COMPUTER RELAYING SCHEME FOR PROTECTION OF LARGE MOTORS

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree
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MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(With Specialization in Measurement & Instrumentation)

By

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Dated : 24th June, 1989

(RAJEEV GUPTA)

CANDIDATE'S DECLARATION

I hereby certify that the work presented in this dissertation entitled **COMPUTER RELAYING SCHEME FOR PROTECTION OF LARGE MOTORS** in partial fulfilment of the requirements for the award of the degree of **Master of Engineering (Electrical)** with specialization in **Measurement & Instrumentation,** UNIVERSITY OF ROORKEE, is an authentic record of my own work carried out during the period January 1989 to June 1989, under the supervision of Dr. H.K. Verma, Professor, Electrical Engineering Department, University of Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Dated : 24th June, 1989

(RAJEEV GUPTA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dated : 26th June, 1989.

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ABSTRACT

The present day power plants and industrial units utilize larger motors than the plants of late 1970s. Motors power the vital fuel, air, gas, water and coolant systems in power plants and drive varied loads in industries. To ensure reliable and smooth operation of these plants, it is necessary to reduce the outage time of these motors to minimum. The safe working of motors can be endangered by a number of abnormalities that may appear during motor operation. During these abnormalities, some preventive measures have to be taken to prevent the motor from being damaged. This is achieved by providing automated relaying which isolate the motor from the supply when any abnormality occurs.

In this thesis, the various abnormalities that may occur in induction and synchronous motors and the conventional protection provided to safeguard the motor against them have been reviewed. Comprehensive protection scheme for induction motors with details of such a relay have also been reviewed. A digital relaying scheme based on monitoring of motor winding and bearing temperatures along with sequence components of stator current, for the protection of large induction motors has been developed and implemented on a 8085 based microprocessor. To incorporate the concept of an independent back up protection, the schemes has been divided into two parts - slow protection and fast protection and implemented on two separate microprocessors. The details of the digital relaying scheme both hardware and software are presented. The results of test conducted on it are also reported.

CONTENTS

CHAPTER - I

INTRODUCTION

The capital investment involved in large motors in industries & power plants being very large, considerable precautions are taken to ensure that the motor not only operates as nearly as possible to peak efficiency but also that it is protected from accidents. To protect these motors from the abnormal conditions that may appear during the functioning of such motors, automated protective relaying is employed.

The primary function of protective relaying is to cause the prompt removal of any element from service when it starts to operate in an abnormal manner that might damage it or otherwise interfere with the effective operation of the rest of the system. The relaying equipment is aided in this task by circuit-breakers that are capable of disconnecting the faulty equipment when they are called upon to do so by the relaying equipment. A secondary function is to provide indication of the location and type of failure. Such data not only assist in expediting repair but also provide means for analyzing the effectiveness of the relaying scheme.

1.1 NECESSITY OF PROTECTIVE RELAYING

Protective relaying prevents accidents to operating personnel and minimises damages to connected equipments. From economic considerations, protective relaying is identical to an insurance of the machine. The cost of the protecting unit is very small (less than 2%) compared with the cost of equipment protected in case of large motors. Considering the cost of one major repair of the machine, which may turn out to be many times the cost of the protective relaying equipment & the cost involved because of the loss of production during the repair of the machine, one can very well visualize the reasons for the great emphasis on reliable, sensitive and fast automated protective relaying.

1.2 PRESENT WORK

1.2.1 Scope of the Work

Digital relaying using computers or microprocessors is becoming popular these days because of certain advantages it has over the static type relays. This dissertation work was undertaken with the objective of developing a computer based relaying scheme for the protection of large motors. It reviews the conventional relaying practices for the protection of large motors and deals with the design, development and testing of a comprehensive protection scheme implemented on 8085 microprocessor for the protection of large induction motors.

The scheme is based on monitoring of motor line currents and temperature of windings & bearing for the protection and is divided into two parts-fast relaying and slow relaying. Each part is implemented on a separate microprocessor, primarily from the reliability consideration.

1.2.2 Organization of Thesis

The thesis is divided into seven chapters in addition to the present chapter.

Chapter II discusses the various abnormalities in motors & Chapter III reviews the conventional methods of protection of large motors against these abnormalities.

Chapter IV reviews comprehensive protection scheme for large induction motors and describes one such typical relay.

Chapter V covers the principle & the hardware details of the developed relaying scheme.

Chapter VI gives the details of the slow relaying scheme and the associated software.

Chapter VII brings out the details of the fast relaying scheme and the associated software.

Chapter VIII presents the results of the relay testing, discussions, conclusions on the work done and scope for further work.

CHAPTER - II

ABNORMALITIES IN MOTORS

There are a number of abnormal conditions that may appear during motor operation. These abnormal conditions may threaten the life of the motor depending upon their severity. Thus the motor has to be protected against these abnormalities. Protection may be provided against some or all of the abnormal conditions depending upon the size of the motor and the operating conditions for which it is designed.

Contingencies for which automated protection of motors should be provided can be divided into two broad categories [1,3,4] :

(a) Conditions imposed by external power supply network

It includes unbalanced supply voltages, undervoltages, single phasing and reverse phase sequence.

(b) Internal faults either in the motor or in its driven plant

It includes bearing failures, winding faults and overloading.

The majority of motor failures are either directly or indirectly caused by overloading, operation on unbalanced supply voltages or single phasing, which all lead to the deterioration of the insulation until an electrical fault occurs in the windings.

The various abnormal conditions that may appear during the motor operation are discussed below.

2.1 OVERLOADING

Overloading generally occurs because of higher mechanical loads, clogging of cooling vents, faulty bearings, variation in system frequency, drop in voltage & self restarting of motors. Motor overloading leads to overheating of windings & insulation with subsequent shortening of the life of the latter[2]. The heating of motor occurs in accordance with I^2t function. However, with the presence of large number of motor designs & operations for which they are designed, it is not possible to obtain a single thermal curve for them. So the thermal withstand curve has to be obtained from the thermal time constant of the motor. Danger of premature deterioration of the insulation arises only when the maximum permissible operating temperature is exceeded. Short time overloads do not present any danger to the motor since they are too short to increase its temperature to a significant degree. However for long term overloads, the motor must be disconnected from the supply before the insulator's life and its strength are endangered considerably.

2.2 STALLING

Stalling may be either three phase stalling or single phase stalling.

Single phase stalling occurs either because of blowing up of a back up fuse during starting or because of disconnection of any phase when the motor is running, depending upon the load.

Three phase stalling occurs either because of failure of bearings or because of excessive mechanical load on the motor shaft.

During stalling the motor draws heavy current from the supply, equal to the locked rotor current in case of three phase stalling and in single phase stalling if the motor is at rest and equal to 0.866 times this value if the motor is in motion (1 ϕ stalling). This heavy current leads to over-heating and thus the motor should be disconnected from the supply as soon as possible to prevent insulation breakdown [1,2,3].

2.3 REVERSE PHASE SEQUENCE CONDITION

If the phase sequence of any motor is changed because of reversal of any two phase leads, the motor will run in the direction opposite to that in the normal conditions. This is not acceptable for practically any load. This can, however, happen only after some repair on maintenance work in the supply system or motor and not during normal motor operation.

2.4 SINGLE PHASING AND SINGLE PHASE STALLING

The most likely cause of single phase stalling in motors is the loss of one phase of the supply caused perhaps by the blowing of a back up fuse by the heavy inrush current when the motor is first energized. Under this condition the motor would fail to start and would remain stationary with a single phase supply applied to the stator terminals. The motor may also stall if one phase is open-circuited while the motor is running, depending on the load at the time of the open circuit. The actual value of the current drawn by the motor will be less than the locked rotor current, being equal to 0.866 of this value. However, excessive heating is likely to ensue [1,2,3,5].

With a balanced three phase supply applied to the machine a rotating flux is induced in the rotor causing symmetrical heating of rotor winding. However, in case of loss of one phase, a pulsating flux is induced in the rotor which is the sum of fluxes due to positive and negative phase sequence currents. Thus causes unequal heating of the rotor winding depending on the position of the rotor bars & may eventually damage them.

For this reason it is essential that under this condition the motor be disconnected from the supply as quickly as possible.

2.5 UNBALANCED SUPPLY VOLTAGES

The voltage supplied to a three phase motor can be unbalanced for a variety of reasons : Single phase loads, imperfect transposition of feeders or blown fuses in the power factor correction plant. This results in unbalanced sequence currents in the windings [2].

In addition, the accidental opening of one phase lead in the supply to the motor can, depending upon the load, leave the motor still running, supplied by two phases only. The condition of an open-circuit in one line of the supply to a three phase induction motor is generally regarded as the worst possible case of unbalance likely to cause overheating of the machine windings [1,3,5].

It should be noted that it is not the unbalanced voltage which is of importance but the relatively much larger negative sequence component of the unbalanced current in the machine windings that results from the unbalanced voltage. The actual value of negative sequence current depends on the degree of unbalance in the supply voltage and on the ratio of negative to positive sequence impedance of the machine. This negative sequence component of the stator currents induces high frequency currents in the rotor. The frequency of these currents is equal to (2-S) times the nominal frequency of the supply (S = slip). The resistance of the motor windings is increased by the skin effect, the actual value depending mainly on the depth of the winding in the rotor slots. In Squirrel Cage Induction Motors the ratio of the 100 Hz a.c. resistance to the d.c. resistance varies from 1.25 to 6. The rotor heating due to the positive sequence component of the stator current

Such faults are dangerous only when the motor neutral is earthed, since in this case the fault current in the leads and motor phases may exceed the motor starting currents in magnitude [2].

2.6.2 Phase to Phase Fault

Because of the relatively greater amount of insulation between phase windings, fault between phases seldom occur. In case of such a fault, the fault currents are many times larger than the rated motor current in view of the fact that the supply circuit power capacity greatly exceeds the motor power ratings [2].

As the stator windings are completely enclosed in grounded metal, the fault would very quickly involve earth & result in a earth fault. Thus for smaller motors protection against phase to phase type faults is not provided. However, for motors above 1300 h.p. protection against phase to phase fault is also provided [1,2,4].

2.6.3 Inter-Turn Fault

It is caused by short-circuiting of a number of turns within a phase winding. This leads to disturbance of symmetry in the motor & to an increase in the current flowing in the phases. The magnitude of the current depends upon the number of turns shorted and in the worst case, is equal to the earth fault current incident to faulting of a phase lead to an earthed neutral [2].

2.7 BEARING FAILURE

There are two type of bearings that are used :

(a) Antifriction ball or roller bearing

(b) Sleeve bearing

The former is used on smaller motors upto 500 h.p. whereas the latter is used on larger motors.

The failure of ball or rollér bearing occurs because of mechanical fatigue or crushing of bearing material after prolonged use. The pieces of damaged roller often get entangled with the others bringing the motor to a standstill [1]. In such a condition the motor current can become equal to the locked rotor current & can thus result in insulation breakdown because of overheating.

The sleeve bearing failure is generally due to loss of bearing oil which results in seizure of the bearing due to heating, and melting of white metal [1,4,5].

Thus, the motor has to be disconnected from the supply in order to prevent it from three phase stalling because of bearing failure.

2.8 TERMINAL FAULT

This is also referred to as three phase short circuit. In such a case, the motor current may rise to a very high value (approx. ten times the normal value of current) & this leads to excessive heating. In order to safeguard against these heavy currents, the motor must be disconnected instantaneously from the supply in case a terminal fault occurs [1,2].

2.9 VARIATION IN SUPPLY VOLTAGE & FREQUENCY

Motor torque is proportional to the square of supply voltage. Drop in supply voltage leads to an accompanying loss in motor torque & when load torque remains constant, it causes the slip to increase. As the slip increases the motor consumes more reactive power from the supply with an accompanying increase in full load motor current. The voltage drop in the cable increases and makes it difficult for the motor to regain its normal speed even after the disappearance of the cause of initial dip in voltage i.e. the motor will continue to operate in a current overloaded condition sometimes.

Drop in system frequency reduces the motor inductive reactance and causes the motor to draw more current from the supply. This leads to decline in voltage & as a result further overloading of the motor takes place [2,3].

HT induction motors are designed for ±10% voltage fluctuations and ±3% frequency variations. It is observed that in the grid system prevalent in our country, the fluctuations may be higher. Thus this protection is necessary so that the motor may ride through when voltage drops beyond 15% of the normal voltage.

2.10 ABNORMALITIES IN SYNCHRONOUS MOTORS

In addition to the above mentioned abnormalities synchronous motors may be subjected to certain abnormalities typical to them [1]. They are described below.

2.10.1 Loss of Synchronism

This condition occurs in motors subjected to sudden instantaneous overloads. The value of overload could exceed the pull out torque of the motor, causing it to fall out of step. If the field excitation is kept on, the motor stalls drawing a heavy stator current, and is unable to resynchronize even if the overload disappears. Thus some preventive action has to be

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is proportional to the d.c. resistance value, while the heating effect on the rotor windings of the negative sequence component is proportional to the 100 Hz a.c. resistance.

Thus it is seen that the heating effect of one unit of negative sequence component is greater than the heating effect of one unit of positive sequence current. In general, the larger the motor, the more prone it is to damage under unbalance conditions, mainly because of the relatively high rotor resistance to the 100 Hz negative sequence current. Also at higher values of unbalances, the losses in the stator phase carrying the higher currents are not so evenly distributed, because of the greater distances between phases.

Any overload device used to protect the motor must take this into account while protecting the motor against unbalances. The criterion for the design of the protecting mechanism is that while it should prevent prolonged overloads on the motor from causing excessive heating in either the motor stator or rotor, it should not disconnect the motor unnecessarily and so cause loss of output [1,3,5].

2.6 WINDING FAULTS

Winding faults generally result from the breakdown of insulation and can be of three type :

Earth faults, Phase to phase fault, Interturn faults.

2.6.1 Earth Fault

These are the most frequent type of fault amongst the three and involve grounding of one phase of the stator.

taken to avoid this condition.

2.10.2 Overheating of Damper Winding

If prolonged operation out of synchronism takes place either after a pull out, prolonged start or a sucession of attempted starts, the damper winding may get overheated. Thus to ensure smooth operation of the motor, overheating of damper winding has to be avoided.

2.10.3 Thermal Overloading of Field Winding

In machines equipped with automatic field forcing, a failure in field excitation control circuit could lead to a continuous current in the field winding greater than the rated value. This will result in overheating of field winding and may lead to insulation failure.

2.10.4 Sudden Restoration of Supply

If the supply is either automatically restored or restored without the knowledge of the machine operator, after being interrupted, the supply may be restored out of phase with the motor generated voltage. This situation is to be avoided to prevent any damage to the machine.

CHAPTER - III

CONVENTIONAL METHODS OF MOTOR PROTECTION

In present days, considerable emphasis is being laid on protection of motors against most abnormal conditions that may appear during motor operation. The purpose of the protecting mechanism is to disconnect the motor from the supply in case of an abnormal condition. Since it is not possible to provide protection against each & every type of abnormal condition, because of higher costs & the complicacy of the protecting mechanism, an optimization is made between the requirements and constraints, and protection is provided for those conditions which have serious effect on the motor working and also have a relatively higher probability of appearance. The most vulnerable part in the motor being the insulation, considerable protection is employed to prevent its breakdown.

This chapter reviews the conventional method of motor protection. Typical settings and operating times are also mentioned.

3.1 OVERLOAD PROTECTION

The ordinary inverse definite minimum type current relay is not suitable for protection of motor against overloading. The motor heats according to an I^2t function & good protection is provided by thermal overcurrent relays using bimetallic spiral movements. The bimetal plate is heated by the current passed either directly through the plate or through a surrounding heating spiral. As it is heated, the plate is caused to bend in the direction of the metal having lower temperature coefficient of elongation untill it closes the relay contacts [2] . The time in which contact closing is accomplished depends upon the magnitude of the current. Such relays are set to operate on 15% overloads with continuously rated motors and upto 40% overload with motors having overload capacity, depending upon the service factor [2,4].

Temperature detectors embedded in the stator windings are also used to detect heating due to overloads in case of large motors.

3.2 STALLING PROTECTION

The best protection is provided by a thermal device which is operable only during a stalled condition. A typical relay provides this feature by means of an attracted armature unit which switches a thermal unit into the circuit if the current is more than three times the motor full load current. Tripping occurs if the motor current fails to fall to normal value within a time decided by time-current characteristic of the thermal unit [4].

This scheme, however, does not serve the purpose for motors with high overload capacity in which the starting time may be more than the stalling time. In such a case, it is difficult to differentiate between stalling & healthy starting. For this purpose, a speed sensor is mounted on the motor shaft for detecting stalling condition.

3.3 PROTECTION AGAINST REVERSAL OF ROTATION

Protection against reversal of rotation is provided by negative phase sequence voltage relays, operating on induction principle and consisting of three coils energized by the three phases. All the three coils produce torque on the disc in a direction to keep the contact open. If any of the coil is inversely energized, the torque is reversed closing the contacts of the relay and thus resulting in tripping of motor [3].

3.4 PROTECTION AGAINST SINGLE PHASING

This condition generally does not arise in large H.T. motors but may occur in low and medium voltage motors. A single phasing condition is usually detected by a relay energized by the negative sequence component of the motor current and provided with suitable setting.

3.5 PROTECTION AGAINST UNBALANCED SUPPLY VOLTAGES

For protection against unbalanced supply voltages, unbalance current relays are used. One of such relays uses three bimetallic spirals energized by currents from the three phases, whose contacts are arranged so that if either spiral moves differently from the others, due to more than 12% unbalances their contacts meet and trip the supply breaker. The same spiral also serves to provide overload protection [4].

3.6 PROTECTION AGAINST STATOR WINDING FAULT

3.6.1 Earth Fault Protection

For protection against earth faults, instantaneous overcurrent relay with a setting of 20% of motor full load current, connected in the residual circuit of three current transformers is used. To achieve stability, which may be affected by spill currents due to saturation of current transformer(s) during motor starting, it is usual to increase the minimum operating voltage of the relay by inserting a stabilizing resistance in series with it [1,2,3,4].

3.6.2 Phase Fault Protection

For smaller motors protection against phase to phase faults is generally not provided assuming that such a fault would very quickly involve earth and would then operate the instantaneous earth fault element.

However, for large and important motors, differential protection is used to protect them against phase to phase faults [1,3,4,5].

3.6.3 Inter-turn Fault Protection

Unless each phase winding of the stator is divided into two or more circuits the protection available to detect this condition is rather complex and for this reason not normally applied [1,3,4].

3.7 BEARING FAILURE PROTECTION

The scheme/device used for bearing protection depends upon the type of the bearing used.

For ball or roller bearing, a seismic (vibration) transducer is placed on to the bearing which can detect changes in the vibration of the bearing & hence the failure of the bearings [1,3,4].

For sleeve bearing, a temperature sensor is embedded in the bearing, since the failure of the sleeve bearing occurs generally due to loss of bearing oil because of which the temperature of the bearings increases leading to its seizure. The temperature detector senses the increase in bearing temperature and causes breaker tripping.

3.8 TERMINAL FAULT PROTECTION

Instantaneous over-current relays with high setting are often provided to protect against phase faults occuring at the motor terminals. Care must be taken when setting these units to ensure that they do not operate on the initial peak of the motor starting current. The assymetry in the starting current decreases rapidly and generally falls to its steady state value after one cycle [5]. A delay of 2 or 3 cycles is introduced in the relay operation to render it insensitive to this transient assymetry.

3.9 PROTECTION AGAINST UNDERVOLTAGE & UNDERFREQUENCY

Running on undervoltage will generally cause overcurrent which will cause overload or temperature relays to operate. However, an exception to this is the fan motor whose load drops sharply with speed preventing the current from increasing. It is usual to provide undervoltage protection having an inverse time characteristic which will override temporary voltage drops [2].

Normally no protection is provided against variations in frequency since the variations are generally limited to ±4% of the rated frequency (50 Hz).

3.10 ROTOR PROTECTION

On wound rotor machines some degree of protection against faults in the rotor winding can be given by an instantaneous overcurrent relay that measures the stator current. As the starting current is normally limited by resistance to a maximum of twice the full load, the instantaneous unit can safely be set to about three times the full load current with the incorporation of slight time delay of approx. 30 milliseconds [1].

3.11 PROTECTION OF LARGE MOTORS

As stated before, the actual protection scheme may vary as per the motor size and function [3]. However, the protection scheme has become fairly standardized in the recent times. In general all large motors are protected against the following :

(a) Thermal Overload

(b) Locked Rotor Condition

(c) Unbalances in Supply Voltages

(d) Reverse Phase Sequence

(e) Single Phasing

(f) Winding Faults

3.12 ADDITIONAL PROTECTION FOR SYNCHRONOUS MOTORS

3.12.1 Protection Against Loss of Synchronism

The relay recommended for the protection of synchronous motors against loss of synchronism is one which is sensitive to the power factor of the stator current. When the motor loses synchronism, a heavy current at a very low power factor is drawn from the supply. The relay will detect this condition and operate within the first half cycle of slip frequency.

3.12.2 Damper Winding Thermal Protection

For thermal protection of damper winding, a thermal relay in the field circuit of the machine connected in parallel with an inductance is used. The current through the relay is proportional to the slip frequency, being greater at high values of slip. By this means graded protection is obtained for the damper windings.

3.12.3 Protection Against Sudden Restoration of Supply

There are a number of forms of protection available which guard against this condition. They may be in the form of Underpower, Reverse power, Overvoltage or Underfrequency protection.

Underpower protection is used when there is a possibility of no other electrical load being connected to the busbars on the failure of the supply. If there is always another electrical load connected, a reverse power relay has advantages over the underpower relay. It is more stable in the presence of small power reversals caused by loading conditions. The overvoltage protection will operate when the supply fails if there is little other load connected to the busbars supplying the motor & there is no load on the motor itself. Under these conditions the voltage could rise instantaneously, because of the open circuit regulation of the machine. The underfrequency relay will operate in the case of the failure of supply when the motor is already loaded. This, failure of supply causes the motor to declerate fairly quickly, resulting in the operation of the relay.

CHAPTER - IV

COMPREHENSIVE MOTOR PROTECTION

To avoid complicacy of protecting mechanism, it is desirable that a single relay should provide comprehensive protection against all major abnormal conditions. Since the motor sizes & characteristics vary to a great extent, it is also desirable that a choice of characteristics be available in the relay. The design features and application considerations of one such relay are discussed in this chapter.

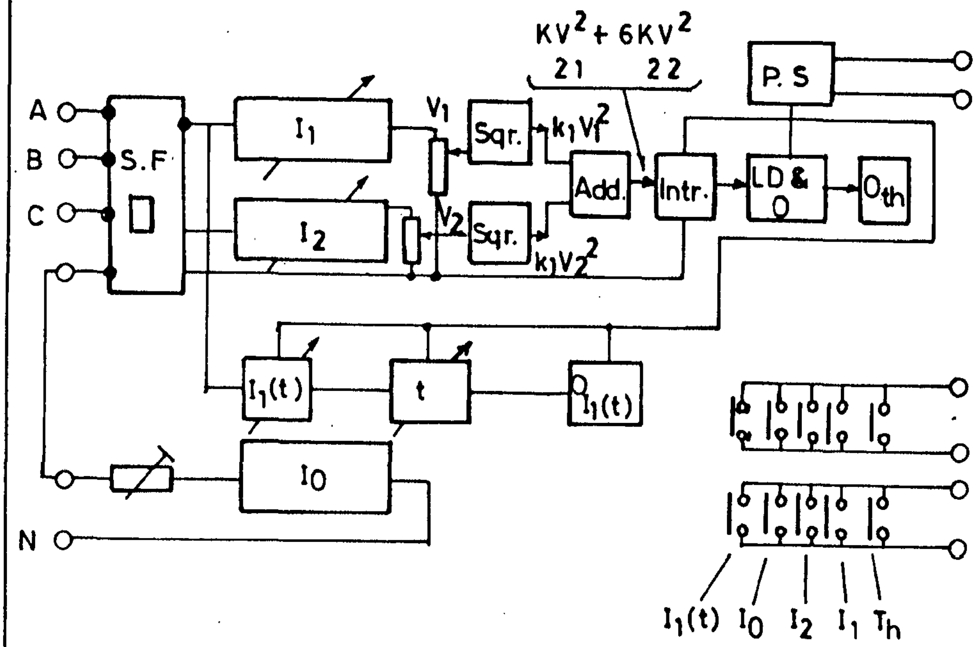
4.1 RELAY SCHEMATIC

Fig. 4.1 shows the block diagram of the relay [1,7,8]. The relay is fed with the motor line currents through a sequence filter and uses the positive and negative quantities in definite proportion to provide protection against thermal damage under all operating conditions.

The thermal characteristics of the relay are designed to follow closely the thermal withstand characteristics of typical motors and hence the motor breaker is tripped only when the insulation life is threatened. The relay is provided with three operating characteristics on the thermal unit from which a suitable characteristic can be selected by means of a selector switch. A definite time overcurrent element is provided for protection against stalling. The operation of instantaneous positive sequence, negative sequence & zero sequence units does not depend upon auxillary supply since they operate directly on the CT secondary current.

4.2 CIRCUIT DESCRIPTION

The output of the current transformers carrying the motor line currents, are fed to a sequence filter which separates the positive and negative seq-



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S.F	SEQUENCE FILTER
I_0	INSTANTANEOUS
I_1	TIME DELAY 60 ms
I_2	TIME DELAY 60 ms
Sqr.	SQUARRING CIRCUIT
Intr.	INTEGRATOR
P. S	POWER SUPPLY
LD&O	LEVEL DETECTOR AND OUTPUT

FIG. 4.1 COMPREHENSIVE MOTOR PROTECTION RELAY

uence components of the input current. These quantities are in turn fed into separate setting potentiometers via instantaneous operating elements I_1 & I_2. The potentiometer provide two output voltage V_1 & V_2 which are proportional to the positive & negative sequence components of the input currents. V_1 & V_2 are fed into squaring circuits to give $K_1V_1^2$ & $K_2V_2^2$. These values are added to give an output voltage equal to $K_2V_1^2 + 6K_2V_2^2$. A feedback circuit across the integrator causes the output voltage from the integrator circuits to raise exponentially from zero upto a voltage equivalent to 105% of the relay setting current. The output voltage from the integrator is fed to a level detector which, when the set voltage is reached, energizes an electromagnetic output unit. This operates two pairs of electrically separate contacts used to trip the circuit breaking controlling the supply to the motor & to initiate an alarm simultaneously.

Three instantaneous elements are provided for overcurrent protection (I_1), single phasing & unbalance protection (I_2) and earthfault protection (I_o).

The I_1 & I_2 element have about 3 cycles delay in operation to prevent flase tripping by starting current & their settings are continuously adjustable over their setting ranges. The I_o element has a fixed setting and is included in the neutral connection of the C.T. secondary circuits together with a continuously adjustable stabilizing resistor. This ensures stability under motor starting conditions, when unequal saturation of the C.T. might cause operation of the relay.

The input to the delayed overcurrent element $I_1(t)$ is derived from the positive sequence output of the sequence filter and is meant for protection against stalling.

4.3 RELAY OPERATION

The operation of various elements of the relay under abnormal conditions are discussed below [1,7,8].

4.3.1 Thermal Overload Unit (I_{TH})

Under normal conditions the motor draws a balanced load current from the supply. The sequence filter delivers only positive sequence current component & the magnitude of negative sequence component is negligible. If the motor current exceeds the relay setting, tripping will occur in accordance with time-current characteristic of the motor (Fig. 4.2).

Because of unbalanced supply voltage, the negative sequence stator currents induce a corresponding negative sequence rotor currents of approx. twice the normal frequency. The ratio of the rotor A.C. resistance at double the system frequency is of the order of 3 to 6 times the d.c. resistance. Thus one unit of negative sequence current will have a much greater heating effect than one unit of positive sequence current [1,3,5,8].

This unequal heating effect is taken into account in the expression of the equivalent current responsible for the relay operation.

$$I_{eq} = \sqrt{I_1^2 + 6\ I_2^2}$$

where

I_{eq} = equivalent relay operating current

I_1 = positive sequence current component

I_2 = negative sequence current component

The multiplying factor of 6 is choosen to provide adequate protection

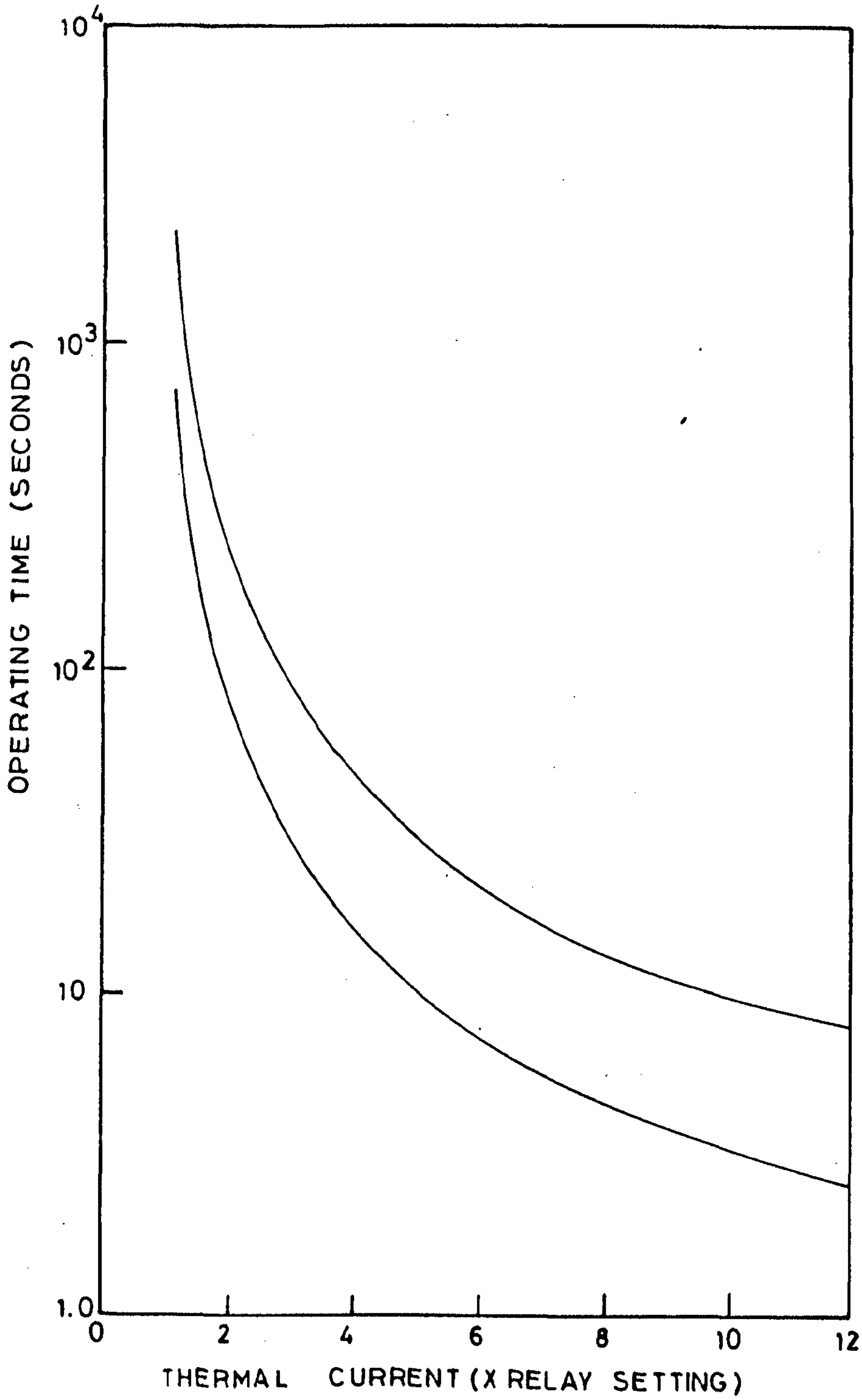


FIG. 4.2 TYPICAL THERMAL CHARACTERISTICS OF A MOTOR

to both the stator and rotor windings for all designs of motor without causing false tripping.

4.3.2 Time Delay I_1 Unit

The definite time overcurrent element operates from the positive sequence current and has a constant (but adjustable) time delay. It is used for protection against three phase stalling.

4.3.3 Instantaneous I_2 Unit

Instantaneous I_2 element is used for protection against single phase stalling. Because of the low setting it also provides instantaneous phase to phase fault protection to the stator circuit but will not operate under normal starting. This element is time delayed by about 3 cycles to render it insensitive to initial transient starting current assymetry. This element also serves to protect against reversed phase sequences and supply unbalances.

4.3.4 Instantaneous I_1 Unit

Instantaneous overcurrent unit (I_1) is used for protection against terminal faults. This element is set to operate just above the starting current of motors and is time delayed by about 3 cycles to render it immune to initial starting current transients.

4.3.5 Instantaneous I_o Unit

Instantaneous zero sequence current unit (I_o) connected in the residual circuit of the C.T. secondary is used for protection of motors against earth faults. The I_o element has a fixed setting and is connected in series with a stabilizing resistor. The stabilizing resistor, when properly set, avoids possible mal-operation of the relay during starting.

4.4 MERITS OF COMPREHENSIVE PROTECTION RELAY

Comprehensive protection relay has some advantages over individual relays. They are discussed below :

1. Comprehensive protection relay is a compact & less complicated unit than would result from using individual relays to protect against the various abnormalities.

2. Availability of a number of characteristics enable the comprehensive relay to be used for a wide range of motors.

3. A load indicator is also provided in the comprehensive protection relay to monitor load of the motor.

4. This relay offers a reliable & complete protection to the motor against all the faults in one unit only which individually would require a number of relays.

CHAPTER - V

MICROPROCESSOR BASED RELAYING SCHEME FOR THE PROTECTION OF LARGE INDUCTION MOTORS

In this chapter details of a digital (microprocessor based) relaying scheme developed for the protection of large induction motors are presented.

5.1 ADVANTAGES OF DIGITAL RELAYING

Digital relaying is perferred over static relaying because of the factors stated below :

(a) Ability to Implement Complex Relaying Functions

With the use of digital computers, complex relaying functions in which more than one parameter may be responsible for initiating any control or supervisory action can be easily implemented without any additional hardware which otherwise would require additional hardware to perform the same task.

(b) Greater Flexibility of Characteristics & Settings

With the use of digital computers for relaying one can change the threshold settings as per his requirement without having to make any change in the hardware, which would certainly require changes in the hardware in case of static relays.

(c) Ability to Store Data in Memory

In digital relaying, computers can store the pre-fault & post-fault data in the memory for analysis of the fault condition, which is not possible in static relaying.

(d) Ability to Perform Multiple Operation on Data

Complex mathematical & logical operations can be performed on input data with the use of digital computers which would require additional hardware in case of static relays.

(e) Higher Accuracy

With the use of digital computers, two values very close to each other can be easily differentiated. Thus the accuracy of digital relaying is higher than static relaying.

(f) Ability to Interface with Other Control System

The ability of computers to be interfaced with other units increases the utilization of digital relaying in areas other than protective relaying also. Data or signals can be transmitted to or from other units after or without some manipulations without the need of any additional hardware.

5.2 MOTOR PROTECTION RELAYING SCHEME

5.2.1 Principle

Most of the abnormalities against which protection has to be provided for large induction motors are reflected in the sequence components of the stator currents of the motor. Namely earth fault are reflected in zero sequence component, three phase stalling and terminal fault in positive sequence component & single phase stalling, phase to phase faults, single phasing and reverse phase sequence operation are reflected in the negative sequence component of motor currents. From the knowledge of motor line currents the various sequence components of motor current can be calculated from the equations given below [9].

Let I_a, I_b, I_c be the motor line currents, then

Zero sequence component $(I_o) = (I_a + I_b + I_c)/3$

Positive sequence component $(I_1) = (I_a + \alpha I_b + \alpha^2 I_c)/3$

& Negative sequence component $(I_2) = (I_a + \alpha^2 I_b + \alpha I_c)/3$

Where α is an operator equivalent to a phase shift of 120^o & α^2 equivalent to a phase shift of 240^o.

The proposed relaying scheme makes use of this feature & the relay measures, in addition to the three sequence current components, the motor winding and bearing temperatures to detect any abnormality that may arise during motor operation.

The entire scheme is divided into two parts :

(a) Fast Protection

For protection against abnormalities that can harm the motor in a relatively smaller period of time.

(b) Slow Protection

For protection against abnormalities that take a relatively longer time to be able to harm the motor.

Details of these schemes are discussed in the forthcoming chapters whilst general description follows here.

5.2.2 Circuit Description

The protection scheme has been implemented on a 8085 based modular microcomputer system manufactured by M/S Professional Electronic Products [10]. The various cards like I/O card, timer card, ADC/DAC card, EPROM card can be inserted into the slots provided in the card cage system for interfacing without requiring any hardware connection. (briefly discussed in Appendix).

A general schematic of the relay is given in Fig. 5.1. The line currents of the motor are reduced in magnitude by using CTs and converted into voltage signals by simply connecting shunts (resistances across the CT secondary terminals) (Fig. 5.2). The ratio of CT & the resistances should be selected in a way that the maximum possible motor current should not produce a voltage greater than the upper limit of the ADC input. The resultant voltage signals are fed to an ADC (AD 573) via the multiplexer (AD 7503) and a sample & hold circuit. These signals are sampled at a fixed interval (1.66 ms) generated by a hardware timer (Timer-A), whose OUT 1 terminal is connected to the interrupt terminal RST 6.5 of the CPU. The ADC used has a 10 bit resolution with total sampling & conversion time of less than 45 μs. The ADC can be programmed for either unipolar (0-10V) or bipolar (-5 to +5V or -10 to +10V) inputs [11]. The input signals being alternating in nature, ADC has been used in bipolar mode (+5 to -5V range).

Temperature of motor windings & bearings are obtained from the RTDs embedded in the motor windings and bearing. The output of the RTDs being very low in magnitude (≃ mV) are amplified by low noise, low drift instrumentation amplifiers [12] with a gain of 10[illegible] (Fig. 5.3). This amplified signal is fed to the ADC via the multiplexer and sample & hold circuit

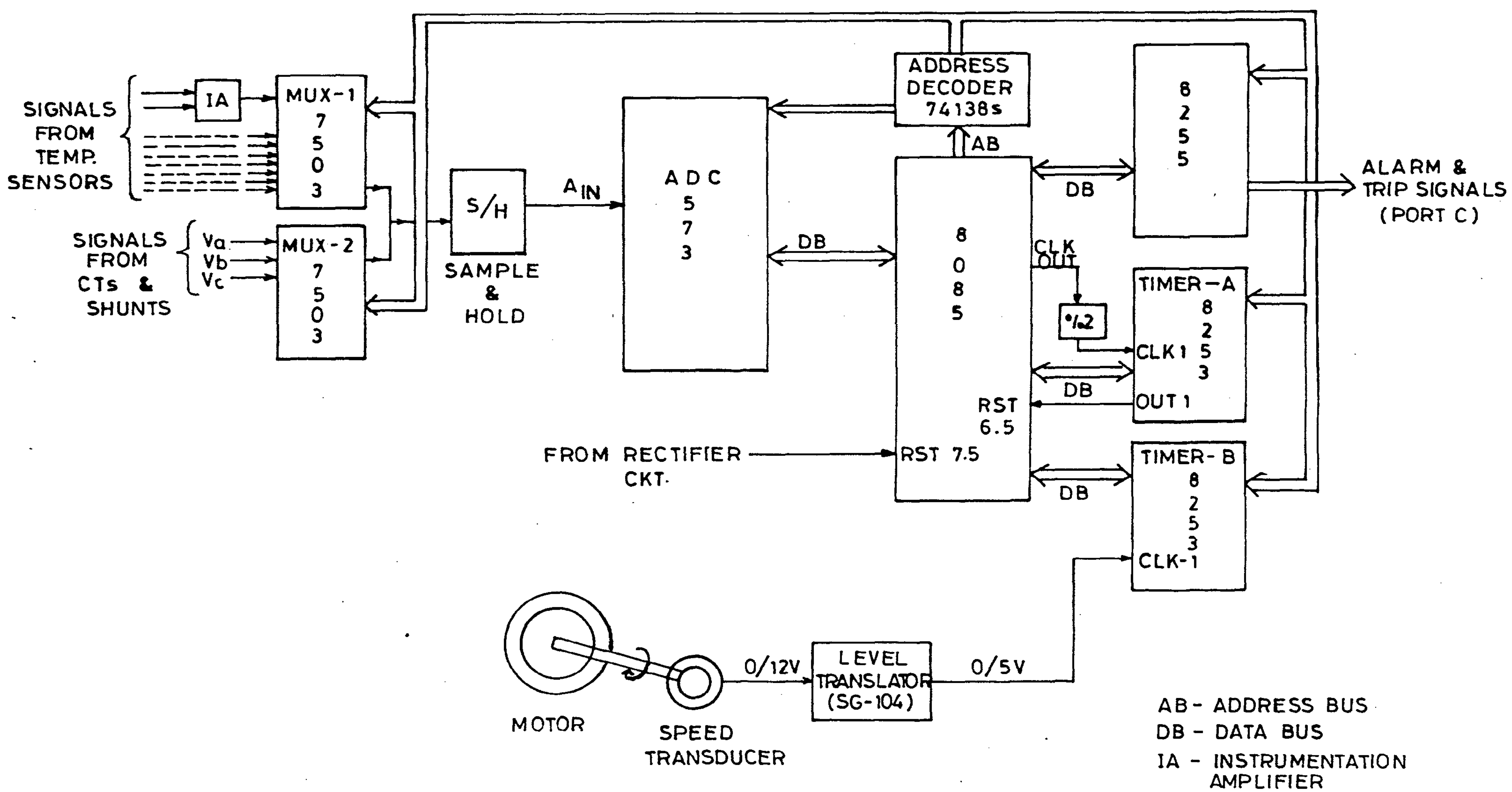


FIG. 5.1 CIRCUIT DIAGRAM OF THE DIGITAL RELAYING SCHEME

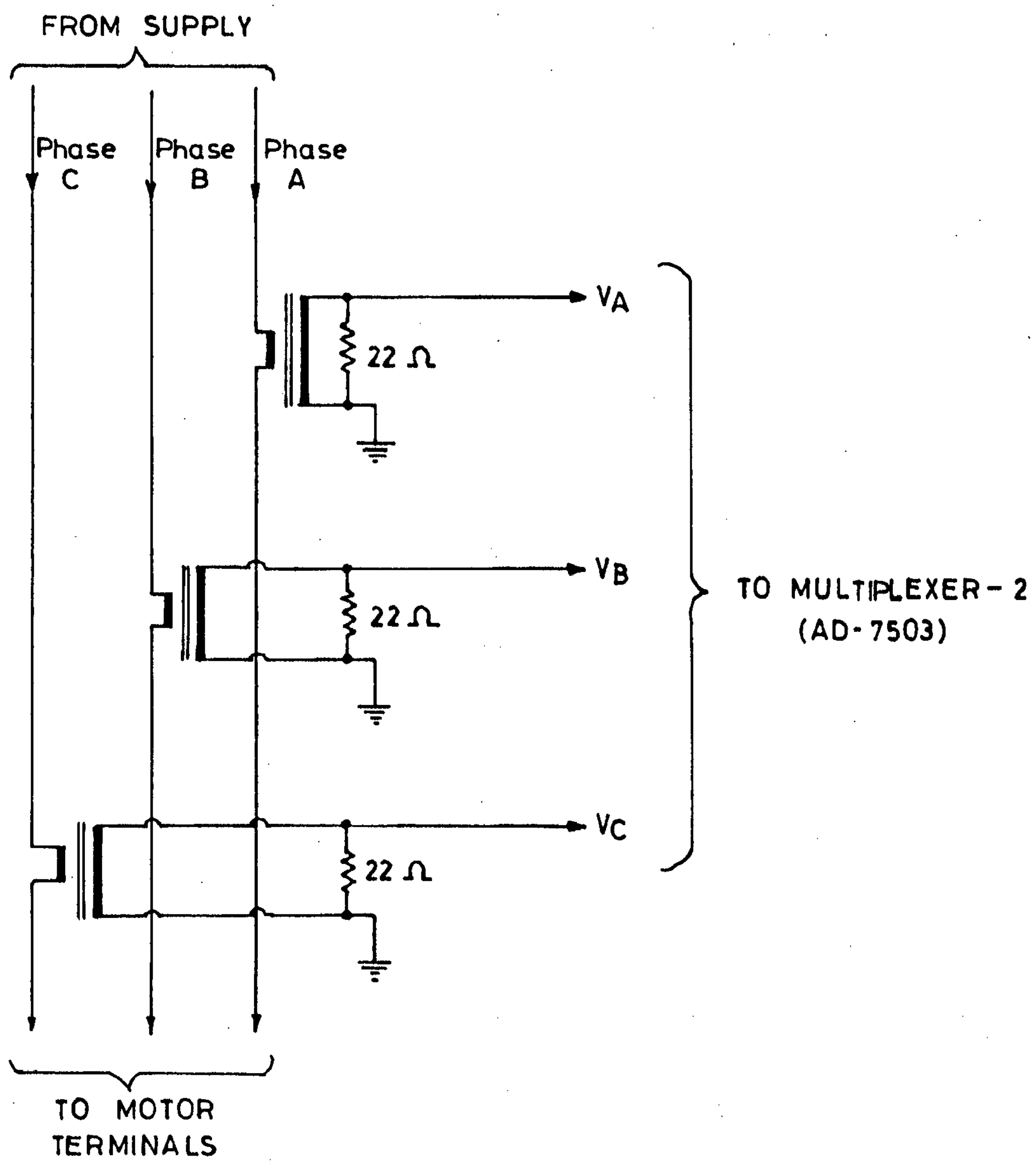


FIG. 5.2 CURRENT CIRCUIT DIAGRAM

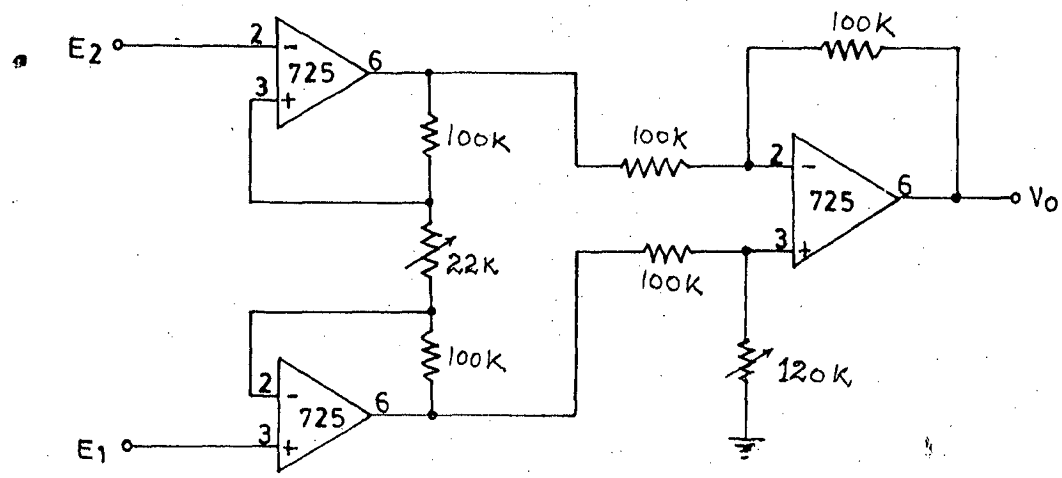


FIG. 5.3 INSTRUMENTATION AMPLIFIER CIRCUIT

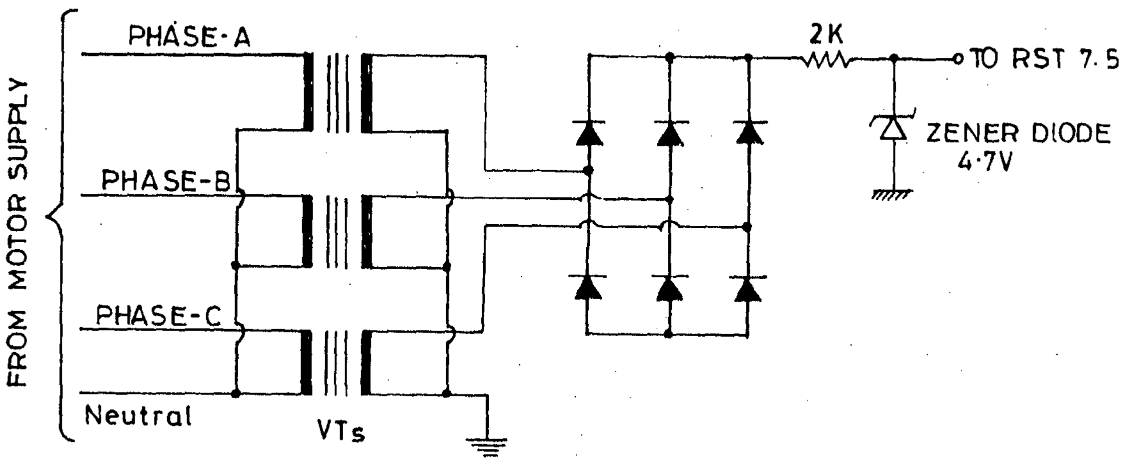


FIG. 5.4 RECTIFIER CIRCUIT DIAGRAM

to enable the microprocessor to check for overheating of motor windings and bearing.

For motor speed, a speed transducer is mounted on the motor shaft. The transducer used in this case is a digital transducer that outputs pulses (0/12V) at a rate proportional to the motor speed. These pulses are made TTL compatable (0/5V) by a level translator & fed as the clock to a counter (Timer-B) whose gate is permanently enabled. The contents of this counter after a fixed interval of time is proportional to motor speed.

The motor supply voltages after being reduced in magnitude by VTs and rectification (Fig. 5.4) is clamped at 4.7V by a zener diode and connected to interrupt pin RST 7.5 of the CPU. Thus until the microprocessor receives an interrupt request at RST 7.5, which shall appear only when the motor is energized from rest, it remains in a halt state.

Port C of PPI 8255 is used to issue alarm & trip signals in case of any abnormality in the motor.

CHAPTER - VI

SLOW PROTECTION SCHEME

Slow protection scheme is used to protect the motor against abnormalities whose rise time is of the order of a few seconds and covers protection against thermal heating (thermal overloads) and bearing protection. Thus this scheme requires constant monitoring of winding and bearing temperatures (in sleeve bearings) and equivalent thermal current.

6.1 GENERAL DETAILS

The hardware details of the scheme have been discussed in the preceeding chapter.

For sensing temperature of windings and bearings eight temperature sensors are provided - two in each phase winding & two in the bearings. The temperature sensors for sensing winding temperatures are embedded in the motor windings and may be either RTDs or Thermocompules. The signals obtained from these sensors being very small in magnitude, are amplified with a gain factor so as not to exceed the ADC range.

For computing equivalent thermal current, samples of the signal proportional to motor currents are obtained at fixed intervals. From these samples the sequence components of motor current can be computed, from which the equivalent thermal current can be calculated from the equation :

$$I_E = \sqrt{I_1^2 + 6I_2^2}$$

where

I_E = equivalent thermal current

I_1 = positive sequence component

& I_2 = negative sequence component

The multiplication factor of 6 has been choosen to take care of the greater heating effect of negative sequence current on the rotor of the motor.

For protection against thermal overloads, the thermal withstand curve of the motor must be known in advance of applying the relaying scheme. This curve can however, be derived from the knowledge of the thermal time constant of the machine [2].

6.2 INPUTS & OUTPUTS

Inputs in this protection scheme are the motor line currents and the temperature of the bearings & windings. Three voltage signals (proportional & motor currents) and signals from the eight temperature sensors after amplification are to be applied to the ADC. A hardware timer (8253) is used to generate inerrupts to RST 6.5 at intervals of 1.66 msec. resulting in 12 interrupt cycles per a.c. cycle of 50 Hz. Thus the voltage signals are sampled 12 times in one a.c. cycle.

Outputs are in the form of Alarm & Trip signals. Fault indicator bits are also set or reset as per the motor state i.e. set on occurrence of any fault & reset otherwise. Port C of PPI 8255 is programmed as output port for issuing these signals.

6.3 SOFTWARE

Figs. 6.1 to 6.4 give flowcharts of the programs for the slow protection scheme.

On receiving the first interrupt at RST 6.5 the microprocessor comes out of the Wait cycle and starts executing the monitoring program. It reads

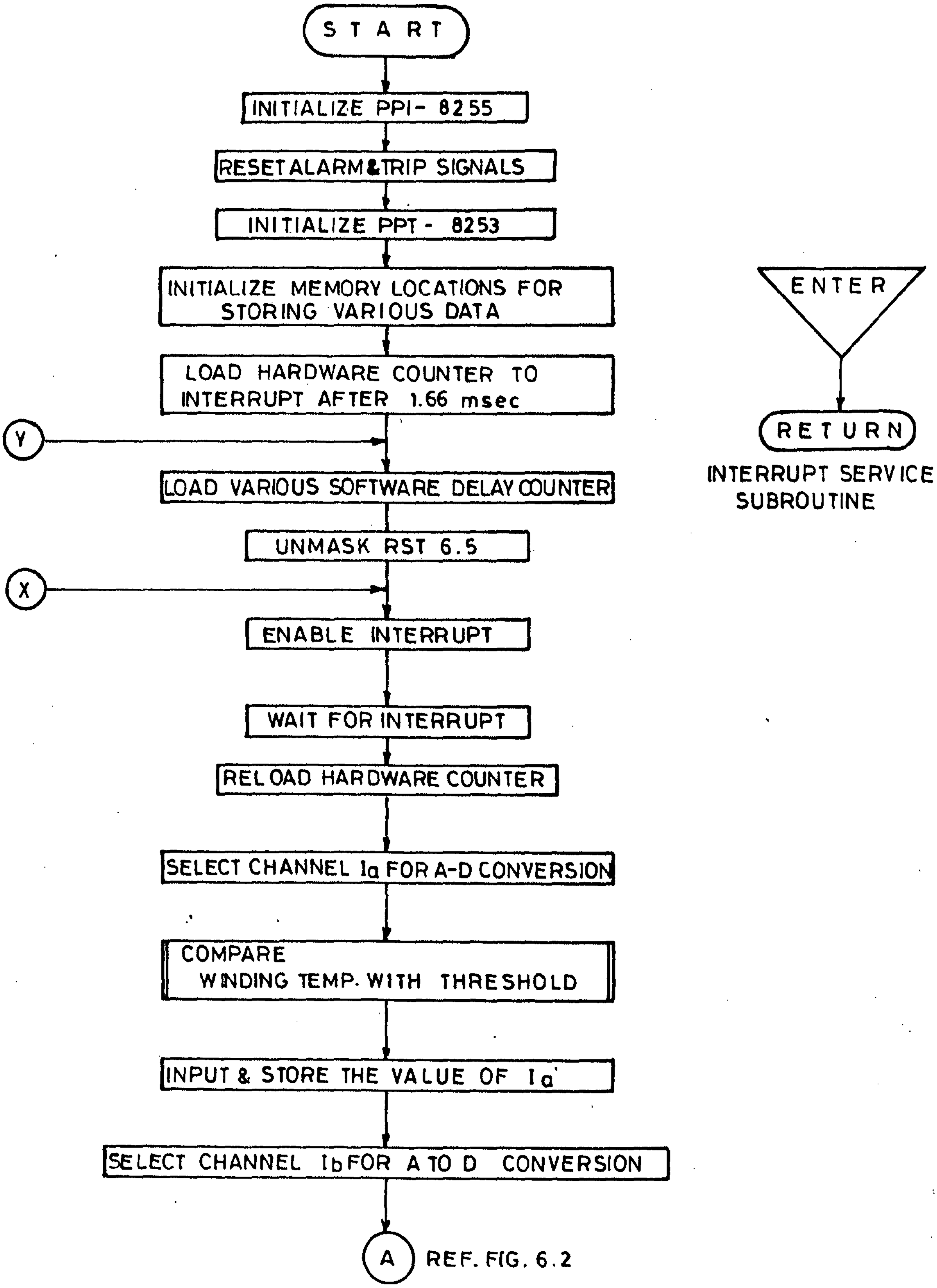


FIG. 6.1 FLOW CHART OF PROGRAM OF SLOW PROTECTION SCHEME

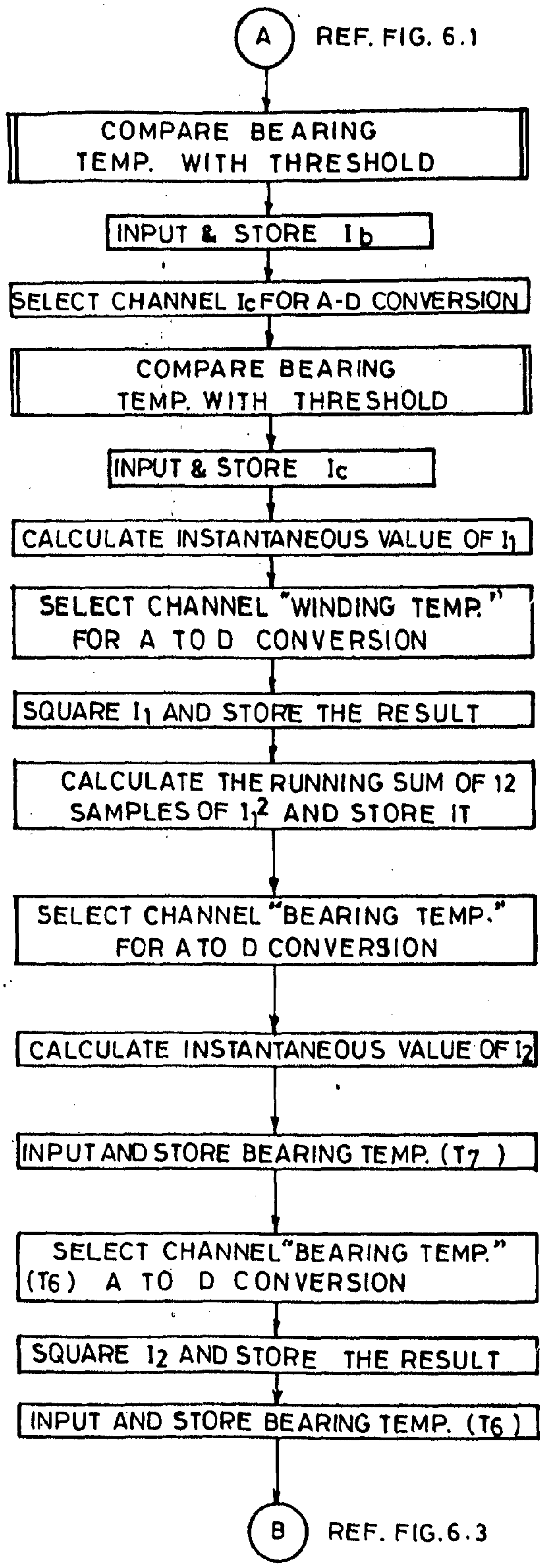


FIG. 6.2 FLOW CHART OF PROGRAM OF SLOW PROTECTION SCHEME (Contd.)

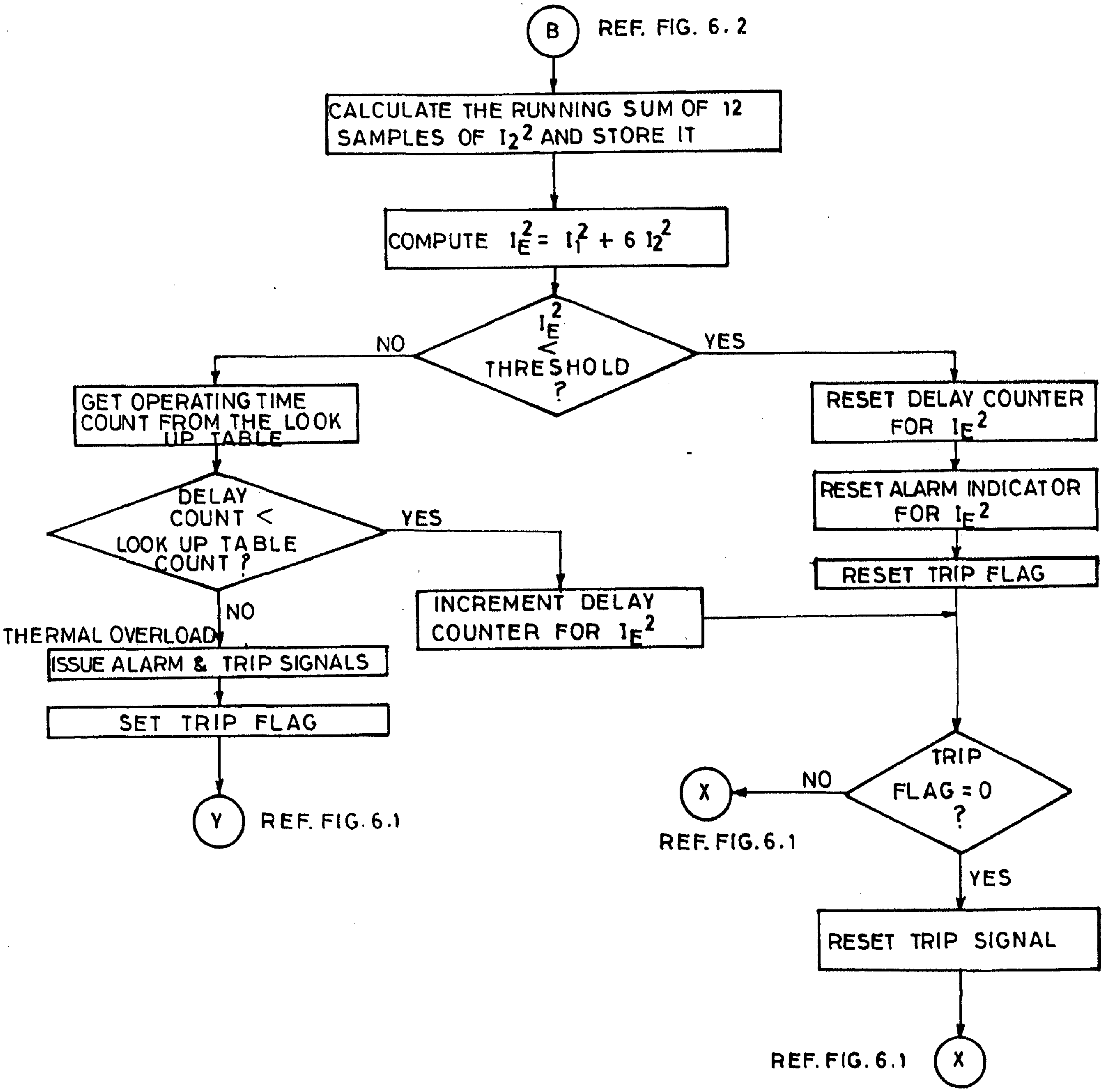


FIG. 6.3 FLOW CHART OF PROGRAM OF SLOW PROTECTION SCHEME (Contd.)

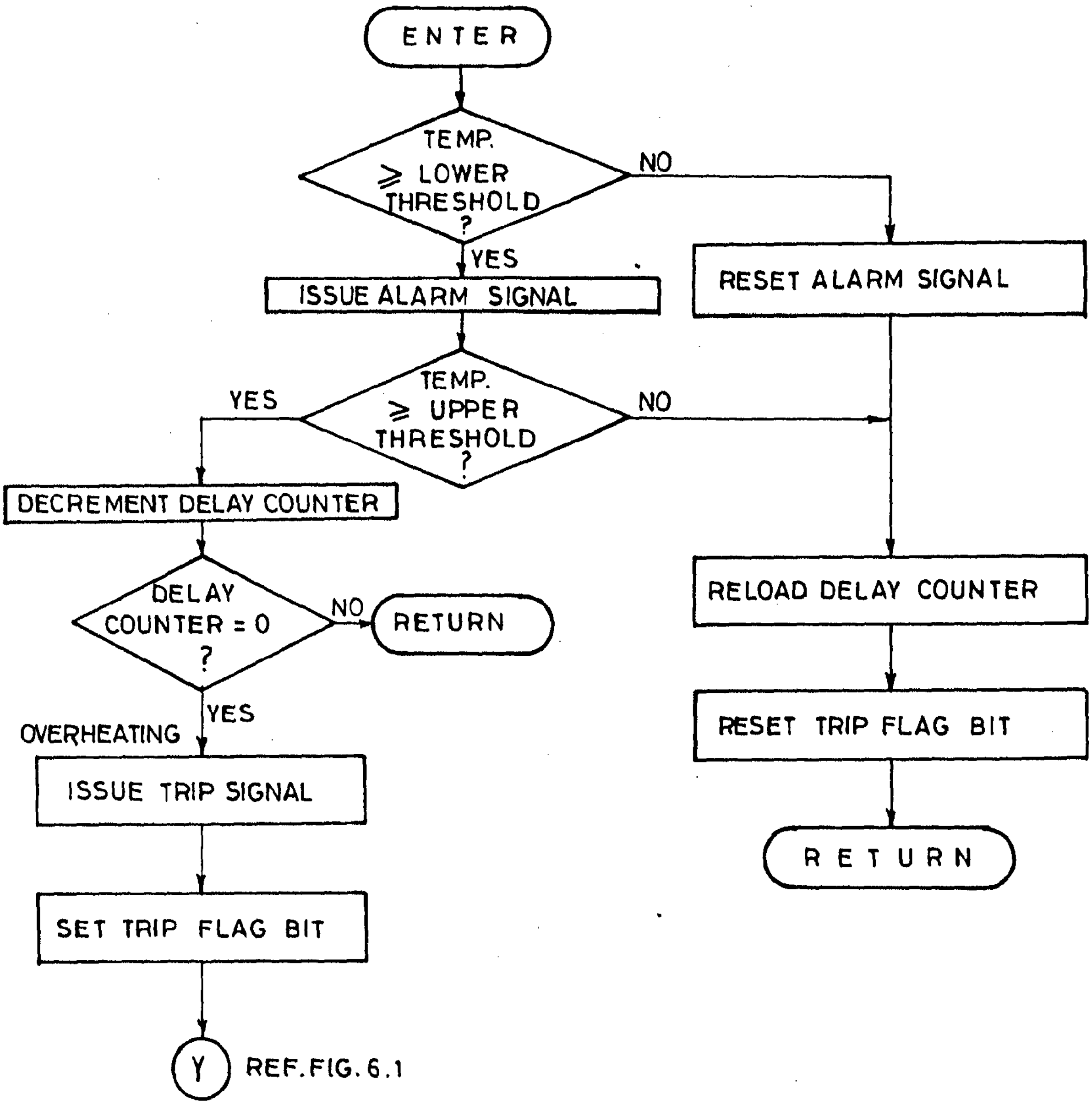


FIG. 6.4 FLOW CHART OF THE SUBROUTINE FOR COMPARING TEMPERATURES FROM THE MOTOR WITH THRESHOLD

samples, through ADC, of the three signals corresponding to the motor line currents. To utilize the sampling & conversion time of the ADC, the micro-processor compares the signals obtained from the temperature sensor (after amplification) with threshold value & generates appropriate (Alarm or Trip) signal if the value of the signal exceeds the threshold. Two thresholds-upper & lower are provided. An alarm signal is issued if the signal is equal to or greater than the lower threshold and a trip signal is issued if the signal is equal to or greater than the upper threshold. In every interrupt cycle both the bearing temp. signals are sampled whereas only one out of six temperature signals from the motor winding is sampled. These six signals are sampled successively in six interrupt cycles i.e. one signal per interrupt cycle. Also the signals sampled in one interrupt cycle are checked in the following interrupt cycle to save the microprocessor from running out of time in an interrupt cycle.

From the sampled values of signals proportional to the motor currents, the positive & negative sequence current components are calculated. The phase shift of 120^o introduced by the operator α in the calculation of sequence current components is taken into account by providing an equivalent time shift.

Since $120^o = T/3$

where

T = time period of the a.c. signal

A displacement of 4 samples (lagging) provides the value of the signal operated by operator α. Similarily it can be shown that a displacement of 8 samples (lagging) provides the value of the signal operated by operator α^2 [13].

From the positive and negative sequence current components the square of the equivalent thermal current is calculated

$$I_E^2 = I_1^2 + 6I_2^2 .$$

To save number of calculations performed during taking the square root, the value of I_E^2, instead of I_E is compared with threshold .

The thermal withstand curve of the motor (operating time v/s I_E) is fed in the form of a look up table containing operating time v/s I_E^2. The calculated value of I_E^2 is compared with a minimum threshold & if it is below that value, the delay counter is reset. However, if this value is greater than the threshold, the operating time of the relay corresponding to this value of I_E^2 is read from the look up table & if I_E^2 persists for more than the operating time read from the look up take, a trip signal is issued and an indicator is set indicating that the abnormality is a thermal overload. In the look up table, the operating time are stored as counts of 1.66 ms interval .

In case of comparison of signal from the temp. sensor with threshold an alarm signal is generated as soon as the signal crosses the lower threshold. A time delay of 10 ms has been provided to avoid false trip signal in the presence of noise or interference. If the signal continues to be equal to or greater than the upper threshold for this time, a trip signal is issued.

Thus the criteria for the alarm & trip signals are :

(a) Alarm

Signal from temp. sensor $\geqslant$ lower threshold

(b) Trip

Signal from temp. sensor $\geqslant$ upper threshold for more than 10 ms

OR

$I_E^2 \geqslant$ threshold for a time corresponding to the thermal withstand curve.

CHAPTER - VII

FAST PROTECTION SCHEME

Fast protection scheme takes care of the abnormalities that can harm the motor in a relatively shorter period of time and whose rise time is very short. This scheme provides protection of motors against earth faults, single & 3ϕ stalling, terminal faults, single phasing, reverse phase sequence, phase to phase faults & unbalanced supply voltages. It measures motor speed and sequence components of motor currents for the detection of these abnormalities. A digital filtering technique has been employed to derive the fundamental component from the signals obtained from the motor currents. The filter algorithm used here is discussed briefly below.

7.1 FOURIER ALGORITHM FOR DIGITAL FILTERING

Fourier algorithm is the simplest amongst the available digital filtering algorithms, for extracting the fundamental component of the input wave. The sine-cosine components of the fundamental frequency can be calculated from these equations :

$$V_s = \frac{2}{N} \left[\sum_{i=1}^{N-1} V_{K-N+i} \operatorname{Sin}(\beta i) \right]$$

$$V_c = \frac{1}{N} \left[V_{K-N} + V_K + 2 \sum_{i=1}^{N-1} V_{K-N+i} \operatorname{Cos}(\beta i) \right]$$

where

N	=	number of samples per fundamental cycle
β	=	$(2\pi/N)$ sampling interval in radians

K = sampling point

V_s, V_c = sine, cosine component of the fundamental frequency voltage

From these components, the magnitude of the fundamental frequency signal can be calculated as

$$V_m = \sqrt{V_s^2 + V_c^2}$$

It is seen that only the cosine component of the fourier algorithm can be used separately instead of using both the sine, cosine components without adversely affecting the filter response as can be seen from Figs. 7.1(a) and (b) respectively. [14].

The expression for the evaluation of fundamental frequency cosine component with twelve samples per cycle is given by

$$V_c = \frac{1}{12} [V_o+V_2+V_{12}+V_{10} - V_4-2V_6-V_8] + \frac{3}{12} [V_1+V_{11}-V_7-V_5]$$

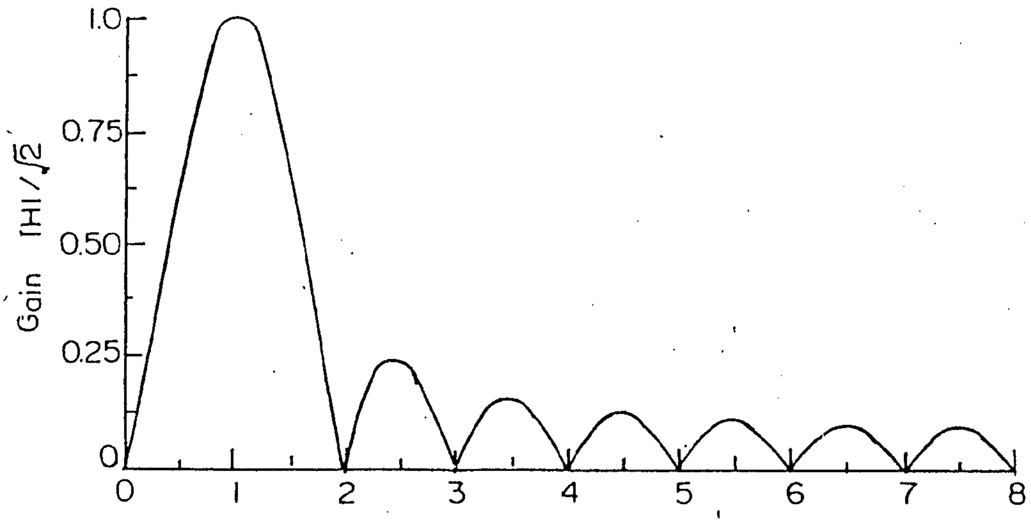
To simplify the computation of the filtered value on the microprocessor, the factor 3 has been replaced by 1.75. Thus the modified equation is given by

$$V_c = \frac{1}{12} [V_o+V_2-V_4-2V_6-V_8+V_{10}+V_{12}] + \frac{1.75}{12} [V_1+V_{11}-V_5-V_7]$$

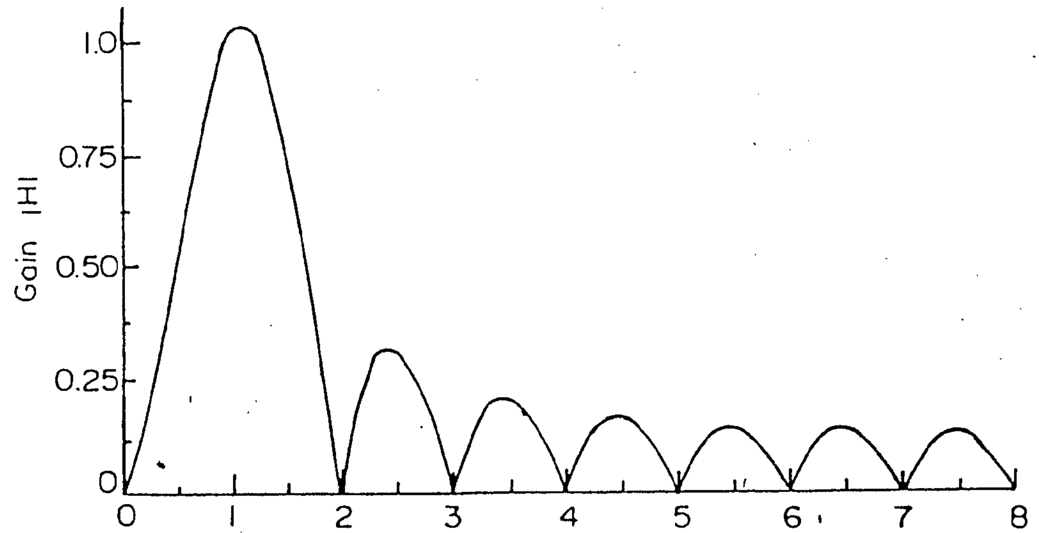
This equation has been used to extract the fundamental frequency cosine component in the fast protection scheme.

7.2 INPUTS & OUTPUTS

Fast protection scheme requires motor speed and the signals obtained from motor line currents for the protection of the motor.



(a) COMBINED FOURIER TRANSFORM - ALGORITHM.



(b) COSINE TRANSFORM - ALGORITHM

Fig. 7.1 - Frequency Response of the Filter

For speed, a speed sensor is mounted on the motor shaft and its output after being converted to electric pulses proportional to motor speed is fed as clock input to a hardware timer whose gate is permanently enabled. The contents of this counter after a fixed interval of time is proportional to motor speed. Contents of this counter (proportional to motor speed) are read at intervals of twenty milliseconds.

The motor supply voltages after being reduced in magnitude & rectification is clamped at 4.7 V. This is fed to the interrupt pin RST 7.5 of CPU. Port C programmed as output port (8255) serves to issue the Trip signal and to set fault indicators.

7.3 SOFTWARE

In this scheme, samples of voltages corresponding to motor stator currents are taken at intervals of 1.66 ms. Fig. 7.2 to 7.4 show the flow-chart of its software.

The microprocessor remains in the halt state until the motor is energized which then sends an interrupt signal at RST 7.5 through the rectifier ckt. (Fig. 5.4). Initially a delay (selectable by the user) is provided to enable the motor speed to rise to at least twenty percent of its rated speed. During this delay period, the motor is not checked for three phase stalling. However, this delay being less then the allowable stall time, any probability of damage to the motor is ruled out.

The sequence components are calculated from the derived fundamental components of the current signals. The filtering scheme has been discussed above and requires thirteen samples to obtain a fresh value. The value of sequence components of currents are averaged over half a cycle and

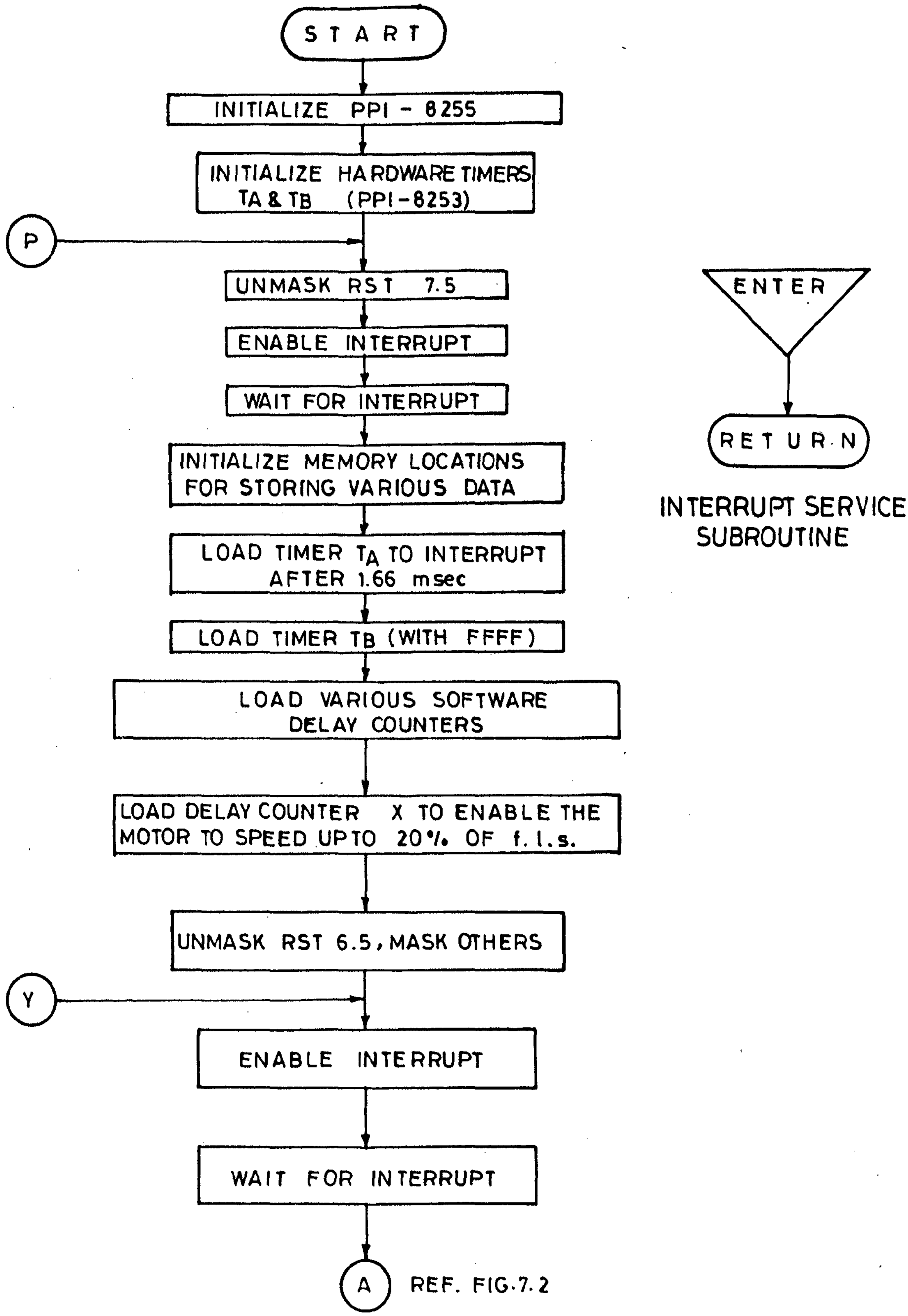


FIG. 7.2 FLOW CHART OF PROGRAM OF FAST PROTECTION SCHEME

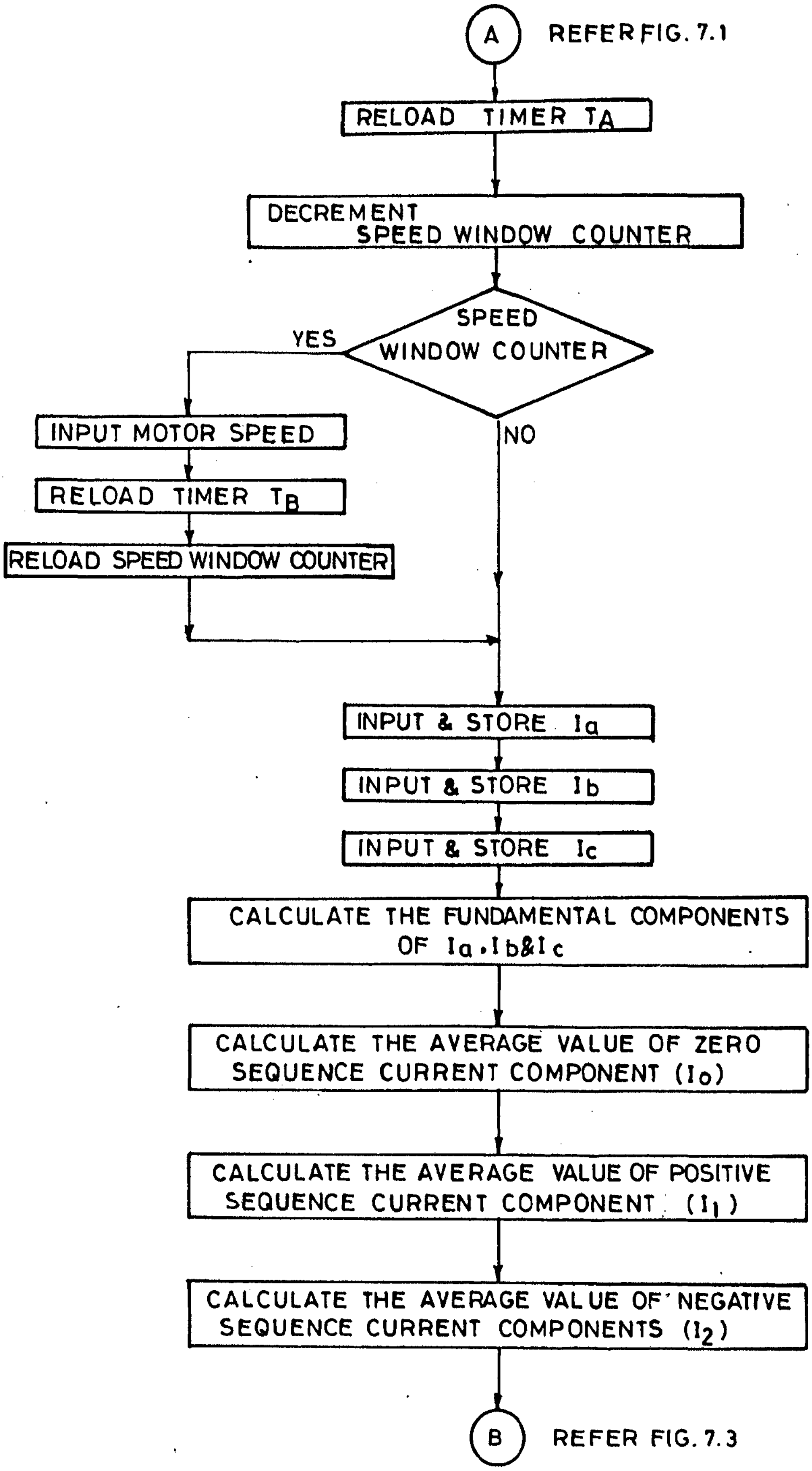


FIG. 7.3 FLOW CHART OF PROGRAM OF FAST PROTECTION SCHEME (Contd.)

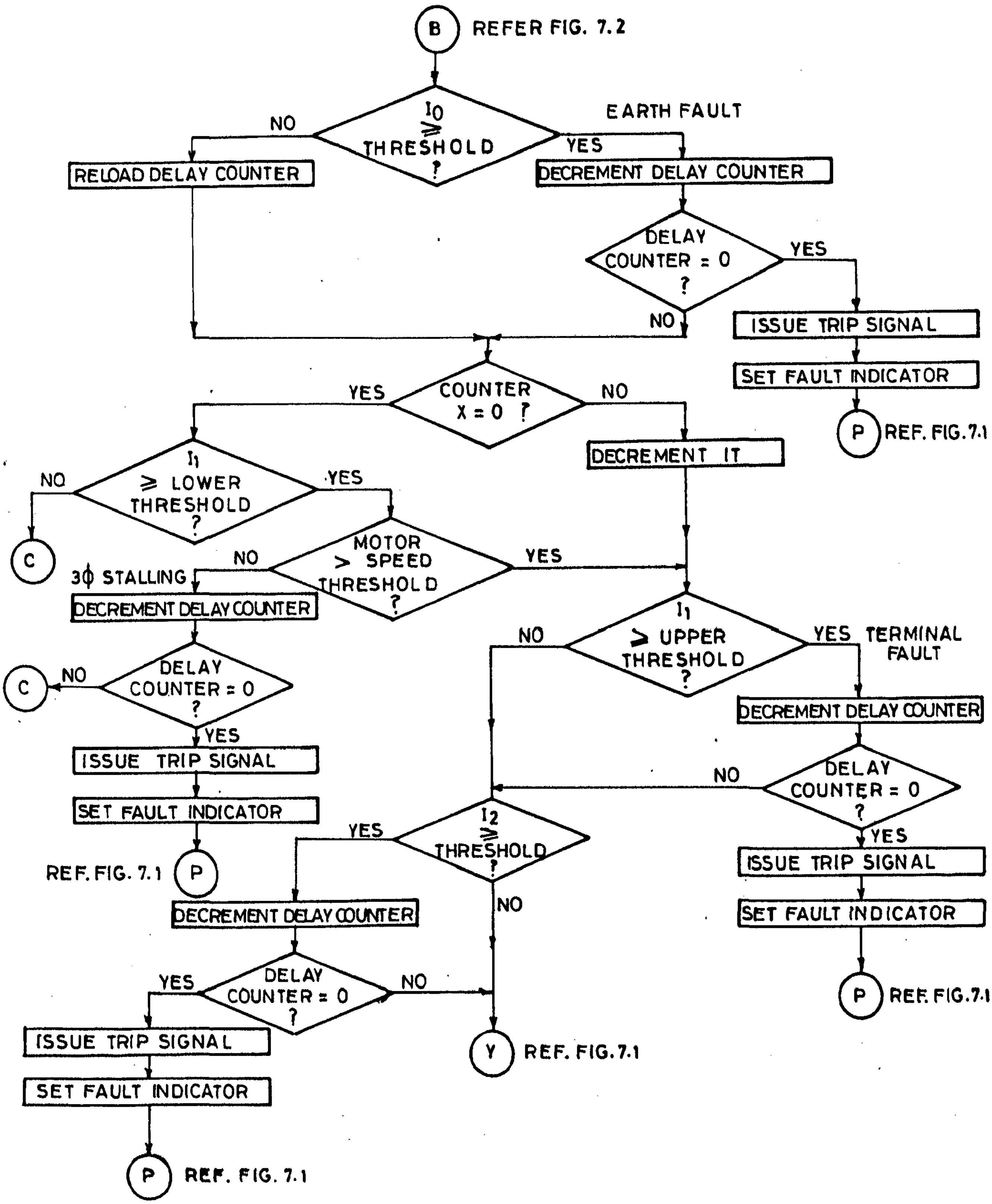


FIG. 7.4 FLOW CHART OF PROGRAM OF FAST PROTECTION SCHEME (Contd.)

the resultant values are compared with certain thresholds selectable by the user to detect any abnormality that may appear. The various sampled data, derived fundamental frequency components & sequence components are stored in circular arrays. If for example, the array can hold twelve values, then the thirteenth value will be written on first space in the array replacing the old value, the fourteenth value on second space and so on .

If the zero sequence current component is greater than the threshold (typically 20% of the rated line current) an earth fault is indicated & trip signal generated.

Similarly if the negative sequence current component is greater than the threshold value, a trip signal is generated. Monitoring of nagative sequence current component provides protection against reverse phase sequence, single phase stalling, single phasing, phase to phase fault and large unbalances in supply voltages.

The positive sequence current component in conjunction with motor speed is monitored to protect the induction motor on terminal faults and three phase stalling. If the positive sequence current component is above a certain threshold and motor speed is below the threshold value (20% f.l.s.), three phase stalling is indicated and if the positive sequence current component is above an upper threshold, a terminal fault must have occured. In either case a trip signal is issued.

A delay of sixty milliseconds between the detection of any abnormal condition & generation of trip signal has been provided in each of the above mentioned abnormal condition except in three phase stalling which is instantaneous in nature, to avoid any false trip signal being generated because of transients which last for one or two cycles. An indicator indicating the type of fault because of which tripping signal has been issued is also set. The criteria for generating trip signal are summarized below :

(a) Zero sequence current component $\geqslant$ threshold for $t \geqslant 60$ ms

OR

(b) Negative sequence current component $\geqslant$ threshold for $t \geqslant 60$ ms

OR

(c) Positive sequence current component $\geqslant$ upper threshold for $t \geqslant 60$ ms

OR

(d) Positive sequence current component $\geqslant$ lower threshold **AND** motor speed < 20% of the full load speed.

CHAPTER VIII

TEST RESULTS & CONCLUSIONS

The developed protection scheme has been tested on a motor of 1.5 h.p, 3.5A, 1430 rpm rating at, no load. The first step prior to the implementation of the protection scheme consists in determining the relevant motor characteristics, viz. starting current & starting time, for deciding the threshold limits of current for terminal fault and three phase stalling.

8.1 MOTOR CHARACTERISTICS

Fig. 8.1 shows the graph between motor speed & time. The curve has been obtained by using a digital speed transducer. The speed is measured by integerating the speed pulses over ten millisecond windows. Thus one may notice abrupt transitions in motor speed at these intervals. From the curve it is seen that the motor reaches its rated speed in about 100 ms and 30% of rated speed in about 25 ms. So the delay provided in the relay to enable the motor to speed upto atleast 20% of its rated speed was taken as 30 ms.

Fig. 8.2 shows the graph between motor current & time during motor starting. The first peak of the motor starting current is as high as 21.5 A (or 15A r.m.s.), whereas the normal current (no load) is 1.4A. From the graph, it can be seen that the starting current settles to a steady state value in about 140 ms. Thus the limit for current in case of terminal fault can be fixed at 17.5A, keeping a safety factor of around 15% over initial starting current value.

8.2 TESTS ON FAST RELAY ELEMENTS

Fig. 8.3 shows the operating time of the relay at various values of

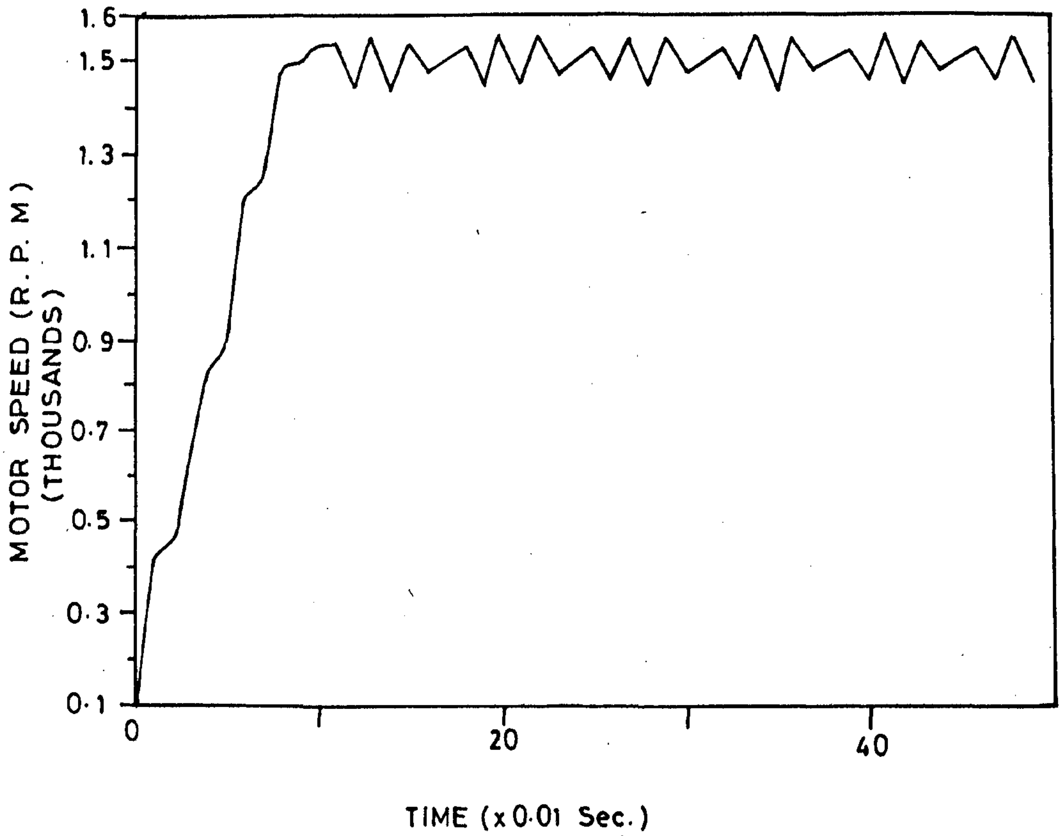


FIG. 8.1 MOTOR SPEED V/S TIME CHARACTERISTIC

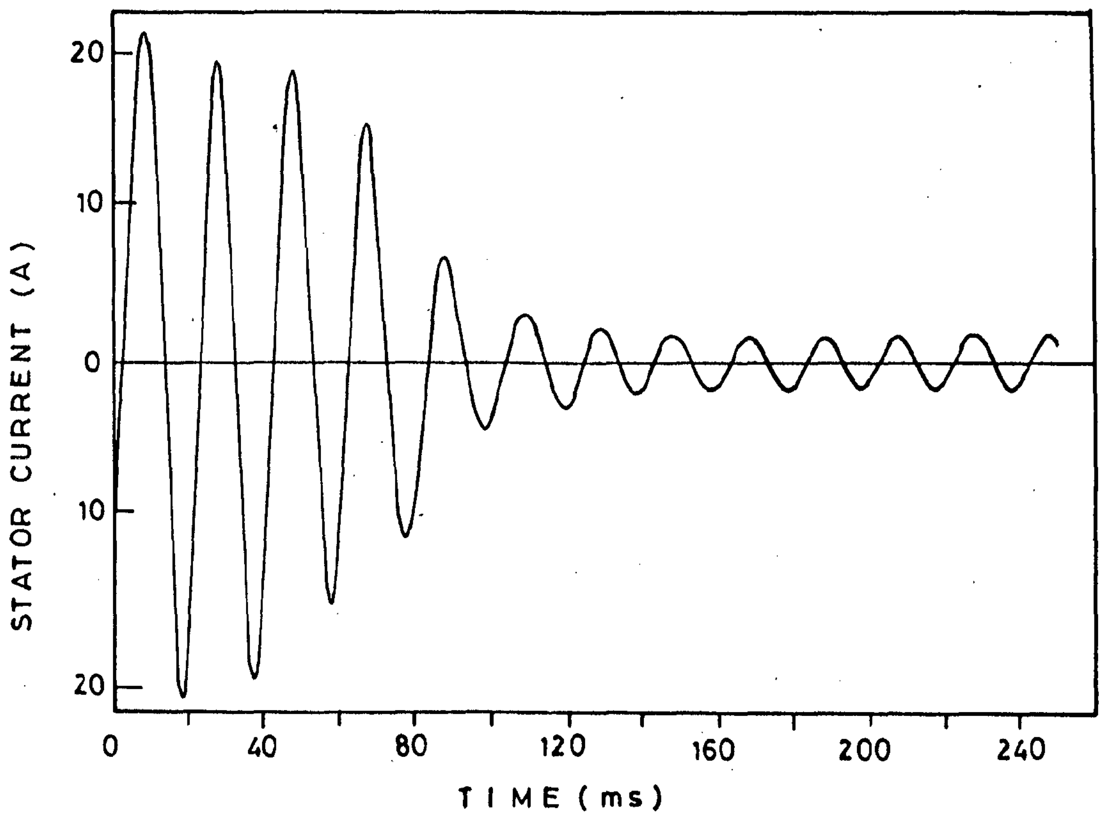


FIG. 8. 2 MOTOR CURRENT V/S TIME CHARACTERISTIC

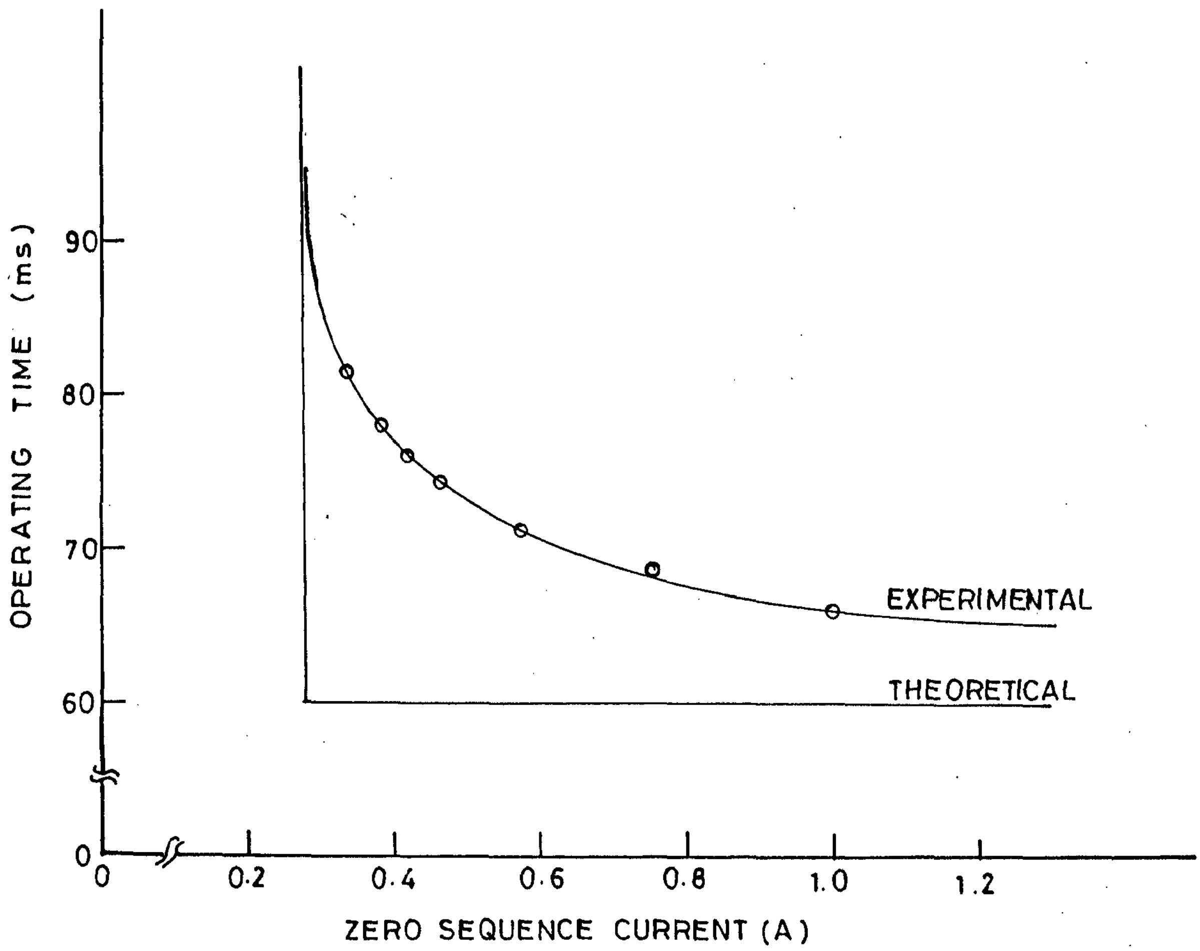


FIG. 8.3 OPERATING TIME CURVE FOR EARTH FAULT-ELEMENT

zero sequence component of motor current. The threshold was kept at 20% of the normal current. Theoretically the relay should operate as soon as the value of input current crosses the threshold value & the delay provided is over (60 ms). But because of the delay introduced by the process of extracting the fundamental frequency component by filtering over one cycle (20 ms) & of averaging the zero sequence current component over half a cycle (10 ms), the calculated zero sequence current component does not attain a steady state value instantaneously. This delay in arriving at the steady state value of zero sequence current component is responsible for the deviation of value of operating time from the theoretical value. As the value of the zero sequence current component increases, the relay operating time finally settles to a constant value. Thus one can see that the practical curve of Fig. 8.3 follows an IDMT pattern.

Curves of Fig. 8.4 (operating time v/s positive sequence current component for terminal fault element) & Fig. 8.5 (operating time v/s negative sequence current component for the negative sequence element) can also be explained in the similar manner. However, the definite minimum operating time is lesser in case of zero sequence element than the positive or negative sequence element. This is because of the fact that the zero sequence current component requires only six new samples of fault current to reach to a steady state average value whereas the positive or negative sequence current components may require upto 15 new samples (in the worst case) to reach to the steady state average value.

The curve of operating time v/s positive sequence current component for 3ϕ stalling (Fig. 8.6) however, does not follow the IDMT characteristic. This is because of the fact that within the time delay provided for enabling the motor speed to rise to at least 20% of the rated speed, the positive

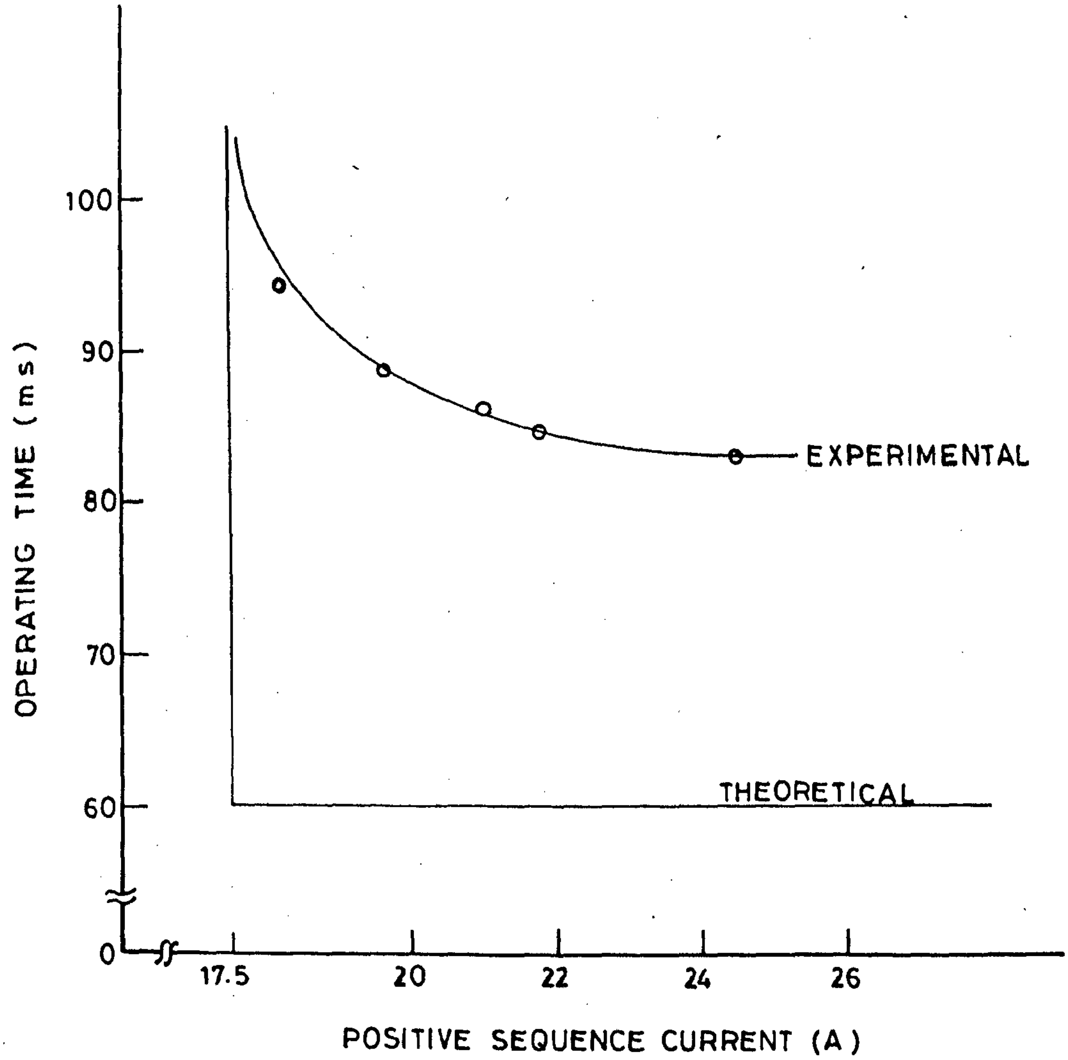


FIG. 8.4 OPERATING CHARACTERISTIC OF TERMINAL FAULT ELEMENT

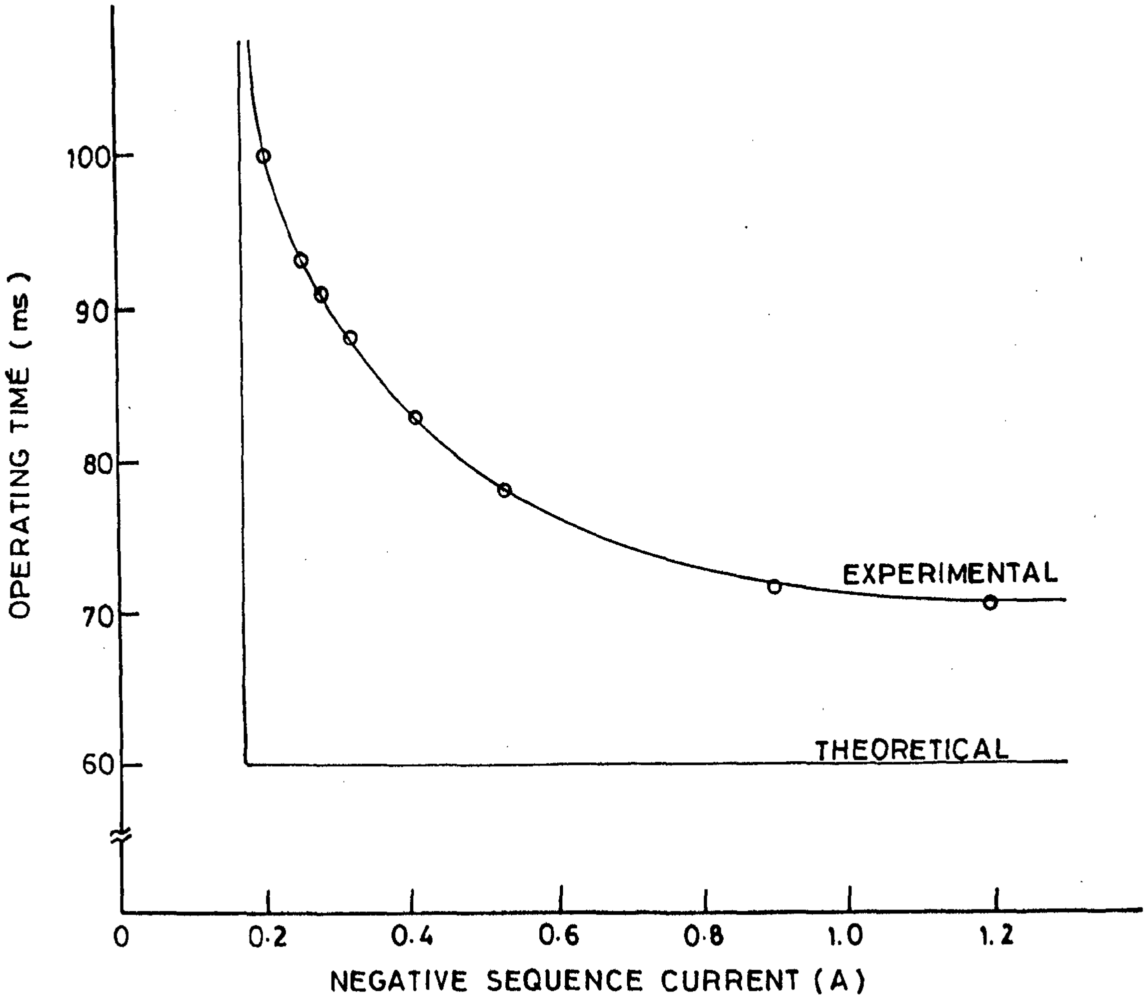


FIG. 8.5 OPERATING CHARACTERISTIC OF NEGATIVE SEQUENCE ELEMENT

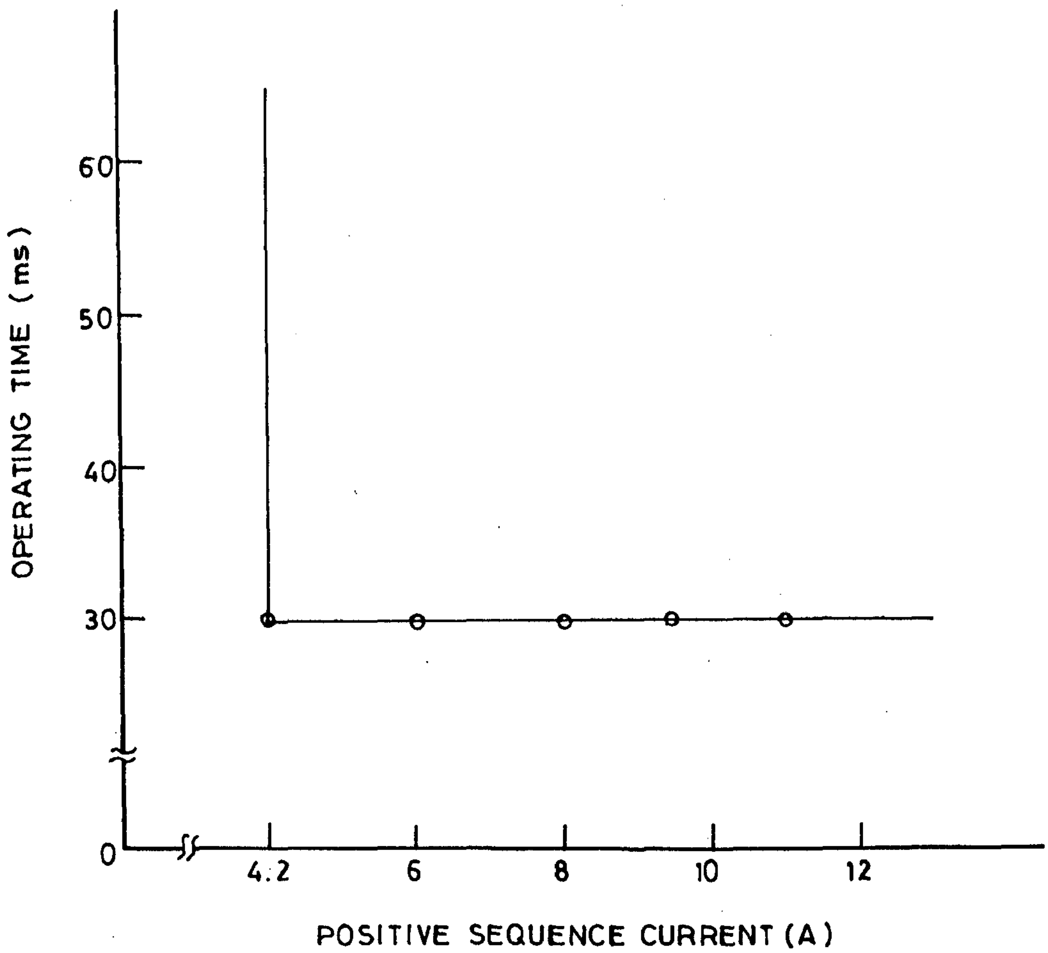


FIG. 8. 6 OPERATING CHARACTERISTIC OF 3ϕ STALLING PROTECTION ELEMENT

sequence current component reaches a steady state fault current value. And as the microprocessor checks the fault current at the end of this delay, it finds out that 3 ϕ stalling has already occured & so it generates a trip signal immediately. Thus the operating time of the relay equals the time for the motor to speed up to 20% of rated speed, which is also the theoretical time for relay operation. Hence the theoretical & experimental curve are identical.

8.3 TESTS ON SLOW RELAY ELEMENTS

8.3.1 Thermal Overload Element

Fig. 8.7 shows the graph between relay operating times and the thermal equivalent current I_E. From the figure it is seen that the practical & theoretical curve are almost similar in shape, though there are differences between the operating times indicated by the two curves. The difference is because of the presence of asymmetry in the supply or shifted neutral i.e. non-zero negative sequence current component even-though the three line currents are equal. The phase angles between phases are not 120^o as assumed for the calculation of I_E. This negative sequence current component is amplified by multiplication by a factor of 6 as per the equation of the thermal equivalent current & so the values of I_E^2 turn out to be higher than the theoretical values. The microprocessor reads the value of operating time from the look up table corresponding to this actual (higher) value of I_E^2 & not the theoretically calculated value I_E^2, which accounts for the difference in operating times indicated by the two curves.

8.3.2 Winding and Bearing Temperatures Element

The signals from the temperature sensors after amplification, were simulated by the signal obtained from a potentiometer. The relay was tested

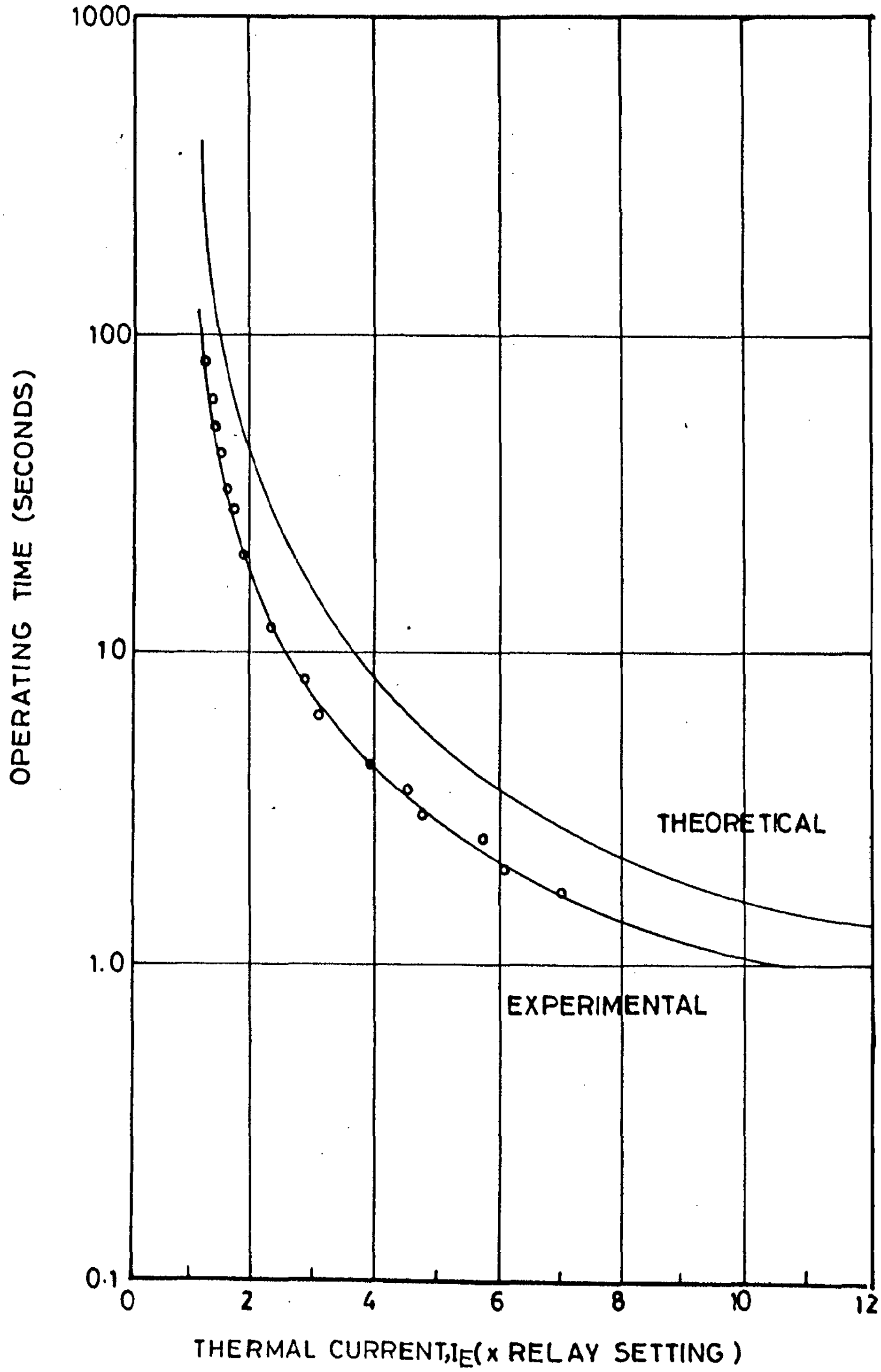


FIG. 8.7 OPERATING CHARACTERISTIC OF THERMAL PROTECTION ELEMENT

for this element in the simulated conditions & was found to be satisfactorily operating.

8.4 CONCLUSIONS

In this dissertation work the various abnormalities in induction & synchronous motors and the conventional methods of protection for both have been reviewed. A modern comprehensive protection scheme for induction motors, along with details of such a relay has also been reviewed. A digital relaying scheme for the protection of large induction motors has been developed and implemented on an 8085 microprocessor. The relaying scheme monitors the sequence current components along with bearing and winding temperatures for the detection of any fault and has been divided into two parts-slow protection and fast protection to ensure availability of slow backup in the event of a failure of fast primary protection. This scheme has been tested thoroughly on a small motor and found to be satisfactorily working.

In this scheme, digital filtering has been employed to extract the fundamental frequency component. This ensures that the relay will operate accurately & reliably on the basis of sequence current components even in the presence of strong harmonics and noise. In 3 ϕ stalling, the delay time allowed in between occurence of 3 ϕ stalling and generation of trip signal is equal to the time for the motor to rise to 20% of rated speed, and not the entire stalling time. The insulation is thus subjected to high stalling currents only for this period and not the entire stalling time which reduces the deterioration of insulation due to heating.

8.5 SCOPE FOR FURTHER WORK

This scheme can be modified to enhance the accuracy of the system by using 12-bit ADC instead of the present 10-bit ADC. Separate sample & hold circuits (with common logic pin) can be provided for the three channels carrying the signals proportional to the motor currents, instead of one sample & hold as provided in this scheme. This will increase the accuracy in calculation of the sequence current components, since all the three motor current signals will now be sampled at the same instant instead of being sampled with a time delay (45 μs) between two samples.

This scheme, though developed for induction motors, can be extended to synchronous motors by incorporating additional protection elements required. This may however, not be possible with 8085 and a 16-bit microprocessor (8086 or 68000 etc.) may have to be used.

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APPENDIX

Brief description of the cards of the modular micro computer system used in the implementation & testing of the relaying scheme, are given below.

1. PROCESSOR CARD

This card has on board an 8085A CPU, 16 K byte EPROM, 8K byte RAM, three programmable timers (8253), programmable interrupt controller, key board/display controller and a USART (8251A) with an RS 232C interface. Inputs of all the three timers are connected to 1.536 Mhz clock and the gates are permanently enabled. The input of timer 0 is connected to USART clock & the output of timer 1 is connected to interrupt pin RST 6.5 of CPU. The output of timer 2 can be connected (through jumper) by the user to either TRAP pin for single step execution or to interrupt pin RST 7.5.

2. EPROM CARD

This card has eight 28 pin IC sockets for the user EPROMs. The user may insert 2716, 2732 or 2764 EPROMs to made the total capacity of the card 16K bytes, 32K bytes or 64K bytes respectively for permanent storage of the user control program.

3. PARALLEL I/O CUM TIMER CARD

This card has 48 parallel I/O lines and three 16-bit timers. 8255 PPI chips have been used for the I/O lines and 8253 chips for timers. There is on board timing chain providing frequencies from 1 MHz to 1 Hz which can be used as clock input to the timers. External clock can also be connected to the counters, to use them as event counter. There is facility for driving bus interrupt lines from this card also (timer outputs). The output of the two 8255 ICs is available on two 26 line flat cable headers on the card.

(4) ANALOG INPUT/OUTPUT CARD

This card supports both analog input and output functions. It provides two independent analog voltage outputs & consists of two 8 bit D/A converters (DAC 0800).

This card also provides data acquisition of analog signals from 8 differential or 16 single ended channels. The resolution of the A/D conversion is 10 bits (using AD 573 IC) and the overall multiplexing, sampling and conversion time is about 40 μs. The card includes an 8/16 channel analog multiplexer, a differential amplifier and a sample & hold circuit. The input voltage range is jumper selectable and can be set to 0/10V, -5 V/5V, -10 V/+10V. The A/D converter gives straight binary output code for unipolar analog input and offset binary code for bipolar analog input.

In unipolar mode, the O/P code given by the ADC is :

Input voltage (volts)	Code outputted (binary)			
	MS byte		LS byte	
0.0	0000	0000	CXXX	XX00
5.0	1000	0000	CXXX	XX00
9.99	1111	1111	CXXX	XX11

In bipolar mode, the O/P code given by ADC is :

Input voltage		Code outputted			
Input range -10V to +10V	Input range -5 to +5 V	MS byte		LS byte	
-10	-5	0000	0000	CXXX	XX00
0	0	1000	0000	CXXX	XX00
+9.98	+4.99	1111	1111	CXXX	XX11

where C is the conversion complete bit. This bit is 0 if the conversion is complete & 1 if the conversion is in progress. X are irrelevent bits and must be filtered out by the user software.