crossing point of alternating current is sensed and the thyristors are triggered at that point, which ensures the continues supply of electrical energy. When an earth fault occurs a leakage current flows and it is sensed by the leakage current detection circuit. The sensed parameters are evaluated by the microcontroller and necessary instructions are given to thyristors to isolate the load from supply [4].

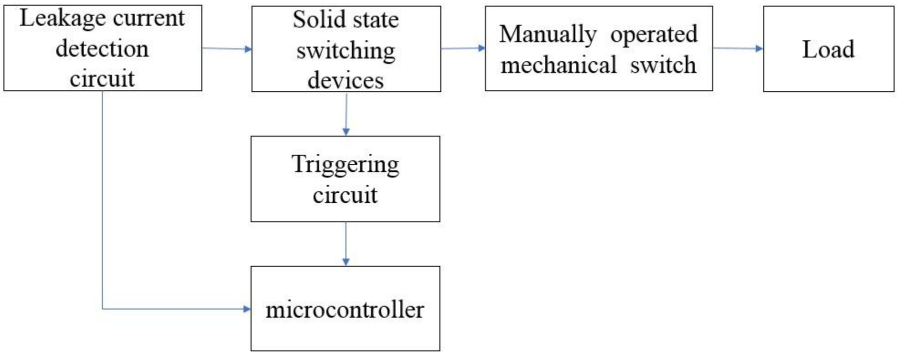

Fig. Block diagram of proposed device

A manually operated mechanical switch is also provided to isolate the load from supply. This manually operated mechanical switch can be used during maintenance in electrical wiring system. This switch is designed to operate during no load condition to avoid electric arching. It can be operated after tripping the circuit breaker using test/ manual trip button.

III. CORE BALANCED CURRENT TRANSFORMER

A. Basic working

The leakage current is detected using a current transducer which is known as core balanced current transformer. The live and neutral conductors are wound on a toroidal CBCT. The design of CBCT is the most important aspect in the design of RCCB in single phase systems. In single phase systems, the vector sum of phase & neutral currents are always zero [4]

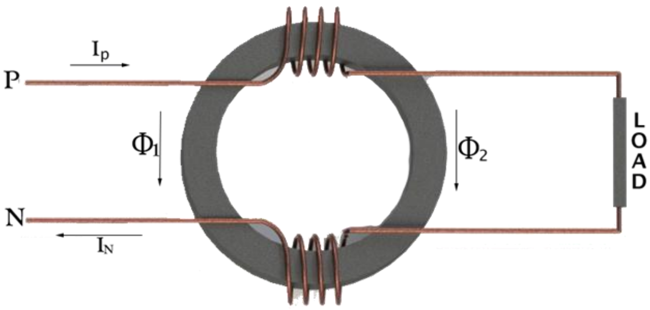

Fig.2. core balanced current transformer

$$IP+IN = 0 \quad (1)$$

Where IP is the phase current and IN is the neutral current. The phase currents IP and IN produces flux Φ1 and Φ2. The number of turns of supply coil and neutral coil will be same so, the magnitude of flux produced will be same. Since, the direction of currents is in opposite direction, they will cancel each other in pre fault conditions. When an earth fault occurs in the system, the vector sum of currents will not be equal to 0. So, the magnitude of flux produced by the supply coil and neutral coil will be different. This produces a change in flux in the core and an EMF is induced in search coil of CBCT [5] as:

$$e = -N\frac{d\Phi}{dt} \quad (2)$$

where N is the number of turns and e is the induced EMF in the coil. No current will flow through the search coil under balanced conditions, so it is not necessary to relate the number of turns of search coil to rated current flows through the load [5].

B. Design of CBCT

A core balanced current transformer takes a magnetizing current, IM from the supply to magnetize the core. A current IL flows through the search coil, hence the current flows through the phase coil can be written as:

$$IP = IM + IL' \quad (3)$$

Where IL' is the current flows through the search coil referred to the primary side of core balanced current transformer

Magnetizing current IM can be obtained using the relation:

$$I_M = \frac{I_L}{[\frac{2\pi N_S^2 \ \ \mu F A}{R_B \times L_M} + 1]} \quad (4)$$

Where LM is the length of magnetic path, NS is the number of turns in search coil. F is the supply frequency. A is the area of cross section of magnetic core, µ is the permeability of magnetic core material. RB is the burden resistor.
The values of magnetic field intensity (H) and magnetic field(B) can be found using:

$$H = \frac{N_P \times I_M}{L_M} \quad (5)$$

Where NP is the number of turns in phase coil and magnetic field is given as:

$$B=\mu H \quad (6)$$

The voltage induced in search coil, VL for a leakage current value IP is given by:

$$V = \frac{2\pi F}{\sqrt{2}} \times B_M \times A \times N_S \quad (7)$$

Where, BM is the peak magnetic flux density.

IV. MANUAL TRIP/TEST CIRCUIT

A manual Test / Trip circuit is included in the design in order to check the reliability of RCCB. The test circuit consists of a resistor and a push switch which is connected in parallel to the supply coil. Whenever the test button is pushed current starts flowing through the test circuit. In normal conditions same current will flow through phase coil, load and neutral coil. Phase coil and neutral coil is wound in such a way that the magnetic flux produced will be in the opposite direction. Under normal condition, same current will flow through the phase coil and neutral coil, hence their magnetic effect will cancel each other.

The current IP flows through the supply coil, but the current which passes through the neutral coil is IP itself, since the currents IP' and IP'' combines in a common point after supply coil. At this instant the current pass through the supply coil, will not be equal to the current passing through neutral coil.

$$IP \neq IN \quad (8)$$

$$\Phi 1 \neq \Phi 2 \quad (9)$$

When the test button is pressed a portion of phase current will flow through the resistor. When the switch is pushed the phase, current IP is split into IP' and IP''.

$$IP=IP' + IP'' \quad (10)$$

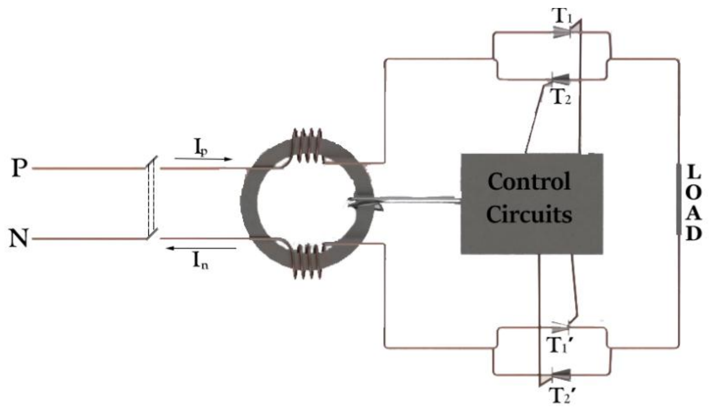

Fig .3. Manual Test / Trip circuit to check the reliability of residual current circuit breaker

Where IP and IN are phase and neutral currents and Φ1, Φ2 are the flux produced due to IP and IN. There will be an unbalance between the line side and neutral side coil of the device and an EMF is induced in the search coil. This EMF is sensed by the leakage current detection circuit and trips the circuit breaker.
This circuit is used to check the health of RCCB. It can also be used to trip the circuit breaker manually. However, it does not test the complete operation of the protection system that the RCCB is supposed to serve.

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V. THYRISTOR AS SOLID-STATE SWITCHING DEVICE

The thyristor-based switching device comprises four thyristors. Two of them are connected in antiparallel to allow bidirectional current flow. The triggering pulse is withdrawn for breaking the circuit. When turn off command is received by the microcontroller due to some fault, the gating pulse is withdrawn from thyristors.

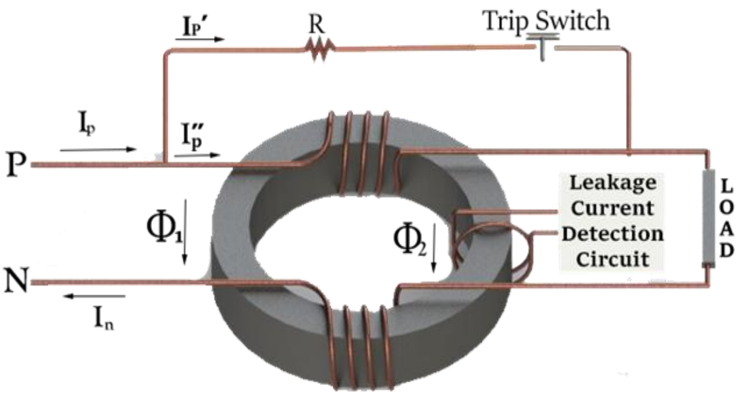

Fig. 4. Thyristor switching, Triggering and Sensing circuitry

Two thyristors are triggered at a time for the continues flow of current. Thyristors T1 and T2' are triggered in the positive cycle of the signal. Thyristors T2 and T1' are triggered in negative cycle of the signal. Synchronization voltage can be obtained from line voltage. The zero-crossing point is obtained using zero crossing detector circuit. The microcontroller detects the zero-crossing point and triggers the thyristors. The main disadvantage of thyristor is the fact that they are not able to actively turn-off current. It can only turnoff when the current commutates to zero.

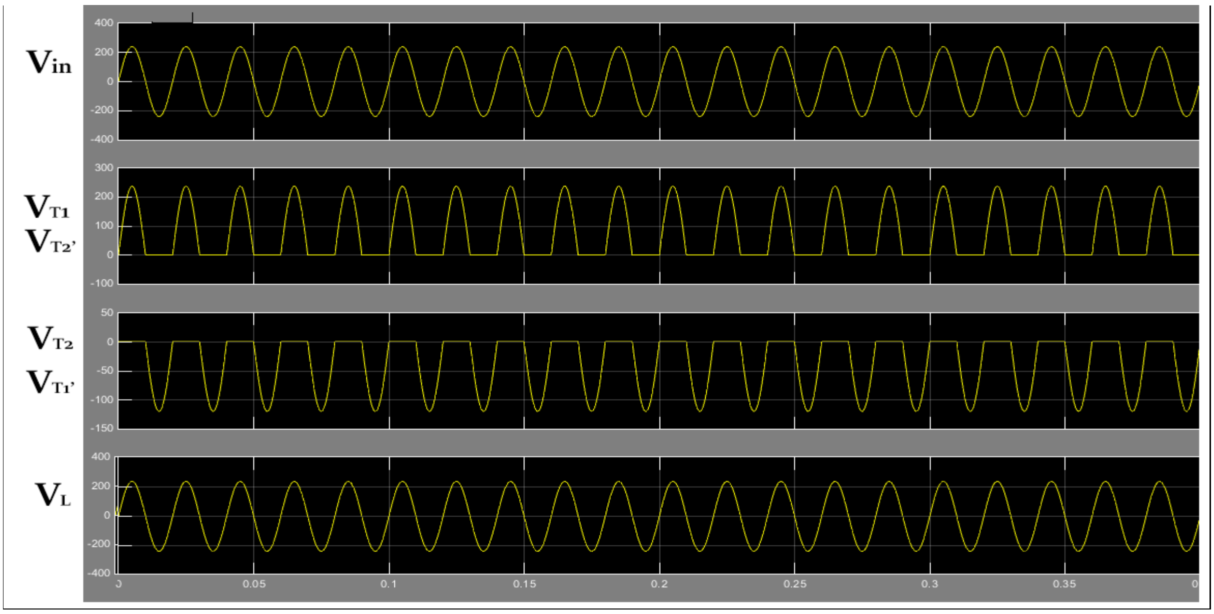

Fig. 5. Simulation results of circuit breaker during pre-fault condition

VI. FLOW OF LOGIC IN MICROCONTROLLER

The microcontroller is the logic circuitry which controls all the processes inside the circuit breaker. The main tasks of the microcontroller include detecting leakage current, judging, processing and providing the triggering pulse to thyristor. The fault analysis is carried out in the microcontroller. The signal which is obtained from leakage current detection circuit is given to the microcontroller. It processes the signal and leakage current is calculated. A predefined value is set as a threshold value. For instance, the value is set as 30 mA. The threshold value can be varied by varying program parameters. Beyond the threshold value the load is isolated by withdrawing the triggering pulse.

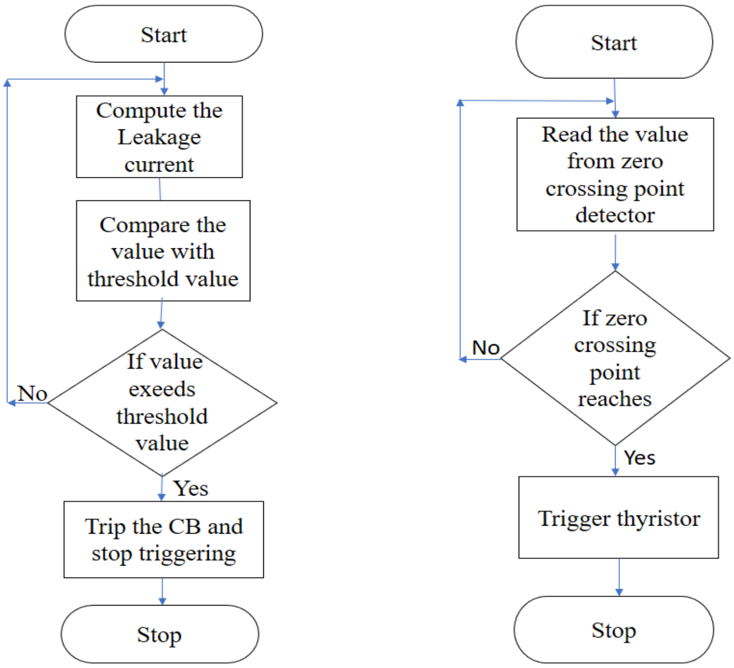

Fig. 7. Flow of logic of breaker and triggering program

VII. CONCLUSION

In this paper, a novel microcontroller based static residual current circuit breaker using thyristor is presented to protect the individuals from electrocution and electrical shocks. This solution offers enormous advantages over mechanical circuit breakers. The major advantages include, very high switching speed, no electric arching during breaking the circuit. The breaking threshold can be varied according to the program parameters, high reliability since there is no arching during operation the life span of breaker can be improved. The lack of complete isolation, chance for leakage current flow, low overheat withstanding capacity and losses are the major disadvantages of solid-state circuit breakers. To provide complete isolation and to avoid leakage current flow during maintenance a manually operated switch is inserted. The proposed solution is an effective means to prevent electrocution and should be included as a necessary element in residual wiring circuits

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