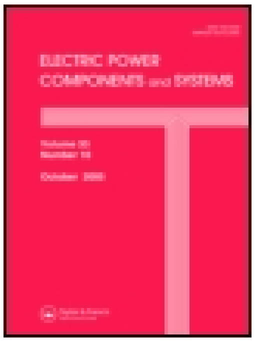

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K. PANDURANGAVITTAL, D. B. FAKRUDDIN, and I. RAGHAVENDRA RAO

Department of Electrical Engineering
Karnataka Regional Engineering College
Srinivasnagar, India

K. PARTHASARATHY

Department of Electrical Engineering
Indian Institute of Science
Bangalore, India

ABSTRACT:

This paper presents a Microcontroller based three phase induction motòr protection relay. The scheme employs the Hall effect current transducers for sensing motor line currents, and an 'Auto ranging ' feature, in order to acquire motor line currents accurately from no load to blocked rotor current. The flexibility of 'Operator selectable thermal current versus time (I-T) curves feature' is incorporated in the relay software, in which using the operator fed cold curve points and the thermal time constant of the motor, the corresponding I-T cold and hot curves can be fitted by the relay Software. The relay performance, with the selected I-T curves has been studied in the laboratory by testing on a three phase, 5 h.p. induction motor and it has been observed that the relay to follow the selected I-T characteristics.

1. INTRODUCTION :

The three phase induction motors are widely used as industrial drive motors. In order to reduce the size and to minimise the cost, large capacity motors are designed so that, the magnetic and current densities are close to the limiting levels. Such motors are sensitive to abnormal operating conditions like overvoltage or over loading etc. and hence require high speed and reliable protection scheme.

The digital relays based on microprocessors or microcontrollers can provide accurate high speed protection. Further, they can be programmed to follow a desired relay characteristic [1,2]. A Microcontroller has in-built features like timers, analog to digital converter (ADC) and digital input output (I/O) units along with central processing unit (CPU). This results in reduced hardware for realising a real time controller and consequently improves reliability [3].

This paper presents Intel 8097BH microcontroller based protection scheme for three phase induction motor. The hardware scheme developed consists of input end hall effect current transducers in current channels, to enhance the bandwidth and

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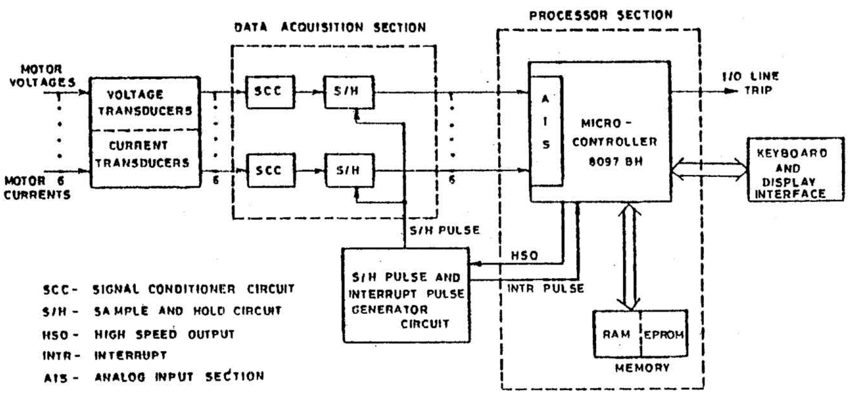

FIGURE 1. Block schematic of the Motor Protection Relay

linearity. Further, an 'Auto ranging' feature provided with these channels, enables the use of the ADC with its full resolution over a wide range of input currents, ranging from no load current to blocked rotor current.

The protection against over loading ideally requires relay I-T characteristics to follow thermal behaviour of the motor. In order to set I-T characteristics to match closely with thermal behaviour of motor under consideration, it requires flexibility in fitting the desired I-T curve. This feature has been incorporated in this protection scheme. To obtain the desired I-T curve the operator has to feed-in at least 6 points of the curve in to the microcontroller system. Then the software will compute the parameters required to simulate the desired I-T curve.

The complete relay system has been tested on a 5 h.p., 3 phase Induction motor in the laboratory by simulating different abnormal operating conditions. The relay performance has been observed to follow the desired characteristics.

2. HARDWARE:

A relay based on programmable devices provides high accuracy ,reliability, flexibility, good system interaction and cost effective solution [3]. Further, the reliability of such schemes can be enhanced by reducing number of peripheral devices, which is achieved in this scheme, by using Intel 8097BH microcontroller [4]. Fig. 1 shows the block schematic of the relay developed based on microcontroller.

The data acquisition section, processor section and control signal generator section are the three modules, which are integrated to constitute the motor protection relay hardware.

2.1 Data Acquisition Section:

The motor terminal phase voltages are sensed and scaled down using 230V/6V,3VA transformers, connected in Y-Y configuration. The line currents are sensed using Hall

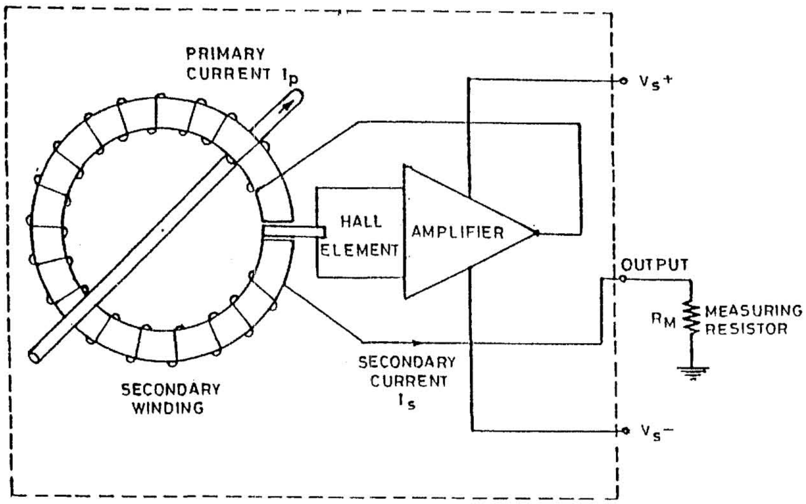

FIGURE 2. Functional schematic of the Hall effect Current Transformer

effect current transducers [5]. These produce an output voltage proportional to the line current and in phase with line current. The bandwidth of the transducer used is DC - 100Khz(-1 dB), which enables it to reproduce the current wave shape with least distortion. Further, these transducers exhibit good linearity, this value for the transducer used is better than 0.1%. The output voltage of hall effect current transducer being in phase with the line current, the overall transducer system behaves like a transfer-resistance, in which, the output is isolated from the input circuitry. The schematic of the transducer is shown in Fig. 2.

The signals as obtained from the above transducers are fed to the signal conditioning circuitry. In this circuitry, the voltage channel signals of the three phases are suitably phase corrected to account for any phase shift introduced by the potential transformers. The Hall effect transducer output voltage is subjected to wide variations due to variations in line current , this may be as high as six times full load current at motor starting conditions and a low value at no load conditions. When the transducer output voltage is at it's higher limit, the signal conditioning circuit which is set to give full scale voltage during rated operating conditions causes ADC output code to clamp at it's highest code limit. Due to this, the estimates of line currents which are above the normal rated value cannot be obtained accurately. This limits the accuracy of thermal I-T curve implementation by the relay logic software. To obtain accurate line current estimates over the entire range of motor current, the output voltage of Hall effect current transducer of each channel is fed to an 'Auto ranging' circuit. An 'Auto Ranging' feature gives a means of attenuation setting which will provide an analog magnitude within V_{ref} of ADC over the entire range of motor current (i.e. no load current to blocked rotor current range). In a way, the dynamic range of the ADC is enhanced, without sacrificing ADC resolution under normal motor load conditions. Fig. 3 shows the functional schematic of the 'Auto Ranging' arrangement.

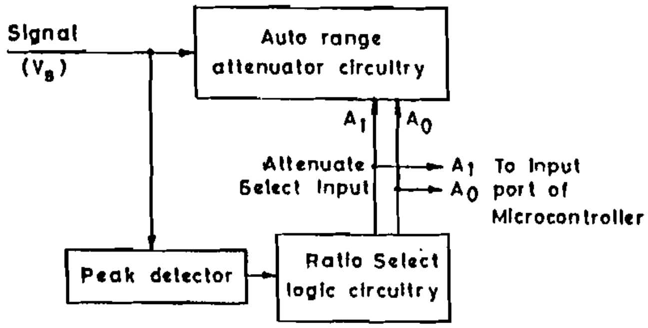

FIGURE 3. Functional schematic of the Auto ranging arrangement

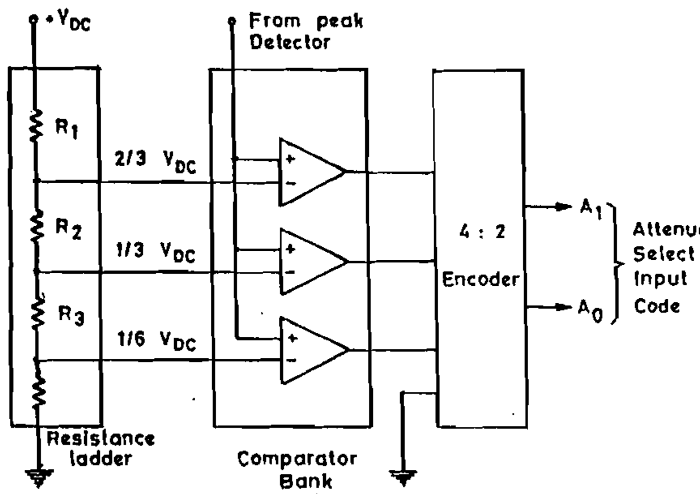

FIGURE 4. Ratio select logic circuit

The peak detector output voltage is fed to a ratio select logic circuit to generate attenuate select input code 'A_1A_0'. This code sets required attenuation level for the signal at the Auto range attenuator circuit.The ratio select logic circuit is designed based on 2 bit flash converter principle and it is employed to derive the necessary digital logic for ratio selection. Fig.4 shows the connection diagram of ratio select logic circuit.

The resistance ladder of the ratio select logic circuit is fed with a reference D.C level, whose magnitude is equal to the voltage output of the hall effect current transducer at blocked rotor current of the motor. The resistance ladder is tapped at 1/6, 1/3 and 2/3 of the above reference level. These levels are used for comparison, with the peak detector's output by the comparator bank. The result of such a comparion is encoded into a 2 bit, attenuate select input code 'A_1A_0'. This 2 bit code is used for addressing the appropriate input of the analog multiplexer, in Auto range attenuator circuit.The auto range attenuator is realized by analog multiplexer and a resistor

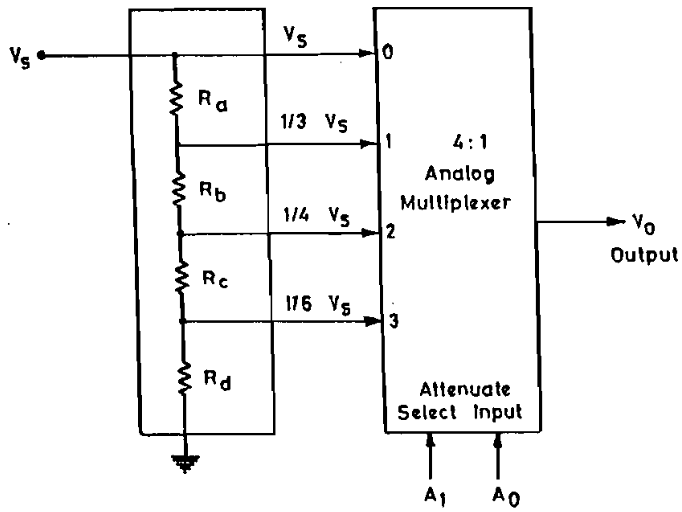

FIGURE 5. Auto range Attenuator circuit

ladder used as potential divider. Fig. 5 shows connection diagram of the auto range attenuator circuit. The resistor ladder provides attenuated levels of input signal.

The multiplexer selects any one of these levels as its output, depending on its attenuate select input code 'A_1A_0'. Further, the 2 bit code of attenuate select inputs are also fed to an input port of the microcontroller, which will be read by the data acquisition interrupt service routine and used as attenuate code multiplier, when the ADC output code is converted into analog magnitude. The voltage signals and current signals thus obtained are then band limited, level shifted and fed to sample and hold circuits.All the six channels are simultaneously sampled at 400Samples/sec. Thus obtained voltage and current samples are stored alternately in two auxiliary tables in RAM . These samples are transferred to Main data tables, only when two consecutive set of samples have arrived. Since, the Main data tables are updated only after two consecutive sample sets have arrived, it provides twice the sample interval time for signal processing and relay logic software program. The Main data tables are accessible during this interval time. Fig.6 shows the motor starting current phase A signal acquired using the 'Auto ranging' data acquisition system of the relay. Fig.7 shows the true r.m.s. and the fundamental r.m.s. value of the motor starting current computed in the relay system. It is seen that, the true r.m.s. and fundamental r.m.s. match closely to each other, because the line current is free from transient noise.

3. OPERATOR SELECTABLE I-T CURVE FEATURE:

The large capacity motors with rating above 50 h.p. are protected against overloading by means of thermal relays or inverse time-current breaker tripping devices. In general, not all the information required to set overload relays accurately will be available for each individual machine. It is therefore, a best choice to design a protection that matches, as closely as possible to the heating characteristics of the

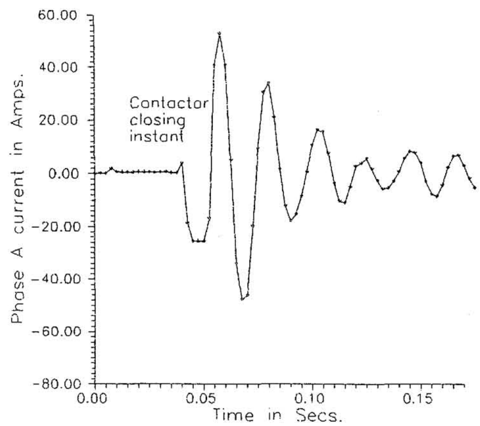

FIGURE 6.Motor starting current signal acquired through 'Auto ranging' data acquisition system

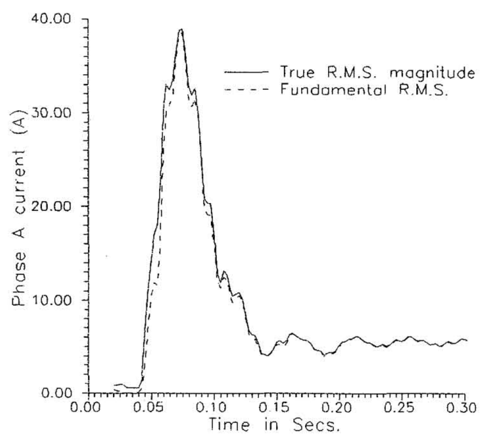

FIGURE 7. Motor starting current computed in relay system

motor under consideration, and a flexibility to modify the relay characteristic by the operator to achieve best protection. The heating in the machine is due to the combined effect of both positive and negative sequence currents. Therefore, a scheme wherein, the relay is made to be responsive to an equivalent 'thermal current', which reflects the total heating in the machine will be adequate [6]. The thermal current is given by,

$$I = \sqrt{I_1^2 + K_{ac} I_2^2} \quad \text{------------->} (1)$$

Where, I = thermal current, I_1 = Positive sequence current , I_2 = Negative sequence current, K_{ac} = a constant , set between 1.5 to 6 to account the increased resistance in the motor winding due to skin effect.

The thermal model of the motor can be given in the form of a time - current relationship, in which the time value represents the time taken for the temperature of the motor to rise to it's maximum permissible value, with the specified steady state current flowing through it. A general curve for thermal electrical relays, based on heating effect, assuming the motor was started from cold condition is specified by IEC recommendation 255-8 as,

$$t = \tau \ln\left[I^2 / \left(I^2 - K.I_b^2 \right) \right] \qquad \text{-------------->(2)}$$

where , t = operating time of the relay, τ = thermal time constant, I = relay current, I_b = Rated current, K = a constant by which I is to be multiplied to obtain the current value to which the accuracy of the current is referred. Then, with regard to preheating on a relay with total memory function, the Hot curve is relevant and specified by equation,

$$t = \tau \ln\left[\left(I^2 - I_P^2 \right) / \left(I^2 - (K.I_b)^2 \right) \right] \qquad \text{------------>(3)}$$

Where I_P = specified load current before the overload occurs.

The cold curve and hot curve resulting out of equation (2) and (3) respectively are incorporated in the relay software. The I - T curves are fitted based on a technique reported by Schweitzer et al.[7]. In this method, when the thermal current (I) exceeds pickup value, a weighted cumulative summation of the thermal current is carried out. when the result of this cumulative summation crosses a particular threshold (T_v) , the relay issues a trip signal. For a chosen T_V , two constants α and β are employed such that the process of cumulative summation yields operating times that match as closely to those given by the desired operating characteristics. The summation is given by equation (4).

$$S_{K+1} = S_K + \alpha I - \beta \qquad \text{--------->(4)}$$

where, S_{K+1}= magnitude of the cumulative summation at $(K+1)^{th}$ sampling point,
I = Magnitude of the motor thermal current at the $(K+1)^{th}$ sampling instant.

The thermal current range over which I-T characteristics have to be fitted, requires sectionalisation of the curve in to two or more sections. For each section of curve to be fitted one set of α, β constants are employed to keep up accuracy constraint of curve fitting. The number of sections and associated α, β sets will be more if higher accuracy is desired.

The operator selectable I-T curve feature employs fixed threshold value and fixed accuracy constraint for curve fitting. The operator has to enter the following data at the specified memory location of the relay read/write memory (RAM),

- The total number of points on the cold curve,that he is intending to enter (up to 6 points,this can be increased by suitable change in software).
- The current magnitudes for the above selected points.
- Corresponding operating-times for the current magnitudes entered above.
- Thermal time constant of the Motor.

- Full load current rating of the motor.
- Pick-up current for the relay.

Once the above data entry is over, the software, estimates the intermediate cold curve points by linear interpolation and these interpolated curve points are stored in current and operating-time tables. In order to incorporate the I-T characteristics by summation equation, it is required to determine number of sections required, range limits of sections and corresponding α ,β constants, keeping accuracy criteria in view. This is done by successive interval reduction technique. At first step, the process of computing α, β is based on points (I_1 ,t_1) and (I_n ,t_n) [first and last points of I-T curve] and the associated equations (5) and (6) are,

$$(\alpha.I_1 - \beta).t_1 = T_V.2.\Delta t \qquad \text{---------->(5)}$$

$$(\alpha.I_n - \beta).t_n = T_V.2.\Delta t \qquad \text{---------->(6)}$$

where Δt = sampling interval.

Equations 5 and 6 are then solved simultaneously to yield α and β. This α and β are used in computing t, at intermediate intervals of I and accuracy of fitting is verified by using corresponding 't' from operating time table. If required accuracy of fitting is not met, then α , β are recomputed with (I_1 ,t_1) as section start point, (I_{n-1} ,t_{n-1}) as section end point. This process of section end point shift is done in steps as, (I_{n-2} , t_{n-2}), (I_{n-3} ,t_{n-3}) ..... so on. Fig. 8 depicts this scheme of calculation. At every step, α ,β constants valid for the section is computed and curve fit accuracy is verified for that section. If all the points of the curve section are well fitted, then that section end point thermal current will be known. In this way, end point of the section is determined and recomputed value of α and β constants with this start and end points gives best fitting for the section of the curve. Similar way other sections of the curve are identified with associated α, β sets. Fig.9 shows the thermal current - time characteristics fitted using operator fed cold curve points. Fig.10 shows the flow chart for the operator selectable I-T characteristics curve fitting subprogram. Table 1 shows computed α,β values valid over intervals of thermal current expressed in p.u.

Once the cold curve is fitted based on operator fed data, the relay software determines the initial counts required for the summation counter, in order to incorporate hot curves. Hot curves for 1/2 Full load, 3/4 Full load and Full load preheating conditions are fitted by the relay software and shown in Fig.9. Table 2 indicates the hot curve initial count values for S_K counter. Under motor running condition, the relay software will be computing thermal current and if thermal overload occurs (i.e. if relay picks-up) then it selects the initial S_K count automatically based on pre load condition as per Table2. Then follows the summation equation with the new initial count. If the thermal overload current falls below the pickup value, the reset of the relay is performed. A linear reset characteristic is obtained using the equation (7) and the summation counter is decremented to zero for reset.

$$S_{K+1} = S_K - \beta \qquad \text{---------->(7)}$$

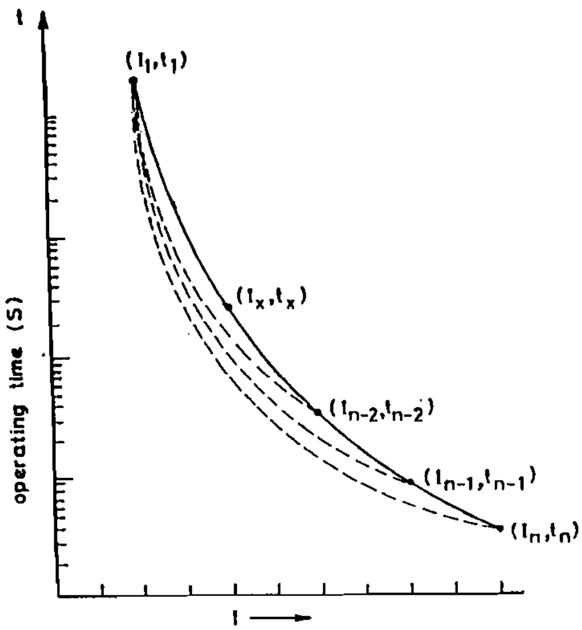

FIGURE 8. Successive interval reduction technique for i-t curve fitting

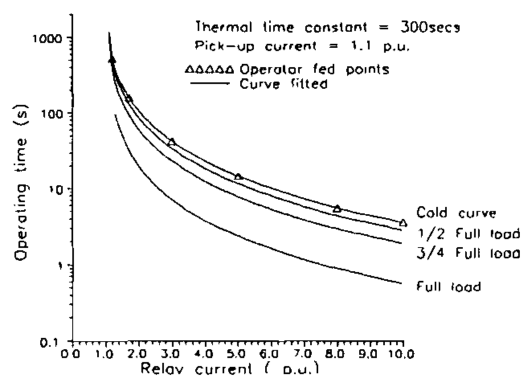

FIGURE 9. Thermal current - time characteristics

TABLE 1 : Current intervals with pertinent α,β values for 5% accuracy constraint

$T_V = 14342$ $\quad\tau = 300$ Seconds

Current range (p.u.)	1.1-1.9	2.0-2.9	3.0-4.5	4.6-7.0	>7.0
α	0.33	0.49	0.75	1.16	1.71
β	0.33	0.62	1.38	3.23	7.1

TABLE 2: Initial count for S_K counter to fit-in Hot curves

Predisturbance Thermal current	Inital count for S_k counter
1/2 Full load	3,003
3/4 Full load	6,769
Full load	12,060

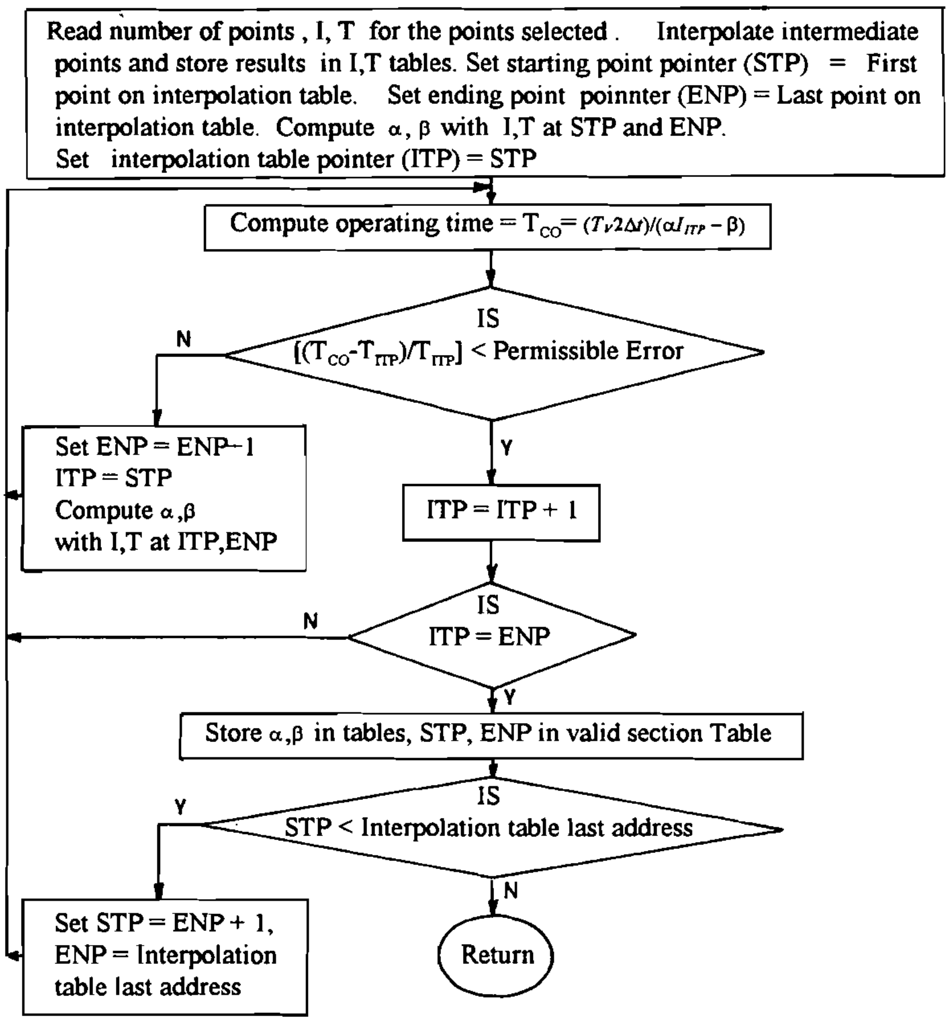

FIGURE 10. I-T Characteristics curve fitting subprogram

4. RELAY SOFTWARE:

The motor protection relay scheme has several protection functions integrated in it by means of software. The protection functions integrated are, thermal overload protection, voltage unbalance protection, prolonged starting protection, blocked rotor protection, earth fault protection,over voltage and under voltage protection. The relay logic software computes sine and cosine components of line current by employing Full cycle window Fourier algorithm as per equations (8) and (9).

$$I_{p\sin} = \tfrac{1}{4}\{(I_{P3} - I_{P7}) + 0.7071(I_{P2} + I_{P4} - I_{P6} - I_{P8})$$ --------->(8)

$$I_{p\cos} = \tfrac{1}{4}\{(I_{P1} - I_{P5}) + 0.7071(I_{P2} - I_{P4} - I_{P6} + I_{P8})$$ --------->(9)

Where, $I_{p\sin}$ and $I_{p\cos}$ are respectively the fundamental sine and cosine components of the line current in phase 'p'.
The $I_{P1}.......I_{P8}$ are current samples of phase 'p' ,available in Main data table.

The quadrature components of the positive, negative, and zero sequence currents are obtained from the sine and cosine components of the individual line currents by applying symmetrical components transformation [8]. The equations (10) to (15) give expressions for the peak values of the sine and cosine components of the sequence currents.

$$I_{1SIN} = \tfrac{1}{3}\{I_{a\sin} - 0.5(I_{b\sin} + I_{c\sin}) - 0.866(I_{b\cos} - I_{c\cos})$$ ---------->(10)

$$I_{1COS} = \tfrac{1}{3}\{I_{a\cos} - 0.5(I_{b\cos} + I_{c\cos}) + 0.866(I_{b\sin} - I_{c\sin})$$ ----------->(11)

$$I_{2SIN} = \tfrac{1}{3}\{I_{a\sin} - 0.5(I_{b\sin} + I_{c\sin}) + 0.866(I_{b\cos} - I_{c\cos})$$ ----------->(12)

$$I_{2COS} = \tfrac{1}{3}\{I_{a\cos} - 0.5(I_{b\cos} + I_{c\cos}) - 0.866(I_{b\sin} - I_{c\sin})$$ ------------>(13)

$$I_{0SIN} = \tfrac{1}{3}\{I_{a\sin} + I_{b\sin} + I_{c\sin}$$ ------------>(14)

$$I_{0COS} = \tfrac{1}{3}\{I_{a\cos} + I_{b\cos} + I_{c\cos}$$ ------------>(15)

The peak values of sequence components are then computed using equations (16) to (18) as,

$$I_1 = \sqrt{I_{1SIN}^2 + I_{1COS}^2}$$ ----------->(16)

$$I_2 = \sqrt{I_{2SIN}^2 + I_{2COS}^2}$$ ----------->(17)

$$I_0 = \sqrt{I_{0SIN}^2 + I_{0COS}^2}$$ ----------->(18)

Fig.11 shows complete sequence of the relay logic program incorporated in this scheme. The motor protection relay based on above scheme was tested on line, with 5 h.p., 400V,50Hz, Delta connected, three phase induction motor at the laboratory. The schematic of the test setup is shown in Fig.12. Fault conditions simulated to test the relay and result of tests are presented in Table 3. The relay performance has been observed to follow the desired characteristics.

STEP 1: Start on Reset, Initialise all table pointers, stack pointer, flag status and S_K counters. Enable interrupts. Fake a software timer interrupt.
STEP 2: Call subroutine for sequence component computation using samples from main data table and on returning from subroutine proceed.
STEP 3: Check for start on phase reversal condition. Issue trip siganl to stop the motor, if started on phase reversal, else proceed.
STEP 4: If high starting current prolongs beyond permissible starting time, trip for prolonged starting else proceed.
STEP 5: If blocked rotor current prolongs beyond permissible blocked rotor time, trip for blocked rotor condition else proceed.
STEP 6: If zero sequence current exists under running condition and if it exceeds threshold, trip for earth fault,else proceed.
STEP 7: Compute thermal current and compare with pick-up level. If it exceeds pick-up level, start S_K counter incrementation, otherwise reset the counter and go to step 8. If S_K counter under incrementaion crosses threshold, then issue trip signal else go to step 8.
STEP 8: Compute voltage and compare with over/under voltage pick-up level. If voltage crosses pick-up, start of OS_K/US_K counter incrementation, otherwise reset the counter and go to step 9. If OS_K/US_K ounter under incrementation crosses threshold, then issue trip singnal, else go to step 9.
STEP 9: Check whether main data tables are updated. If updated proceed else wait until it gets updated by the HSI.0 interrupt sevice routine.
STEP10: Call subroutine for computing sequence components using samples from main data tables and on returning from subroutine go to step 5.

FIGURE 11. Complete sequence of the relay logic program

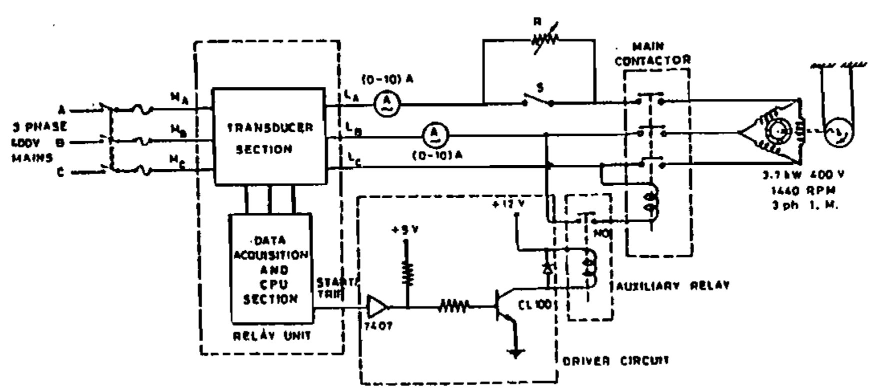

FIGURE 12. Schematic of the test set-up

TABLE 3. Relay performance evaluation test results

Type of Test	Test conditions and settings	Nature of operation	Relay trip time
Start on phase reversal	Set for RYB, Started on RBY	Instantaneous	One cycle time
Prolonged starting	Threshold current = 2.4 p.u., Minimum run up time = 120msecs.	IDMT characteristics	0.123 secs
Blocked rotor condition	Blocked rotor current = 2.8 p.u. Time delay set = 130 msecs	Time delayed trip	0.13 secs
Single phasing	$I_2 \cong I_1$	Instantaneous	One cycle time
Thermal Over load Test with Unbalance supply operation on Full load	Set R (Ohms) I_2 I (p.u.) a) 32.0 0.77 2.52 b) 21.5 0.67 2.25 c) 10.0 0.57 2.00	Thermal i-t characteristics	 56.0 Secs 63.5 Secs 96.0 Secs

5. CONCLUSIONS:

The Hall effect current transducers used in the relay scheme gives true transformation of line currents and improves relay accuracy performance. The auto ranging circuit devised for the use in current channel enhances dynamic range of ADC, without sacrificing ADC resolution under normal motor load conditions. With this, the motor line currents ranging from noload to blocked rotor currents are effectively presented to the relay signal processing software. Further, the Operator selectable I-T curve feature provided in the relay scheme helps in selecting desired thermal I-T curves(cold and hot curves) matching the protection requirements of the motor under consideration. This operator selectable I-T curve feature can also be extended to any time-parameter functional relay.

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