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Development of Stand-Alone Numerical Relay for The Protection of Three-Phase Induction Motor

Pankaj B. Thote*, Mohammad Ashar**, Kartik Rao*** and Mansmita Kapade****

Induction motors are highly reliable; they are susceptible to many types of abnormalities like overload, over voltage, under voltage, phase reversal, ground fault and insulation failure. Due to these electrical conditions the winding of motor gets overheated which leads to insulation failure and hence reduces the life of the motor. These can cause production shutdowns, personal injuries, and waste of raw material. Therefore, to protect the motor the fault must be detected in the initial stage. In the proposed protection scheme, a panel has been designed which alone can protect induction motor from various abnormal conditions such as overload, overvoltage, under voltage and phase reversal. A microprocessor based relay is designed and is tested with the setting of various preset values of parameters. The simulation and hardware results are presented to validate the proposed method.

Keywords: *Current Transformer (CT), faults, three-phase induction motor, numerical relay, microcontroller, MATLAB/SIMULINK.*

1.0 INTRODUCTION

The induction motors are the significant motors widely used in industries and has many applications. It is used to convert electricity into mechanical energy. It is a low cost and a high performance solution. Its reliability and less maintenance make them the most popular and useful motor in the industrial and commercial fields. These motors are flexible in nature and can be used for various application fields. They can be utilized for low power applications viz. household appliances or can be used for large power applications viz. petroleum industry. Despite the fact of high reliability of induction motors, the operating conditions may render the motor into different fault conditions. These faults may cause to machine shut down and causing production losses in industries.

In [1], multifunctional numerical relays with the switching equipment, renewable energy source facility and the distribution network have been modelled in DIgSILENT Power Factory software. The paper [2] demonstrates simulation and steady-state performance of three phase squirrel cage induction motor and detection of rotor broken bar fault using MATLAB. The paper [3] proposes a protection scheme for three phase induction motors against single-phasing faults using MATLAB/ SIMULINK software. In [4], the protection and control of 3-phase IM is achieved using the M3 XD-26 controller which is programmed using FBD logic. In [5] the performance of the induction motor is improved in direct torque control scheme. The fault identification and protection of induction motor is done using PLC and SCADA [6].Monitoring the speed, torque and protection of three phase induction motor from

*Associate Professor, EE Department, S B Jain Institute of technology, Management & Research, Nagpur-441501, thote.pankaj@gmail.com, Mob +91-9422803865
**Assistant Professor, EE Department, S B Jain Institute of technology, Management & Research, Nagpur-441501, 1069ashar@gmail.com, Mob +91-7030449605
***Ex-Student, EE Department, S B Jain Institute of technology, Management & Research, Nagpur-441501,kartik.srinivas.rao@gmail.com
**** Ex-Student, EE Department, S B Jain Institute of technology, Management & Research, Nagpur-441501, mansmitakapade123@gmail.com

overload by implementing ZigBee based wireless sensor network is proposed in paper [7]. The performance of induction motor with respect to current improvement is presented in [8]-[11]. The above said methods [1]-[3] are merely simulation based methods. In these literatures, hardware implementation for various abnormalities is not performed. The Programmable Logic Controller (PLC) is also used in some of the methods [4] and [6].In these literatures, the computer based protection methods are used which are costlier and the electrical parameters cannot be visualized by PLC based method. These old classical methods are complex. Hence in the proposed paper, in order to protect an Induction motor easily, a microcontroller based fault detection and protection of Induction motor is presented which is cheap solution and easier for implementation as compared to techniques mentioned in the reviewed literature. For hardware implementation we have used microcontrollers ATmega16 and ATmega8 whereas for software implementation we have used MATLAB/SIMULINK software.

The novelty of our project is that it provides a low cost solution for the complete protection of 3ph induction motor used in agricultural sector, small scale industries, variable frequency drives, air compressors, pumps etc. by development of single integrated digital relay which will provide over current, over and under voltage, single phasing and phase reversal protection embedded in a single relay. It is based upon Current Transformer (CT) less technology which differentiates it from similar line of products. As it is fully digitally controlled, it overcomes the drawbacks of the electromechanically operated relay with better control, accuracy, sensitivity and increased relay life. Moreover, the developed multifunction protection relay is efficient and uses unique technology.

2.0 ABNORMAL CONDITIONS IN INDUCTION MOTOR

The three phase induction motors are used in many industrial applications due to their reliability, low cost and high performance. The different fault situations may arise in the machine while operating at different conditions. The main external faults experienced by the Induction motors are overcurrent due to overloading, single phasing, unbalanced voltage supply, phase reversal, locked rotor, under voltage, over voltage and ground fault.

2.1 Overload

Motor overload condition is mainly a result from abnormal use of motor, harmonics or unbalanced supply voltages. The load on the motor is mechanical load. When mechanical load on the motor is gradually increased, the speed of the motor gradually decreased and slip is increased. With increase in the slip the current increases. The heat generated goes on increasing the temperature of the winding and with increase in the temperature, the rate of heat dissipation also increases. In this manner when the load is increased beyond the rated load the current will increase to subsequently very high level.

2.2 Under voltage

When the motor is running at rated load and if there is a voltage drop, the current taken by the motor increases. This is because the power to be delivered remains constant and the voltage is reduced from the normal rated voltage. With the increase of motor current, motor winding insulation could get damaged over a prolonged period of time.

Over voltage

When the voltage in a circuit or part of it is raised above its upper design limit, this is known as overvoltage. Due to this abnormality there are harmful effects on machines insulation.

2.3 Phase reversal

If the phase sequence in the supply circuit of an induction motor is reversed only the negative sequence currents are taken by the motor and the motor will run in the opposite direction when started. Phase reversal usually occurs as a result of mistakes made during equipment installation, maintenance, or modifications in the power system. In many cases this can cause a hazardous condition that may destroy product, damage machinery, and injure personnel.

3.0 PROPOSED PROTECTION SCHEME FOR INDUCTION MOTOR

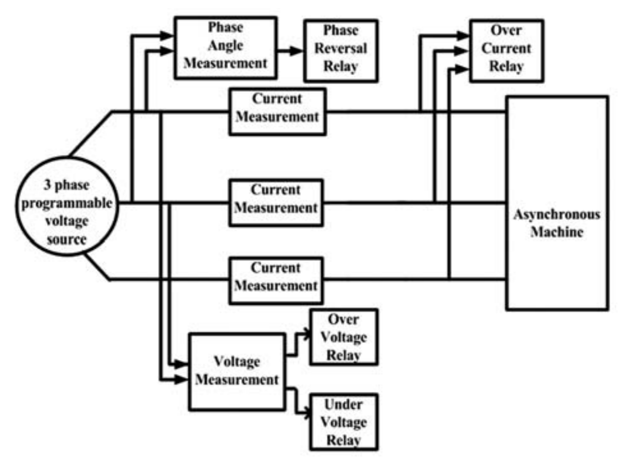

FIG. 1 BLOCK DIAGRAM OF THE PROPOSED PROTECTION SCHEME

In the proposed protection scheme each phase of the supply is given to the current measurement block, for measuring the input current of the induction motor. Figure 1 shows the block diagram for the proposed scheme. The value of input current and the pre-set value of the current is compared in the relay block. For phase reversal, signal from two phases is given to the phase angle measurement block where difference between the two phases is measured. The output of phase angle measurement is then given to the phase reversal relay. For under voltage and overvoltage analysis, voltage between two lines i.e. phase to phase voltage is given to the voltage measurement block where phase voltage is measured and then the output is given to the respective relay. For single phasing one of the phases gets disconnected from the motor and current in all the three phases is measured. Thus the measured current is given to single phase relay. All the above discussed relays together form the complete protection scheme for the protection of three phase induction motor.

4.0 ALGORITHM FOR THE PROPOSED PROTECTION

Figure 2 shows the algorithm of proposed protection scheme of the induction motor. As the programs starts, the initialization of the microcontroller IC i.e IC ATMEGA16 takes place. As soon as the program initialization process takes place, next step is the data of operating condition in which all the parameters of motor like voltage, current, phase angle are measured by microcontroller. The main reason behind this measurement of the motor parameters is that, the microcontroller compares all measured values with pre-set values, here the preset values is the all different ranges (in percentage) which are set for all the measured parameters. The pre-set value is the minimum as well as maximum limit for the measured parameters. The pre-set value for the overload/over current abnormality is 15% above the rated value. Whenever the abnormality arises, and the measured value crosses the pre-set values, the microcontroller will generate trip signal. Similarly for the over-voltage and under voltage the pre-set values are above and below 20% of its rated value. During normal operation the microcontroller will continuously monitor system parameters and since all the parameters are within the prescribe limit, the microcontroller will process the next cycle and therefore the output of microcontroller will be active low.

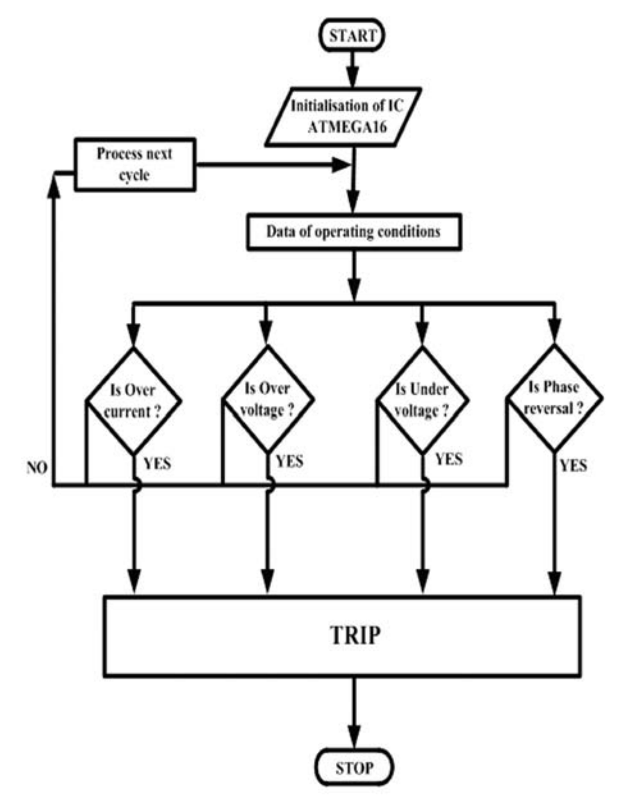

FIG. 2 FLOWCHART FOR THE PROPOSE PROTECTION SCHEME

5.0 HARDWARE IMPLEMENTATION

5.1 Motor specifications

1. Frequency – 50Hz
2. Rated rpm – 1440rpm
3. Rated voltage – 410V
4. HP rating – 1HP
5. Rated current – 1.5A

5.2 Current sensor ratings

1. Sensitivity – 66 to 185mV/A
2. Output voltage proportional to AC currents
3. Vcc – 5V DC
4. Maximum input current – 20 A

5.3 Over current protection

Rated current of 1 HP, 3ϕ, induction motor is 1.5 A. A tolerance band is 15% is considered for over current protection. IC ACS712 which is a current to voltage converter IC is used for over current protection. Thus it is a CT less technology. The output of the IC is fed to the port PA0 of the microcontroller which is an ADC port. It will convert the input analog signal into an equivalent count. Figure 3 shows over current protection circuit diagram.

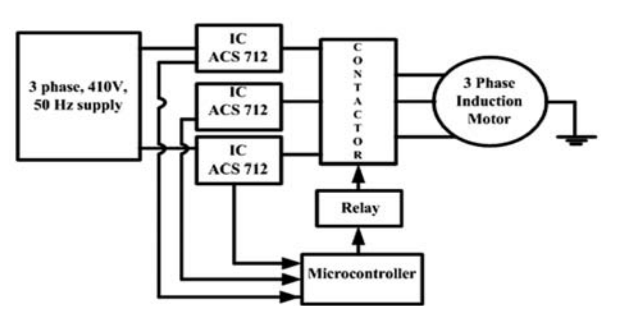

FIG. 3 OVER CURRENT PROTECTION CIRCUIT DIAGRAM

Under normal operating conditions since the counts are within limits, therefore no trip signal is generated. When current exceeds 15% of the rated value port PD0 of the microcontroller gets set (5V). This signal is fed to the input of relay-contactor circuit for tripping the induction motor.

5.4 Under voltage and over voltage protection

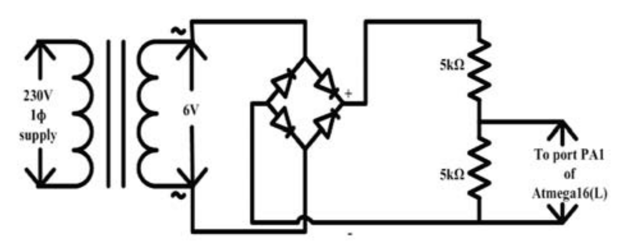

FIG. 4 CIRCUIT DIAGRAM FOR UNDER VOLTAGE AND OVER VOLTAGE PROTECTION (R PHASE)

The per phase voltage of 1HP, 410V and 3ϕ induction motor is around 230V. A tolerance band of 20% is considered for under and over voltages. So, the upper limit of voltage is 276V and lower limit of voltage is 184V. Figure 4 shows circuit diagram for under voltage and over voltage protection (r phase).

Each phase of the supply is fed to a 230/6V transformer. Then the 6V supply is fed to a bridge rectifier. The DC signal is then given to a divider circuit. Voltage output of one of the resistor is given to the port PA3 of microcontroller which is an ADC port. Similarly for Y and B phases, the output voltage is given to ports PA4 and PA5 of the microcontroller. The ADC ports convert the voltage signal into an equivalent count.

Under normal operating conditions since the counts are within limits therefore no trip signal is generated. When the voltage of any phase becomes greater than or equal to 276 or less than or equal to 184V, port PD0 of microcontroller gets set (5V). This signal is given to relay-contactor circuit for tripping the induction motor.

5.5 Phase reversal protection

For phase reversal detection, a separate micro-controller i.e. ATMEGA8 is used to avoid the complexity of programming in the main micro-controller. The phase difference between R and Y phases is 120 degrees. In case of phase reversal the phase difference between R and Y phases changes. When the voltage across photo diode is less than 1.5V (during the zero voltage crossing of the rectified ac supply), the voltage across collector will be +5V in the form of pulse and is given to the interrupt pin of micro-controller. When voltage across photo diode becomes equal to or greater than 1.5V (during the positive cycle of the rectified ac supply), the photo diode emits light and initiates base terminal of the transistor and the emitter which is at ground potential appear across the collector terminal. The output (Ground) of the collector is fed to the microcontroller. Figure 5 shows circuit diagram for phase reversal protection.

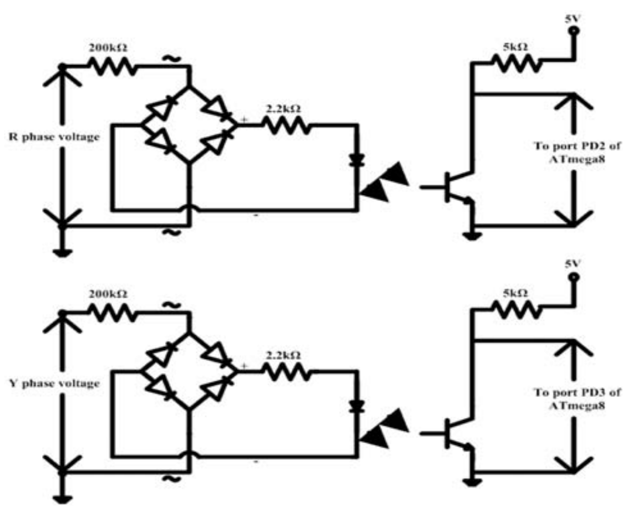

FIG. 5 CIRCUIT DIAGRAM FOR PHASE REVERSAL PROTECTION

When R phase zero crossing is detected port PD2 of microcontroller gets initiated and it takes the main program to a subroutine where timer counts get initiated. As soon as the Y phase signal zero crossing is detected by the port PD3 of the microcontroller the counts get terminated. Then the counts are used to calculate the time lag between the voltages of two phases. The phase angle is calculated using relation $\Theta = \omega t$.

Under normal operation when the phase difference is 120 degrees, no trip signal is generated. When phase reversal occurs, port PD0 of ATmega16(L) gets set (5V) from the ATMEGA-8 which will further actuate the relay-contactor circuit for tripping the induction motor.

5.6 Relay contactor circuit for tripping the motor

Figure 6 shows the relay contactor circuit for tripping the induction motor. The NC contact of relay is used to actuate the motor contactor through a transistor driver. During abnormal condition i.e. during overcurrent, under voltage, over voltage or wrong phase sequence, the micro-controller will generate a trip command which will be processed by the driver circuit and the relay which will further trip the main contactor and protect the motor from the abnormal conditions. The trip signal from micro-controller is given to auxiliary relay via transistor SL100. Since the output signal of the microcontroller can drive upto 20mA-30mA and the relay coil requires 150 mA to energies itself, transistor is used as a driver to drive the relay. When contacts of auxiliary relay changes, coil of contactor will de-energise and the motor will trip.

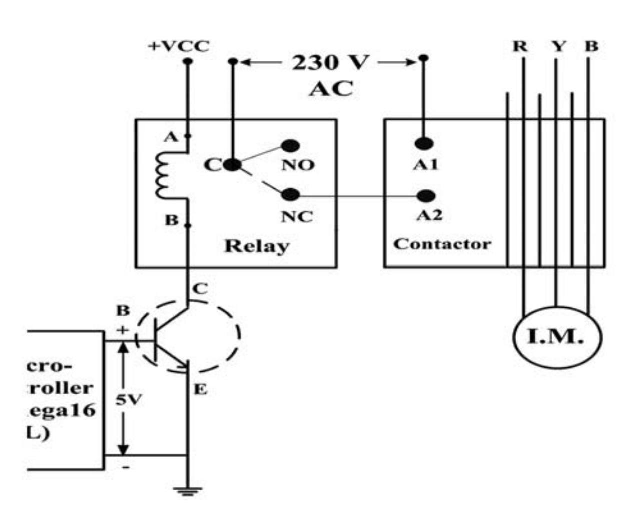

FIG. 6 RELAY CONTACTOR CIRCUIT FOR TRIPPING THE MOTOR

6.0 RESULTS

6.1 simulation result

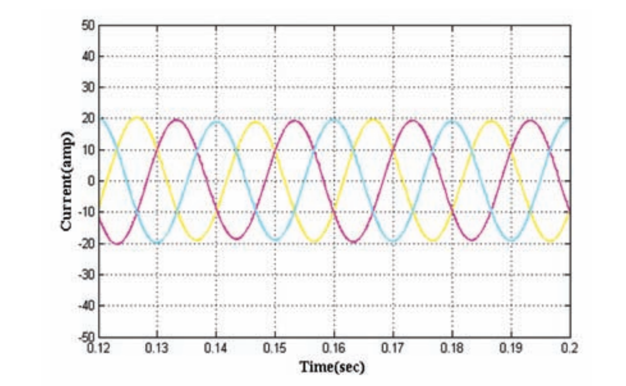

FIG. 7 CURRENT WAVEFORM DURING NORMAL RUNNING CONDITION

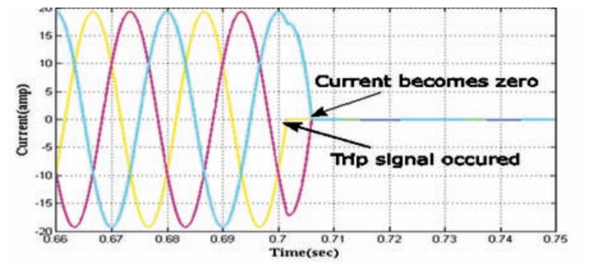

FIG.8 CURRENT WAVEFORM DURING ABNORMAL CONDITION (MOTOR TRIPPED)

Here we have considered steady state operation of motor. When the motor runs under normal condition, the current waveform is shown in Figure 7. But when the motor detects abnormality, current becomes zero by isolating the motor as shown in Figure 8. This shows that fault has occurred and relay has generated trip signal. Similarly, if any of the abnormality is detected in motor, the corresponding relay will generate trip signal as shown in Figure 9.

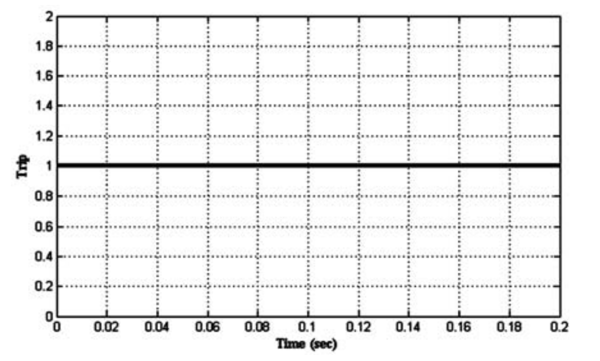

FIG. 9 RELAY GENERATING TRIP SIGNAL

6.2 hardware results

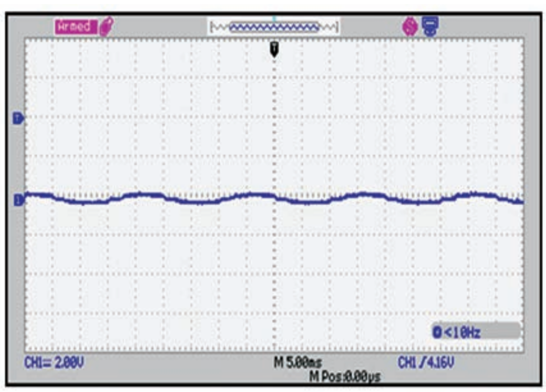

FIG.10 OUTPUT OF MICROCONTROLLER (0V) ON DSO UNDER NORMAL OPERATING CONDITION

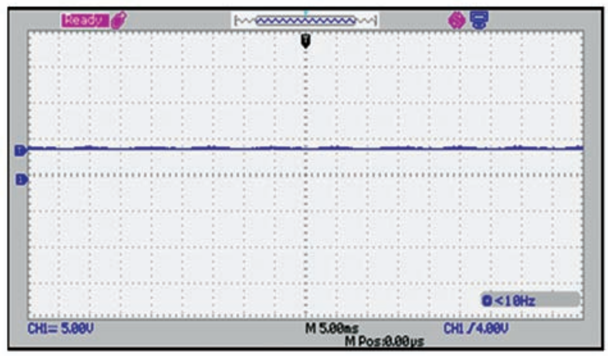

FIG. 11 OUTPUT OF THE MICROCONTROLLER(5V) ON DSO UNDER FAULT CONDITIONS

During normal operating conditions when all the parameters are within desired limits the output of the microcontroller is found to be 0V i.e. it does not generate trip signal as shown in Figure 10. When any of the system parameters exceeds the pre-set value, the output of the microcontroller (port PD0) sets to 5V as shown in Figure 11. The signal is then given to the relay-contactor circuit for tripping the induction motor.

7.0 CONCLUSION

Protection of three phase induction motor from over/under voltage, over current, and phase failure provides the smooth running of motor which also improves its lifetime and efficiency. To make induction motor run efficiently and to protect it from various abnormalities, we have used microcontrollers ATmega16. The software implementation has been carried out using MATLAB software. BASCOM (Basic Compiler) is used for programming purpose. Programming becomes easy with the use of this software as it has integrated simulator for testing, and becomes easier to visualize hardware results on software platform. The overall costing of the relay is around 2500 rupees which is 55.80% less than a relay produced by L&T. MPR300 L&T made relay provides protection against single phasing, over load, earth fault, under current and lock rotor abnormalities whereas the proposed model provides protection against over voltage, under voltage and over current abnormalities.

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