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Power Transformer Protection Using Microcontroller-Based Relay

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Abstract: Protection of power transformers is a very challenging problem in power system relaying. Since it is very important to minimize the frequency and duration of unwanted outages, this is a high demand imposed on power transformer protective relays. Various relaying principles have been proposed and used to protect transformers against different types of faults. Relays that use over current, over flux and overheating principles protect the transformers against overloads and externally applied conditions. Differential relays protect the transformers against internal fault. In this research, software and hardware of microcontroller based relay system has been explained and designed. The design implementation and testing of the system are also presented.

Key words: Power transformer protection, inrush current, differential protection

INTRODUCTION

Power transformers are very expensive and vital components in electric power systems. They occasionally experience faults resulting from insulation failures caused by atmospheric disturbances and switching surges. These transformer faults can be divided into two main classes: The first class is internal faults due to faults between adjacent turns or parts of coils and faults to ground on terminals or on parts of windings. The second class is overload and externally applied conditions include over current, over voltage, external short circuits and reduced system frequency.

This study describes the design and implementation of the microcontroller-based system for protecting power transformer. The system includes facilities for discrimination between internal fault current and magnetizing inrush current, differential protection, over current protection, over voltage protection and under voltage protection have been included. In this study, software and hardware of microcontroller based system have been explained and designed. The design implementation and testing of the system are also presented.

Electromechanical and solid-state relays were and still used for protecting power system for the past several years. Researchers have been studying the feasibility of designing relays using microprocessors (Mao *et al.*, 2001). Due to the advancements in digital technology and decreases in digital hardware prices, digital relays are now available and being used for power system protection which are contribute to improved reliability and reduced costs on electric power systems (Sidhu *et al.*, 1996).

Numerical relays capable of performing sophisticated signal processing functions enable the relay designer to used the classical protection principles and enhance the relay performance, facilitating faster, more secure and dependable protection for power transformers. Kulidjian *et al.* (2001) have used inrush restraint algorithm for protection of power transformers, the algorithm is an extension of the traditional second harmonic method, his algorithm considers a ratio between the phases of the second and the fundamental frequency components of the differential signal (Kulidjian, 2001).

In this research, the design of microcontroller based relay for power transformer protection has been implemented the major emphasis of this work is the description of hardware and software development of the relay. The percentage differential protections, over current protection and external faults, over and under voltage protection have been carried out. The method of rate of change of the primary current with respect to time (di/dt) in the first quarter of primary current wave method has been adopted to discriminate the internal faults current from inrush, this method depends on the fact that the magnetizing inrush current wave has high di/dt compared with di/dt of internal current wave.

MICROCONTROLLER RELAY DESIGN

Microcontroller-based protection system consists of hardware and software.

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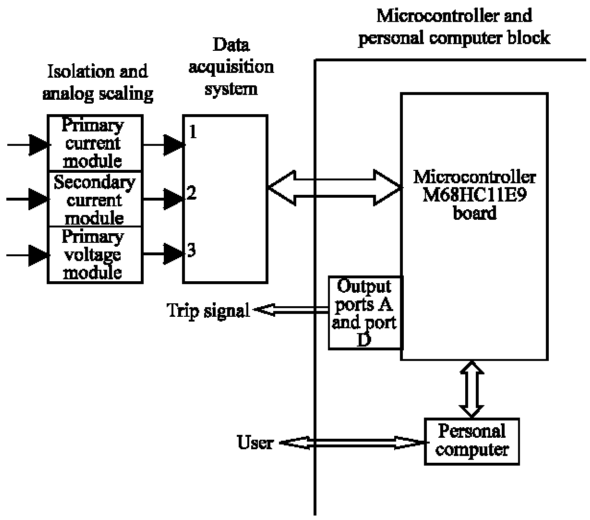

Fig. 1: Block diagram of the microcontroller-based protection system

The system hardware consists of the following three functional blocks:

- Isolation and analog scaling block
- Data acquisition block
- Microcomputer block

Figure 1 shows the connections of these blocks. The isolation and analog scaling block consists of two identical modules for processing currents and one module for processing voltage.

The module of processing current signal consists of Hall Effect Current Transducer HECT that has been implemented in this study. The advantage of using this type of current transducer beside it has better performance and wide frequency operation comparing with electromagnetic Current Transformer CT (Khan *et al.*, 2002), it directly gives voltage signal equivalent to the current signal. Thus, there is no need to use current to voltage converter to convert the current to voltage as the microcontroller only accepts voltage signal.

The data acquisition block of the system consists of hardware circuit that samples and quantizes signal at a specified rate for the interface of analog signals to the microcontroller. This analog signal must first be converted to a digital value then processed by the CPU (Fredrick, 1997). The Data Acquisition System (DAS) has three input channels for sampling analog signals and converting them to equivalent digital numbers. Port E used to input analog signals which connected to MCU's A/D converter. The conversion time is 32E-clock cycle and the sample-and-hold aperture time is 12 E-clock cycle.

The microcomputer block of the relay consists of M68HC11E9 microcontroller board, with 8-bit microcontroller available from Axiom Manufacturing, was selected to be used in this research.

SYSTEM SOFTWARE

The system software is written in the assembly language of the M68HC11 Motorola Microcontroller. This software is divided into two parts; data acquisition software and developed software.

Data acquisition software controls the operation of A/D converter, which samples and quantizes voltage and current at a pre-specified rate. In protection of power transformer the data acquisition system acquires signals of primary and secondary currents and signal from primary input voltage.

At the first step when the transformer switch on, the system needs to read the signal from the primary current circuit, to check the inrush current by calculating the rate of change of the primary current with respect to time di/dt, then the microcontroller converts other analogue signals, secondary current and input voltage to digital. After A/D completes the conversion, the programs of the differential, over current and over/under voltage protections will start and if there is detection of any fault, the tripping procedure will take place, other wise return to the beginning step to read new data for next loop of checking. Figure 2 shows the flowchart of data acquisition software.

Software programs has been developed in assembly language to detect different types of faults and to give the proper indications and tripping signal if necessary, it could be divided into of three parts:

Inrush current and internal fault discrimination software: Magnetizing inrush current in power transformers results from any change of the magnetizing voltage and it may be caused by occurrence of external faults. Since the magnetizing branch representing the core appear as shunt element in the transformer circuit, the magnetizing current upsets the balance between the currents at transformer experienced by the differential relay as fault.

Initial magnetizing due to switching a transformer on is considered the most sever case of an inrush. When a transformer is de-energized, the magnetizing voltage is taken away, the magnetizing current goes to zero while the flux follows the hysteretic loop of the core. These results in certain remnants flux left in the core. When the transformer re-energized by sinusoidal voltage the flux gets biased by the reminisce. The residual flux may be as 80-90% of the rated value and therefore, it may shift the flux far above the

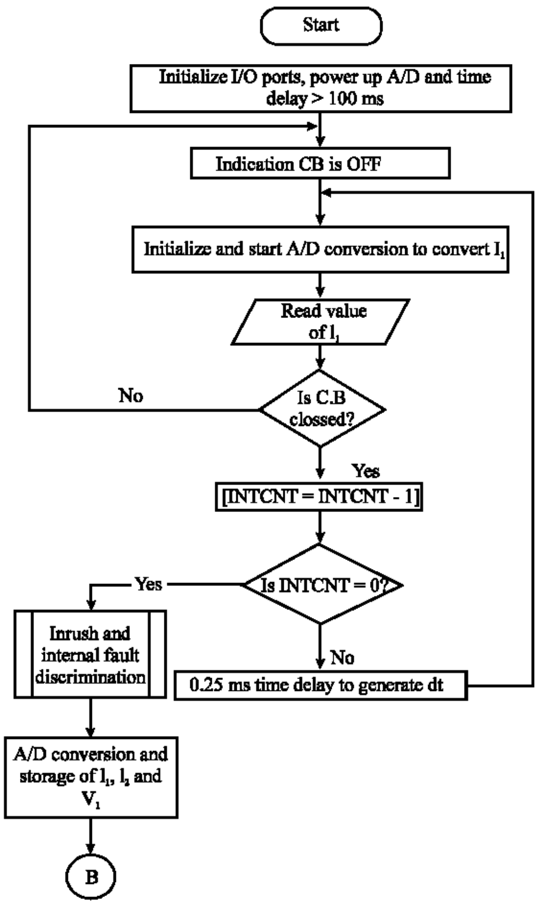

Fig. 2: Flowchart of data acquisition software

knee-point of the characteristic resulting in large peak values and heavy distortions of the magnetizing current.

The sharpened of the inrush current depends on many factors such as size of a transformer, impedance of the supply and magnetic properties of the core, in this research and it has been found equal to 1.25 m sec (Guzman *et al.*, 2001).

This part of the program has been developed to discriminate between internal faults that may occur and inrush current to prevent the differential relay from trip in case of inrush at the instant of switching on the circuit breaker. This part consists of two subprograms, the first one is used only to determine the minimum value of the di/dt of the inrush current wave by calculate di/dt in 1.25 m sec to be used as a threshold value TF. The second program deals with discriminating between the inrush and internal faults, it calculates the value of di/dt and check it, if it is smaller than TF it means internal fault exists and tripping signal will be send to circuit breaker, if not it will go to next checking loop after time delay equal 15 m sec. Figure 3 shows the flowchart of inrush and internal fault discrimination program.

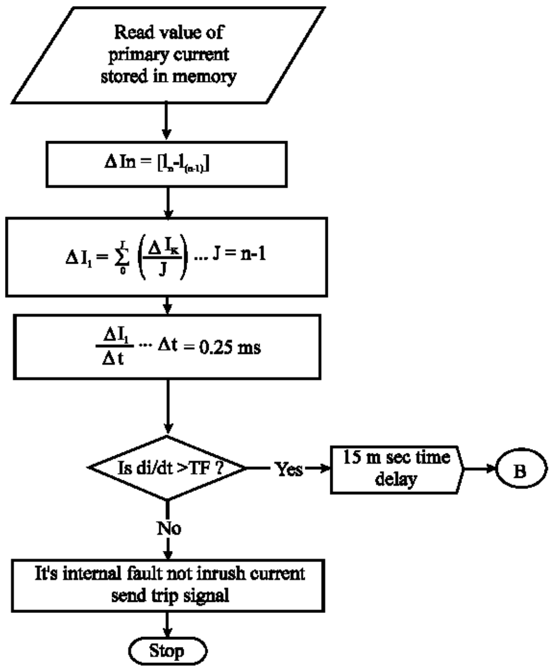

Fig. 3: Flowchart of inrush and internal fault discrimination program

Instantaneous over current protection and differential protection software: The instantaneous over current protection operates when external fault happens outside differential protecting zone. It works as back up protection.

Figure 4 shows the flowchart of the over current and differential protections.

In this research the percentage differential relay method has been used for stability during external faults and load conditions with ratio mismatch and/or saturation of the CTs. A differential relay uses a restraining quantity as a reference for the differential signal. Figure 5 shows the operational characteristic of a percentage differential relay (Sachev *et al.*, 1989; Guzman *et al.*, 2000).

Where I_1 and I_2 are the currents in the primary and secondary of the transformer, respectively. The differential current $I_d = |I_1 - I_2|$. Restrain differential current is fixed TR, this current is given by the ratio between the primary and secondary transformer current $I_R = |I_1 + I_2|/2$. The restraint establishes an upper limit for the differential current in the relay without disconnecting the system. The minimum value of differential current is pickup value I_{PU}. The minimum value of restrain current is I_R. Constant K is the slop of the percentage differential characteristic. The relay operates when the differential current I_d overcome the percentage of the restraining current I_R

Over/under voltage protection software: Over voltage and under voltage software has been developed in this

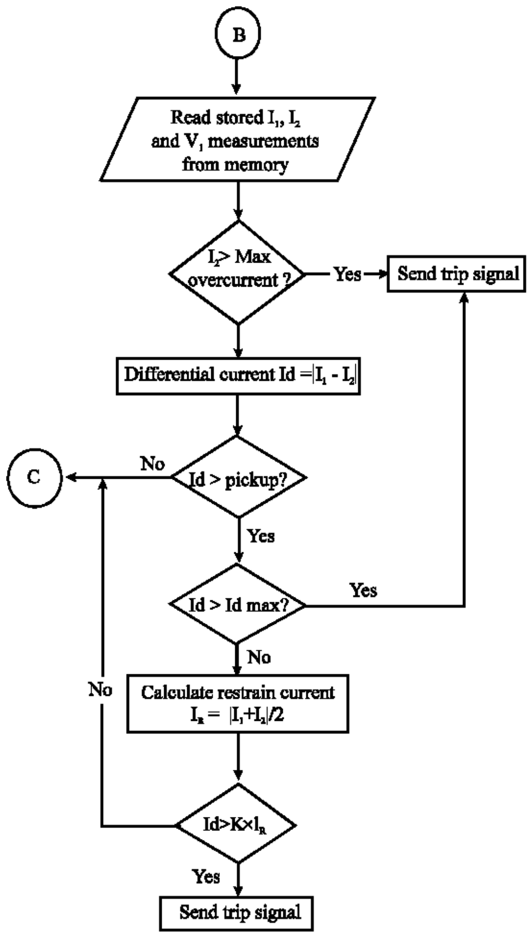

Fig. 4: Instantaneous over current protection and differential protection flowchart

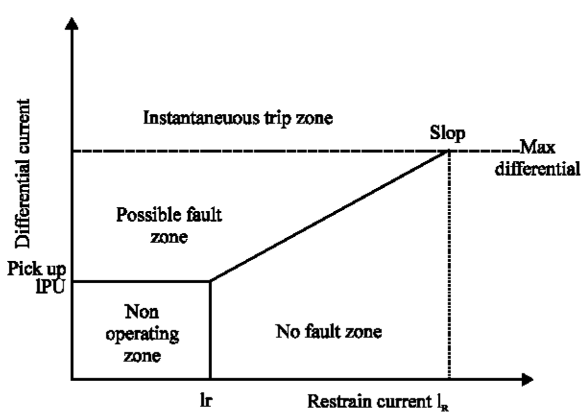

Fig. 5: The characteristic of a differential protection

program section. As shown in Fig. 4 the flow chart of the software is divided into two parts. First part is instantaneous over current protection and the second part is differential protection.

TESTING THE HARDWARE AND SOFTWARE SYSTEMS

The microcontroller-based relay hardware was implemented and tested in the laboratory. The isolation and analog scaling part and the data acquisition part of the relay were calibrated and their transformation ratios were determined.

The software program has been developed and tested in the laboratory. The performance of the software to provide inrush and internal fault discrimination, differential protection, instantaneous over current protection, over voltage and under voltage protection has been checked.

Testing inrushes and internal fault

Discrimination software: Figure 6 shows the inrush current waveform, which recorded by microcontroller-based relay. The function of this software is to show that, if the di/dt of the primary current wave when the transformer is switch on exceeds more than the threshold value, this means the transformer in magnetizing inrush current phenomena (Guzman *et al*., 2001). In this case, the microcontroller relay gives time delay before starting the differential relay software that sends signal on PA4 giving an indication to LED informing the operator that situation is normal. Otherwise there is an internal fault and the relay will send trip signal on PA6 to trip the circuit breaker giving an indication to LED to inform the operator that there is an internal fault in the transformer. In this test, when the transformer is energized the value of di/dt is high and the relay does not trip because of there is no internal fault and gives time delay before starting differential relay program.

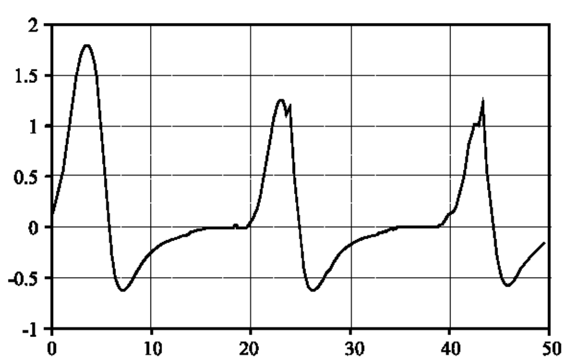

Fig. 6: Inrush current waveform recorded by microcontroller based relay

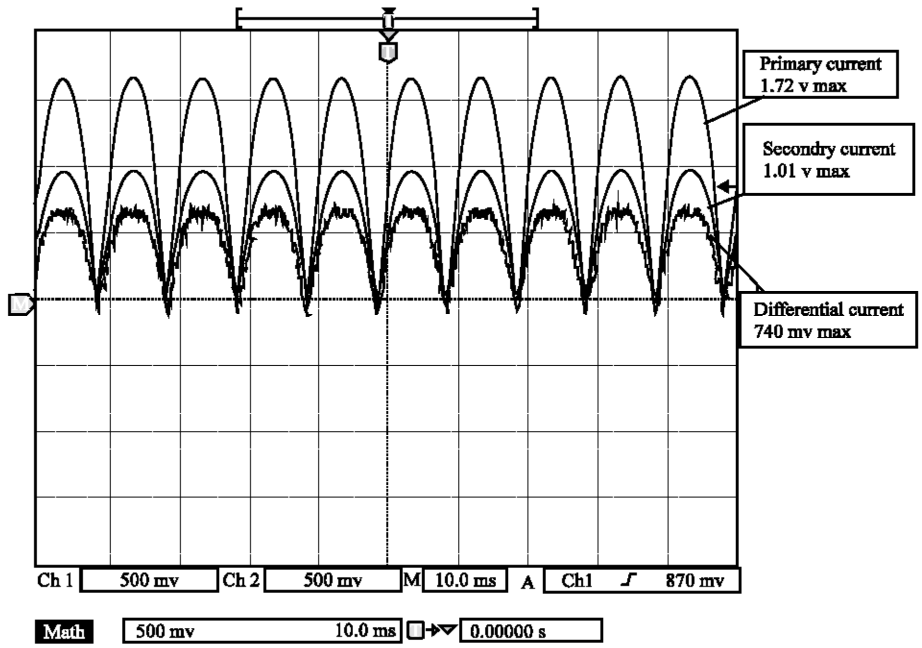

Fig. 7: Primary current, secondary currents and differential current waves in case of internal fault

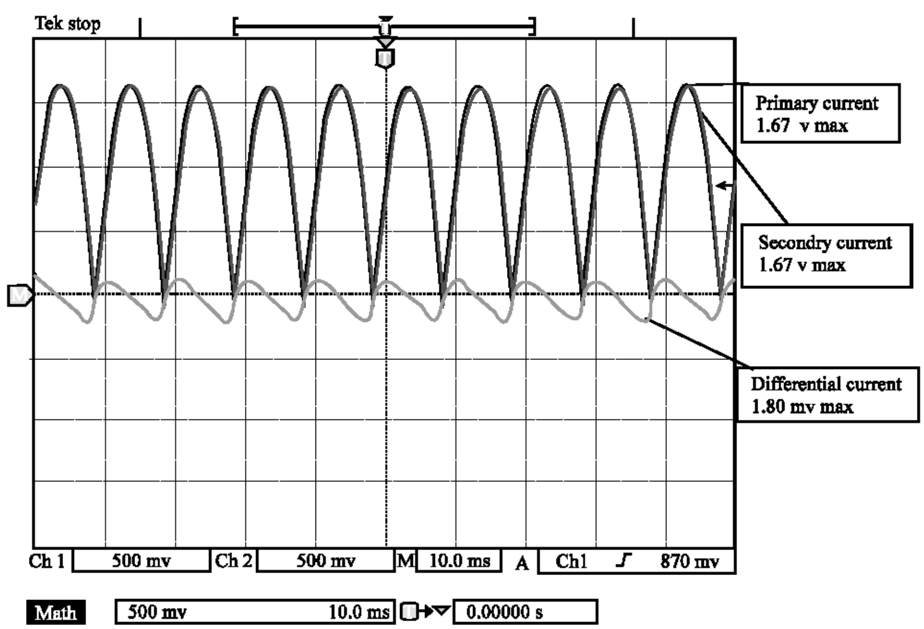

Fig. 8: Primary current, secondary currents and differential current waves in case of external fault

Testing differential protections and instantaneous over current protection: In this test, a short circuit between two current transducers through 10 ohm resistance used to create an internal fault in the transformer differential protection zone. The relay send trip signal on PD4 to trip circuit breaker and gives indication on LED to inform the operator the trip was from differential protection. In this case, the instantaneous over current does not operate. In this test the two relays are functioning. Figure 7 shows primary and secondary currents and differential current when internal fault occurs.

External fault test, the short circuit through 10 ohm resistance used to create an external fault outside the zone of the differential protection. The relay send trip signal on

PD3 to trip circuit breaker and gives indication on LED to inform the operator the trip caused by instantaneous over current relay. Figure 8 shows the primary current, the secondary current and differential current values in case of external fault. In this case, the differential relay does not operate.

Testing over/under voltage protection software: In this test, the output voltage from primary voltage channel has been increased until become more than 110% from nominal voltage. The relay sends trip signal on PD5 to trip circuit breaker and gives indication on LED to inform the operator the trip caused by over voltage relay.

Under voltage test has been carried out, the output voltage from primary voltage channel decreased until become less than 90% from nominal voltage. The relay send trip signal on PA4 to trip circuit breaker and gives indication on LED to inform the operator the trip caused by under voltage relay.

CONCLUSIONS

The microcontroller based relay for power transformer has been constructed and tested. The major emphasis of this study has been on the detailed description of hardware and software development of the relay. The relaying functions implemented include a percentage differential protection with the di/dt restraint for inrush current condition, over current protection to protect the transformer from overload and external faults, over voltage protection and under voltage protection. All these types of protection have been carried out in one relay to protect the power transformer.

The results demonstrated that the discrimination time is around 1.6 m sec, to discriminate between inrush current and internal fault, which means the relay, is fast. The differential relay does not issue a trip command during normal operation, magnetizing inrush and external fault conditions; this means that the relay is reliable. Operating time of the differential relay is 633 μ sec. The instantaneous over current relay does not issue a trip command during normal operation and internal fault conditions, this means the over current protection works as back up protection. Operating time of instantaneous over current relay is 100 μ sec faster than analogue relays. Over voltage relay and under voltage relay-operating time is around 113 μ sec.

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