DIGITAL PROTECTIVE RELAYING FOR OVERHEAD EQUIPMENT OF 25 KV, SINGLE-PHASE TRACTION SYSTEM

A DISSERTATION

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

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled, 'DIGITAL PROTECTIVE RELAYING FOR OVERHEAD EQUIPMENT OF 25 KV, SINGLE-PHASE TRACTION SYSTEM' in partial fulfilment of the requirement for the award of the degree of 'MASTER OF ENGINEERING' (ELECTRICAL) with the specialization in 'MEASUREMENT AND INSTRUMENTATION' submitted in the department of Electrical Engineering of the University is an authentic record of my own work carried out during the period from Nov. 1989 to April 1990 under the supervision of Dr. H.K.Verma, Professor, Electrical Engineering Department, University of Roorkee, Roorkee, India.

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

Dated: , April 1990 (SANJAY SRIVASTAVA)

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

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SANJAY SRIVASTAVA

ABSTRACT

The electromechanical relays, presently used for the protection of the overhead equipment of 25 KV single-phase 50 Hz traction system lack good selectivity and fast operation. Unnecessary interruptions and lack of definite indication of the type of fault result from the poor selectivity and unavoidable delays in clearing faults from slow relay operation. The author has made an attempt to improve the performance of protective relaying of OHE by modifying the relay characteristics suitably and has developed a microprocessor-based relaying system with the modified relay characteristics.

It is shown that a quadrilateral characteristic in place of the present admittance characteristic for earth fault distance relay can ensure the desire selectivity of the relay to various operating conditions. It is further observed that for the wrong phase coupling protection, non-offset admittance characteristic should be discarded because of its unwanted operation and the offset admittance characteristic, wherever in use, may be replaced by another quadrilateral characteristic in the second quadrant of the R-X plane. For a faster back-up protection, definite timelag overcurrent relay may be preferred to the existing inverse definite minimum time overcurrent relay.

All of [redacted] these relays, as also an instantaneous overcurrent relay for clearing closeup earth faults, have been implemented on a system based around the 8-bit, Intel 8085A microprocessor and tested for their steady state and dynamic erformances.

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CHAPTER - I

INTRODUCTION

INTRODUCTION

Traction systems can, broadly speaking, be classified as those which do not involve use electric energy at any stage, such as steam engine drive and internal combustion engine drive and those which involve electric energy at some stage or the other, such as diesel electric drive, battery electric drive and straight electric drive. Straight electric drive is gaining ground due to its various advantages over other drives. Advantages like cleanliness, high starting torque, greater traffic density, low maintenance, low starting time, absence of unbalanced forces and saving in high grade coal give ample reasons for electric traction to be the most preferred mode of operation.

Systems of railway electrification which are or had been in use[1], are: (i) direct current system, (ii) single phase alternating current system operating at (a) low frequency e.g. $16\frac{2}{3}$ c/s, (b) standard industrial frequency 50/60 c/s, (iii) three phase alternating current system.

The d.c. system is the oldest, the first installation being made in 1890 in Great Britain. Its greatest application has been to urban and suburban services at the voltages 500V and above. This can still be found in sections between Bombay V.T. to Virar and Bombay to Igatpuri.

The low frequency 1-Ø system has received its greatest development in Europe, U.S.A., Switzerland, Austria and Scandivania. All electrification schemes undertaken before 1931 in these countries employ this system.

The early applications of 3-ø system were to Swissmountain railways and first to mainline railways operating at 3 KV was in 1902. Presently it is nowhere in use.

Single phase industrial frequency system is widely accepted and has now being adopted for various new and existing railway electrification projects in countries like India. France, Republic of cango, Turkey, Portugal, Japan, U.S.S.R. and Pakistan. This report has been prepared with particular reference to the practices followed by Indian Railways and the problems encountered with the existing protection of overhead equipment, which is comprised of electromechanical relays.

1.1 25 KV, 1-ø TRACTION SYSTEM IN INDIAN RAILWAYS

Railways made their first appearance in India in April 1853, when a station from Bombay to Kalyan (32 miles) was openned to traffic. This was followed by Calcutta Raniganj (120 miles) and Madras-Akronam (39 miles). Electrification project in Railways was first undertaken in India during the period 1925 to 1932. This included 304 route km on Central Railway between Bombay V.T. to Igatpuri and Poona, 62 route km on Western Railways between Churchgate and Virar and 32 route km between Madras Beach and Tambram. This remained static for a period of two decades. This was all d.c. traction. The Indian Railways adopted 25 KV single phase 50 Hz traction system in 1957 as the standard for all trunk services.

Electricity to railways is supplied from transformer substations, receiving power from extra-high-voltage (usually 132 KV) 3-Ø lines of National Grid at 50 Hz.[2] Though traction load is relatively small in comparison to industrial load yet either of the two following steps is taken to minimize the voltage imbalances due to the traction load:

(i) Successive substations are connected to different phase pairs.

(ii) Scott or T-connected transformers are used at every substation.

Normally each substation has two stepdown transformers (one is kept standby) to step down the EHV (132 KV) to 25 KV. One terminal of the transformer secondary is connected to contact wire of overhead equipment (OHE) and other one is grounded through track. A typical supply and distribution system of Indian Railways is shown in Fig. 1.1.

The 25 KV bus of the substation is connected to the OHE at feeding post with a double circuit feeder. Each feeder circuit is controlled by 25 KV 'feeder circuit breaker' and feeds up and down tracks on one side of feeding post through isolators. A dead section (also called 'Neutral section') is provided midway between two substation to keep the out-of-phase

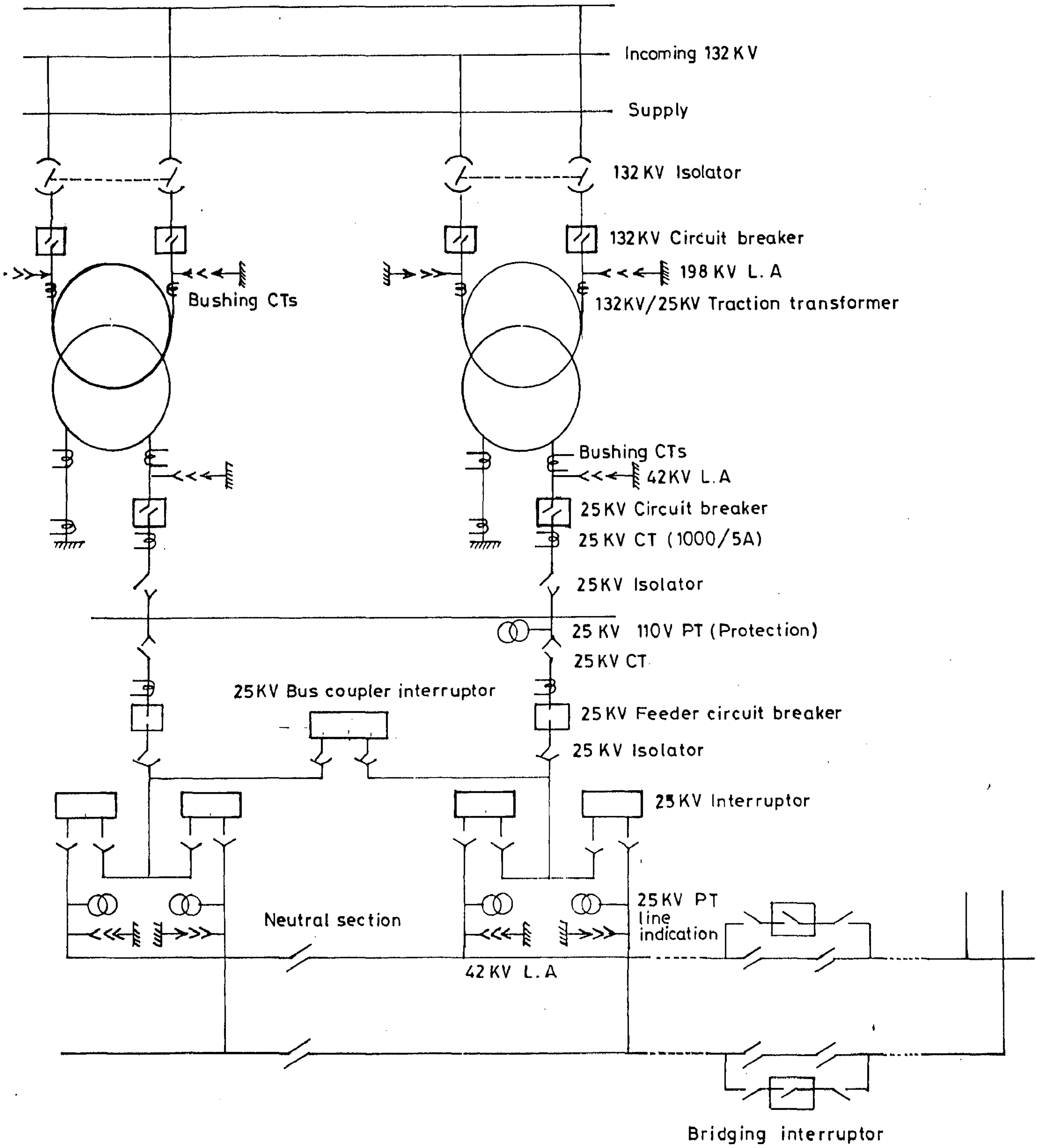

Fig. 1.1 The 25KV traction supply-and-distribution system of the INDIAN RAILWAYS

voltages of the two substations isolated. Neutral section is normally kept open keeping its 'Bridging Interruptor' open and locomotives pass it with power off. In an emergency condition caused by a failure of supply from one substation, the bridging interruptor is closed to extend the supply of the other (healthy) substation up to the next substation. Opposite the unhealthy substation supplies from two adjacent substations are kept isolated by insulated overlap.

1.2 CONVENTIONAL RELAYING FOR OHE

The two types of faults those may occur on traction overhead equipment are given below:

(1) Phase to Phase Fault:

It is commonly known as wrong phase coupling (WPC) and may result from unwanted closing of a neutral section bridging interruptor during normal feed conditions or due to failure in lowering down the pantograph when a locomotive passes an insulated overlap in front of an unhealthy substation during extended feed conditions. The WPC relay is required to operate on phase to phase faults with no intentional delay and should not operate on any other condition.

(2) Phase to Ground Fault:

This fault is the short circuit on the OHE to earth during normal or emergency feed conditions. The relay for this fault should also operate without any delay when a short circuit takes place in the protected zone (upto neutral section during normal feed and upto next substation during emergency feed). It should not operate on other conditions.

In an attempt to completely protect the OHE, four relays are used presently viz. earth fault distance relay, WPC relay, instantaneous overcurrent relay and inverse definite minimum time (IDMT) over current relay. Outof the four relays, the IDMT relay is set for back-up protection having different source of acquiring its relaying signal, while the other three relays are used for primary protection. The relay connections are shown in Fig.1.2[2] and the relay functions and characteristics are described below:

1.2.1 Earth Fault Distance Relay

In traction system the fault current on short circuits at farther end of the emergency feed section is several times less than the normal load current. So an over current relay can not provide the required protection. An impedance relay is, in same way, not suitable as the impedance at shortcircuit is normally greater than the normal working impednace. Impedance arguments on shortcircuits and in working condition are quite different, therefore, an admittance relay with a circular characteristic passing through origin and maximum torque angle approximately equal to the catenary impedance angle is employed for the protection.[3,4] Its reach is set upto the end of the emergency feed section and for single track

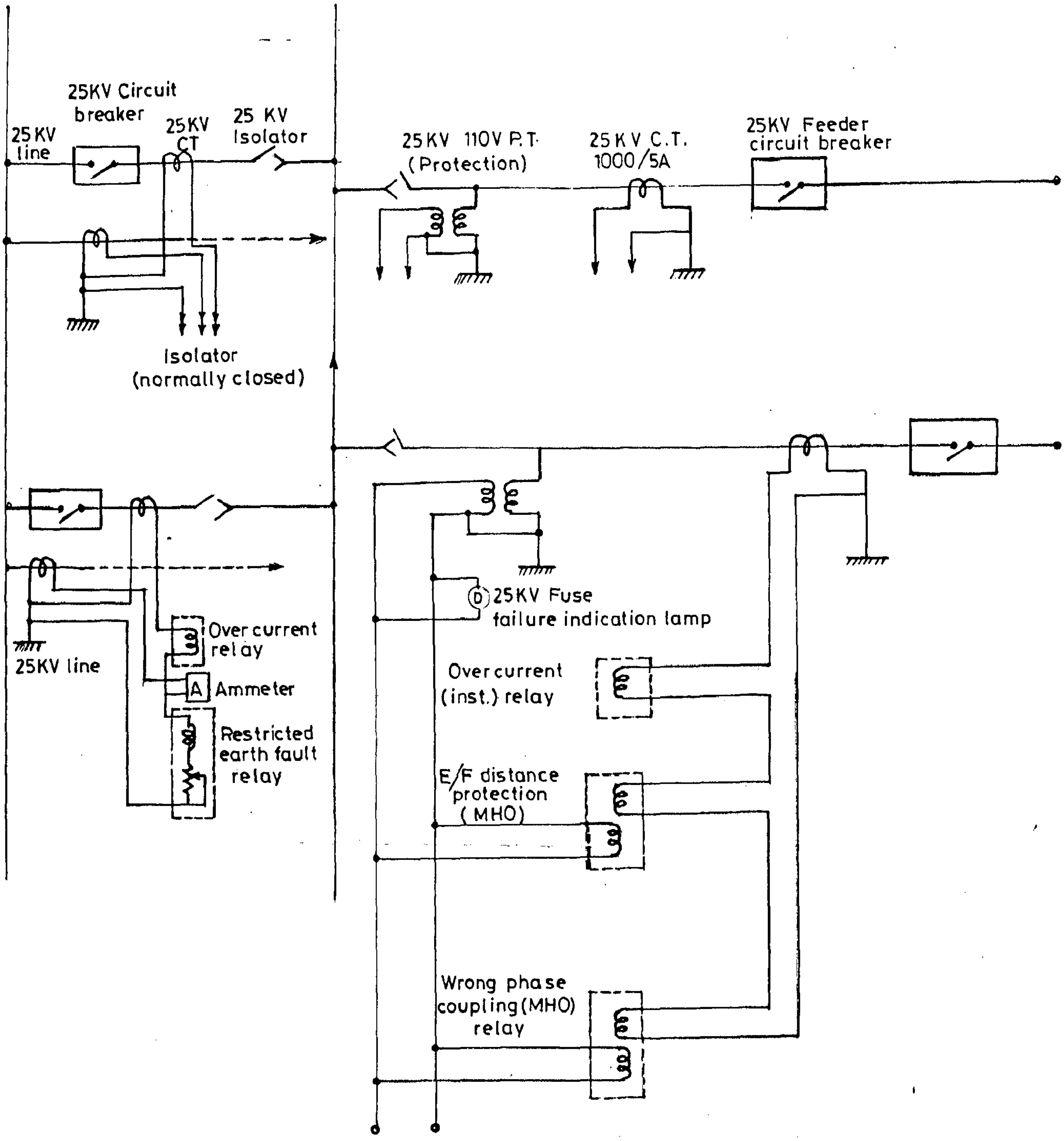

Fig.1.2 Various relay connections

operation. The characteristic of the relay is shown in Fig.1.3.

1.2.2 Wrong Phase Coupling Relay

Similar to earth fault protection, the relay for WPC protection should also discriminate on the basis of argument of impedance. Another admittance relay with an offset in forward direction equal to one tenth of the emergency reach, or without any offset is used for this purpose. Its maximum torque angle lies between 125° to 145°. Thus the characteristic lies mostly in the second quadrant of R-X plane. The relay setting is adjusted for single track operation. In case of a fault, the relay at the lagging phase substation only operates.[4,5] At the other substation the impedance seen by the relay falls in first quadrant, so it does not operate. The characteristic of the relay with WPC points is shown in Fig.1.3.

1.2.3 Overcurrent Relays

A high set overcurrent relay is used for clearing heavy line to earth short circuits near the substation. Such faults may not be cleared by the earth fault distance relay because the collapse of the voltage signal. Another overcurrent relay with inverse definite minimum time characteristic provides back-up protection.[2]

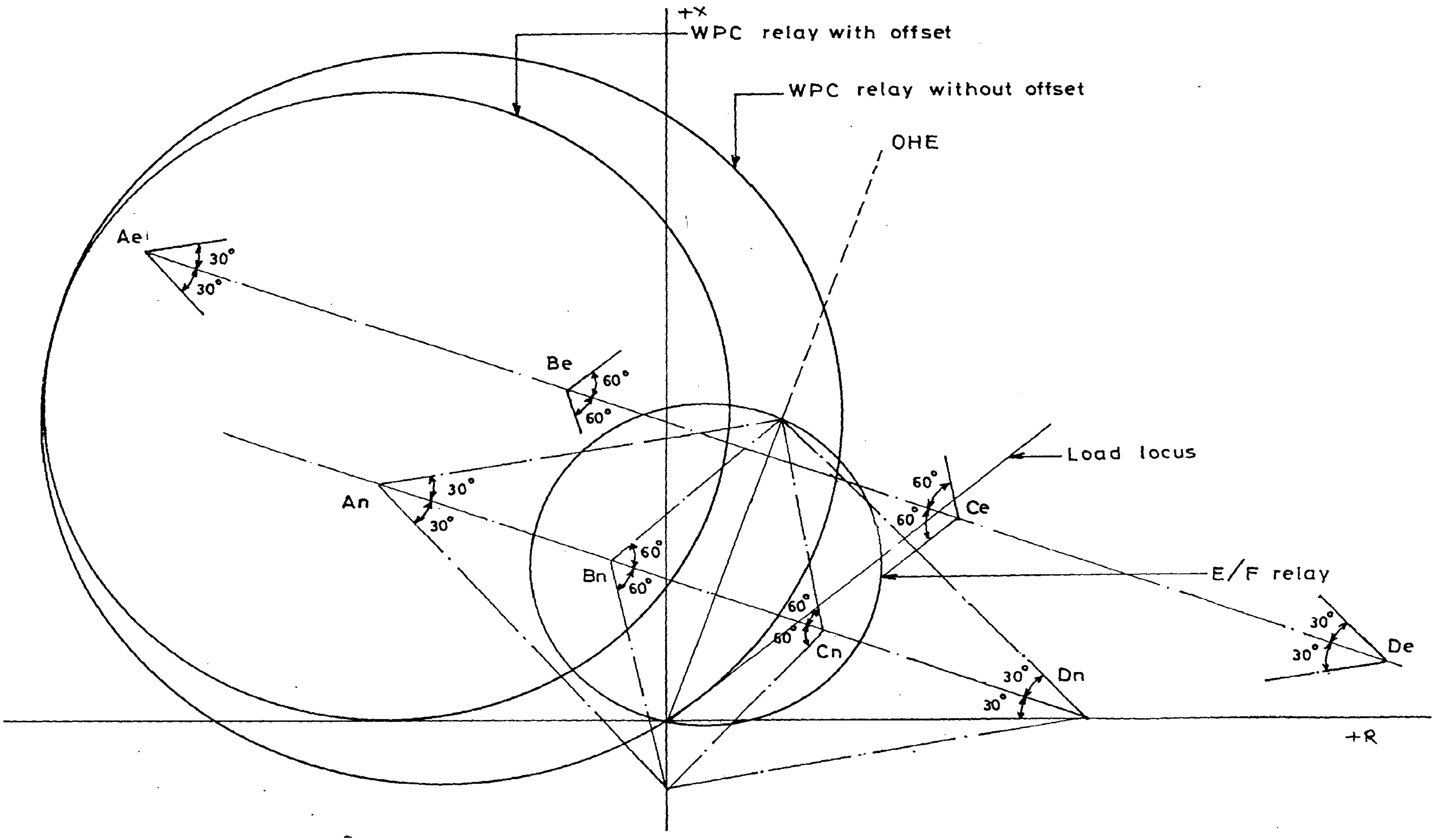

Fig.1.3 Existing characteristics of distance relay

1.3 SCOPE OF IMPROVEMENT

The present OHE experiences large percentage of spurious trippings and often more than one relay operates so that faults are not correctly indicated. These can be assigned to: (i) complicated nature of catenary construction, power feeding arrangement and current collection system, (ii) Poor selectivity of the protection system. The complicated nature of overhead system in traction can not be simplified and as railways expand, this complicacy is likely to increase further. Therefore, the elimination of second drawback, mentioned above, may be chosen as the solution to the said problems. To that end the following two methods are available and should be inducted simultaneously in protective relaying:

(i) Characteristic Modification

It can be illustrated that proper alternations in existing operating characteristics of the relays used in traction system can marshall to complete selectivity in the system.[2] This aspect has been explained at significant length in next chapter and some modifications are suggested.

(ii) New Technology

Solidstate electronic circuits had been proposed to be introduced in 1970s in OHE protective relaying which was shown, to lead to complete selectivity in the system. But unfortunately this area has been little researched after the advent of microprocessor. The microprocessor alongwith other large scale ICs has made considerable impact on power system relaying, instrumentation and control techniques.[6] Many new methods have been proposed which utilize their attractive capabilities and are still cost-effective. A lot of research work is going on worldwide to exploit the microprocessor in power system relaying. The use of µP on protective relaying offers several important advantages, briefly outlined below:

(a) Flexibility: Microprocessor is a programmable device so revisions, modifications can be done by modifying input data and/or by using different programmes. This aspect makes the system highly flexible.

(b) Reliability: A microprocessor based system is continuously active and provides self diagnosis process. Therefore, most of the device failure in the system can be detected immediately and corrective measures can be easily taken.

(c) Economics: The cost of electromechanical hardware has been continuously increasing whereas solidstate hardware is becoming cheaper. The cost of LSI and VLSI devices used largely in microprocessor based systems have still steeper downward trend. This is the important benifit of using microprocessor based system.

Moreover, these system also present a very low burden to instrument transformers and the input data can be multiplexed which helps to reduce the cabling expenses.

Thus these are more than enough reasons to develop the use of microprocessor in the protection of OHE as well.

1.4 ORGANISATION OF THESIS

Chapter-I sets forth a viable solution to the problem of non-selective relaying of the overhead equipment by modifying the relays characteristic and introducing a new technology. The basic informations about power feeding arrangement, different relays used in protective relaying and their characteristics have also been discussed.

Chapter-II is devoted to the modifications of the characteristics of the earthfault, wrong phase coupling and inverse definite minimum time relays and their logical significance. Principle and frequency response of the digital filter algorithm, used to extract the fundamental frequency component of the voltage and current signals, which are used to calculate resistance and reactance of the fault path, have also been elaborated in the same chapter.

Chapter-III describes the proposed primary protective relaying for protection of traction overhead equipment. Method of realizing the characteristics of relays, namely, earthfault, wrong phase couling and instantaneous overcurrent relays, hardware circuit details and software flowchart of primary protective scheme are also put forth in the same chapter. Behaviour of the relays on steady state and transient conditions is checked experimentally. Details of these tests conducted with simulated voltage and current signals are also given.

Chapter-IV is devoted to back-up overcurrent relay (definite timelag overcurrent relay). Its hardware, software flowchart and result of the laboratory testing on this relay are reported.

In Chapter-V, the last chapter, conclusions on the present work are drawn and suggestions for further work are given.

CHAPTER - II

MODIFICATIONS IN RELAY CHARACTERISTICS AND DIGITAL FILTER ALGORITHM

The conventional protection of overhead equipment using four electromechanical relays as described in the last chapter, has tendency towards poor selectivity and slow operation. In this chapter these problems have been investigated and measures to alleviate them have been suggested. These measures consists in modifying the relay characteristics and using microprocessor. Also discussed is the digital filter algorithm to be used in the microprocessor implementation of relaying.

2.1 MODIFICATIONS IN RELAY CHARACTERISTICS

The earth fault relay and wrong phase coupling relay have unnecessarily large area of operation and they merge together in a part of the R-X plane. These two unsound features give rise to problem of poor selectivity with earthfault and wrong phase coupling relays. Solution to the problem lies, therefore, in restricting the operating regions of these relays so as to include only earthfault area and wrong phase coupling points, respectively[2,3].

In back-up protection time delay is provided by IDMT relay which is unwantedly very large for faults at farther end, specially in emergency feed condition. This time delay is reduced by changing suitably the characteristic of the relay.

2.1.1 Earth Fault Relay

Fault area for line to earth faults occuring on emergency feed section, load locus and WPC points are shown in Fig. 2.1. The four WPC points An, Bn, Cn and Dn represent impendances seen by the relay under normal feed condition for the phase angle of ±120° and ±60° between the coupled voltages, similarly points Ae, Be, Ce and De represent the emergency feed condition.

A mho relay, set to cater to earth faults upto the farther end in emergency feed condition and maximum faults resistance simultaneously may enclose one or two WPC points (corresponding to phase difference of ±120° between coupled voltages under normal feed condition). So in this case earth fault relay will undesirably operate when there is phase to phase fault with ±120° phase difference between the coupled voltages.

Further, the junction of mho relay characteristic and load locus (represented by point K in the Fig. 2.1) gives the maximum permissible load on the feed section. Typically this can be 150% of the rated value, while traction transformers can deliver 100% overload for five minutes. Moreover, the longer the track section, larger should be the relay characteristic on R-X plane——— reducing the maximum permissible load. On the other hand longer the track section, larger is the probable number of locomotive running on it at a time, so heavier would be the loading. Therefore, this characteristic will pose a problem where spacing between substations is large.

Both the problems can be overcome by replacing the mho

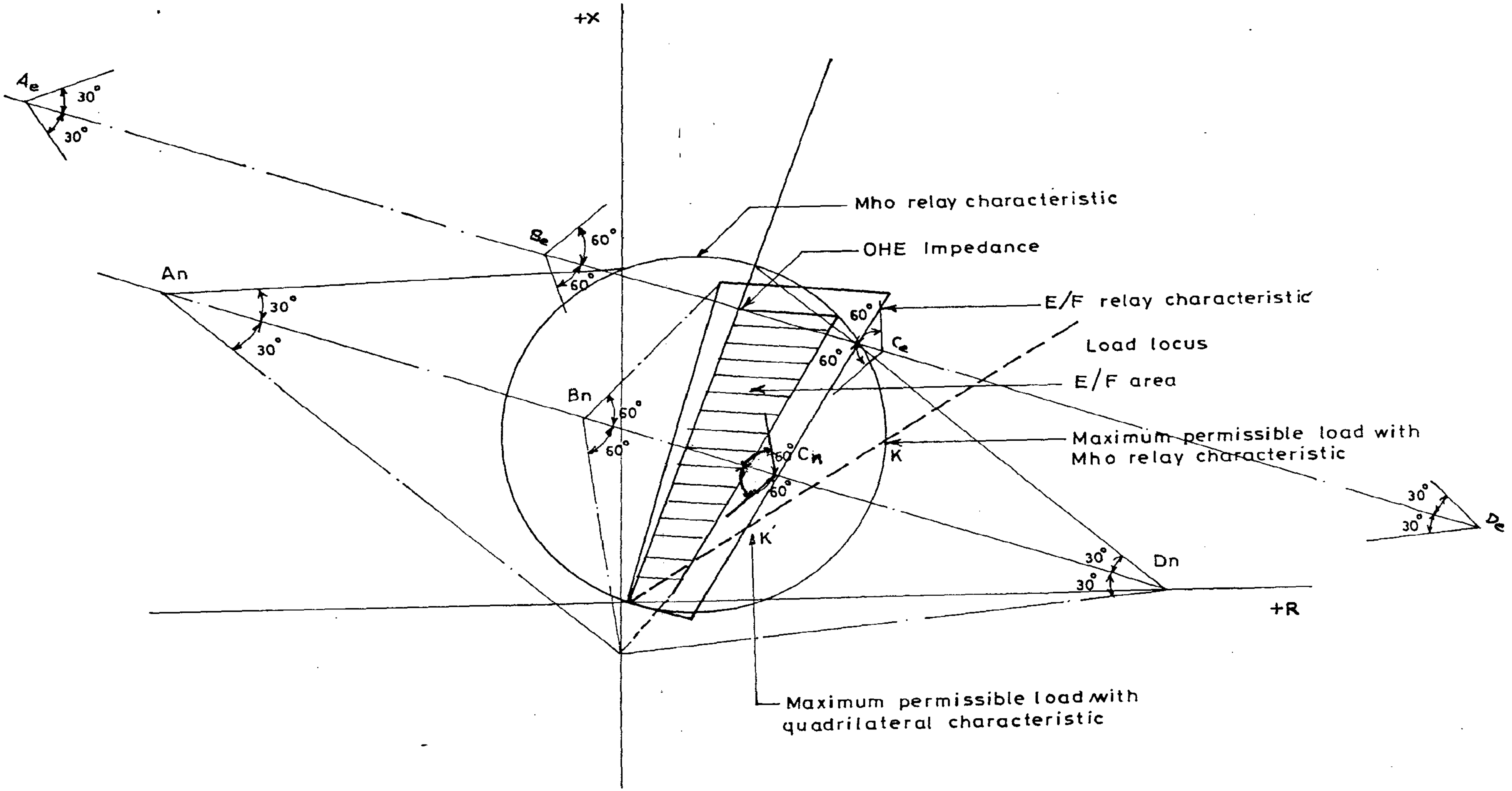

Fig. 2.1 Earth fault distance protection

relay with a quadrilateral relay enclosing the earth fault area with some reasonable allowance at the fault area boundary as shown in the figure.[3] All of the WPC points are well outside the quadrilateral characteristic. Maximum permissible loading is also increased.

2.1.2 Wrong Phase Coupling Relay

The WPC points alongwith the plain mho and offset mho relay characteristics used for wrong phase coupling proteection are shown in Fig. 2.2. Both the plain and the offset mho relays are set to cover wrong phase coupling operation under emergency as well as normal feed conditions. Either relay will operate if the relay voltage lags the other voltage by 60° or 120° (corresponding WPC points are Ae, Be, An and Bn). If the local voltage leads the other voltage by 60° or 120° (corresponding WPC points are Cn, Dn, Ce and De), nither relay will operate.

As it is clearly shown in the Fig.2.2, the operating region of plain mho relay encompasses a substantial part of earth fault area, therefore this relay will operate on earth faults too. On the other hand, offset mho relay characteristic, as shown in Fig.2.2, excludes whole of 'the earth fault area, so this relay is free from the tendency to maloperate on earth faults.[3]

Offset mho relay seems to be a sound choice for wrong phase coupling protection but this relay can also be discarded

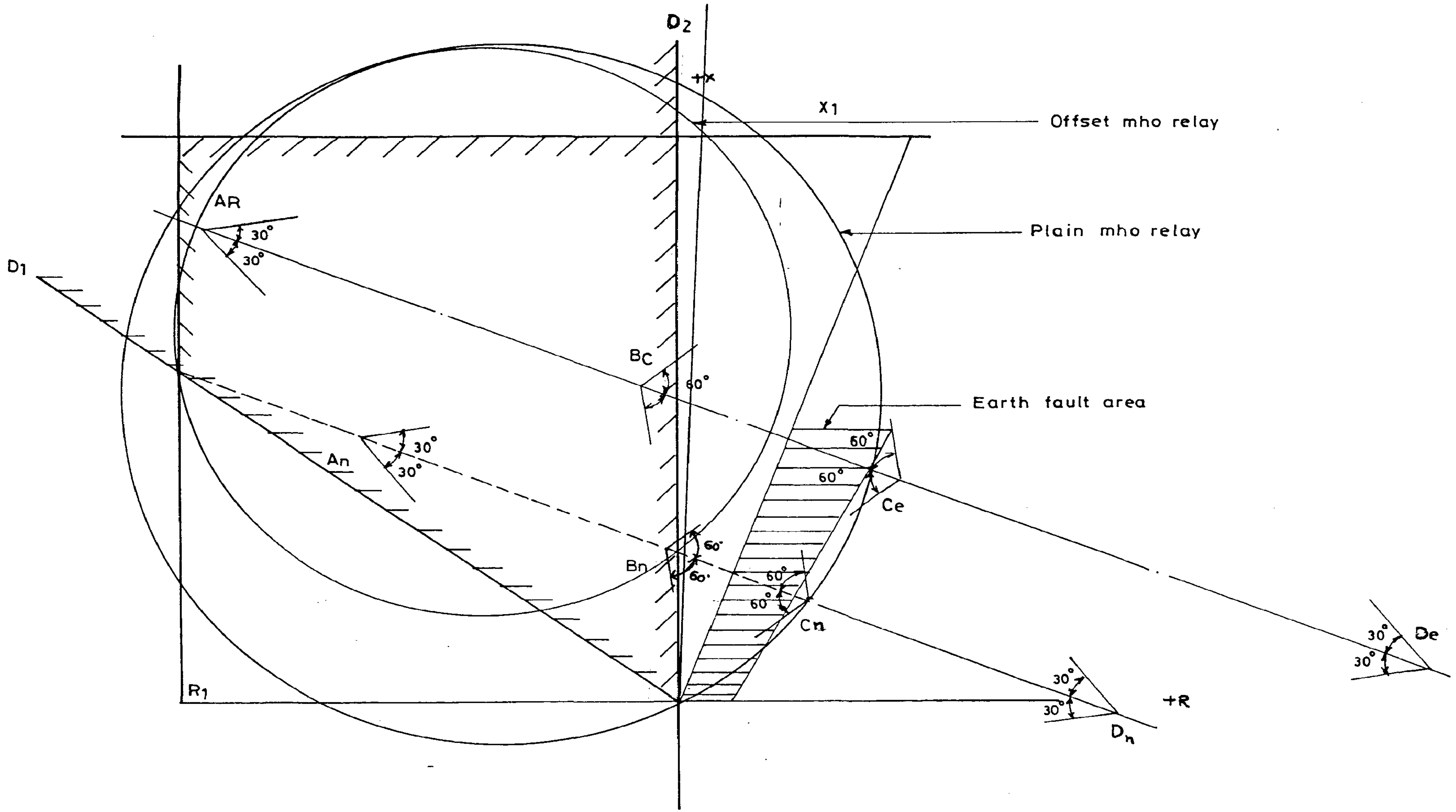

Fig. 2.2 Wrong phase coupling protection

in favour of a quadrilateral distance relay with operating region in the second quadrant of R-X plane, this characteristic is relatively easier to obtain with electronic circuits or microprocessor programming techniques.

2.1.3 Back-up Overcurrent Relay

IDMT ocvercurrent relay is generally employed to back-up the relays having slopy time-current characteristics like its own characteristic. When this relay is used here as back-up relay and its time multiplier setting is chosen such that it maintains a reasonable selective time interval with high speed relay at relay location as shown in Fig.2.3, the time delay provided by this relay for the faults at the farther and are very high and thus the back-up protection is very slow. So use of this relay as backup relay is not justified.

Here, for back-up protection, time lag provided by the relay should be just sufficient to ensure its selective operation with primary relay and it should be constant throughout its reach. Therefore it is more logical to use a definite time-lag overcurrent relay. Such a relay will provide considerable reduction in the time lag for farther faults.[3] Moreover, it will be simpler in construction, cheaper and more reliable.

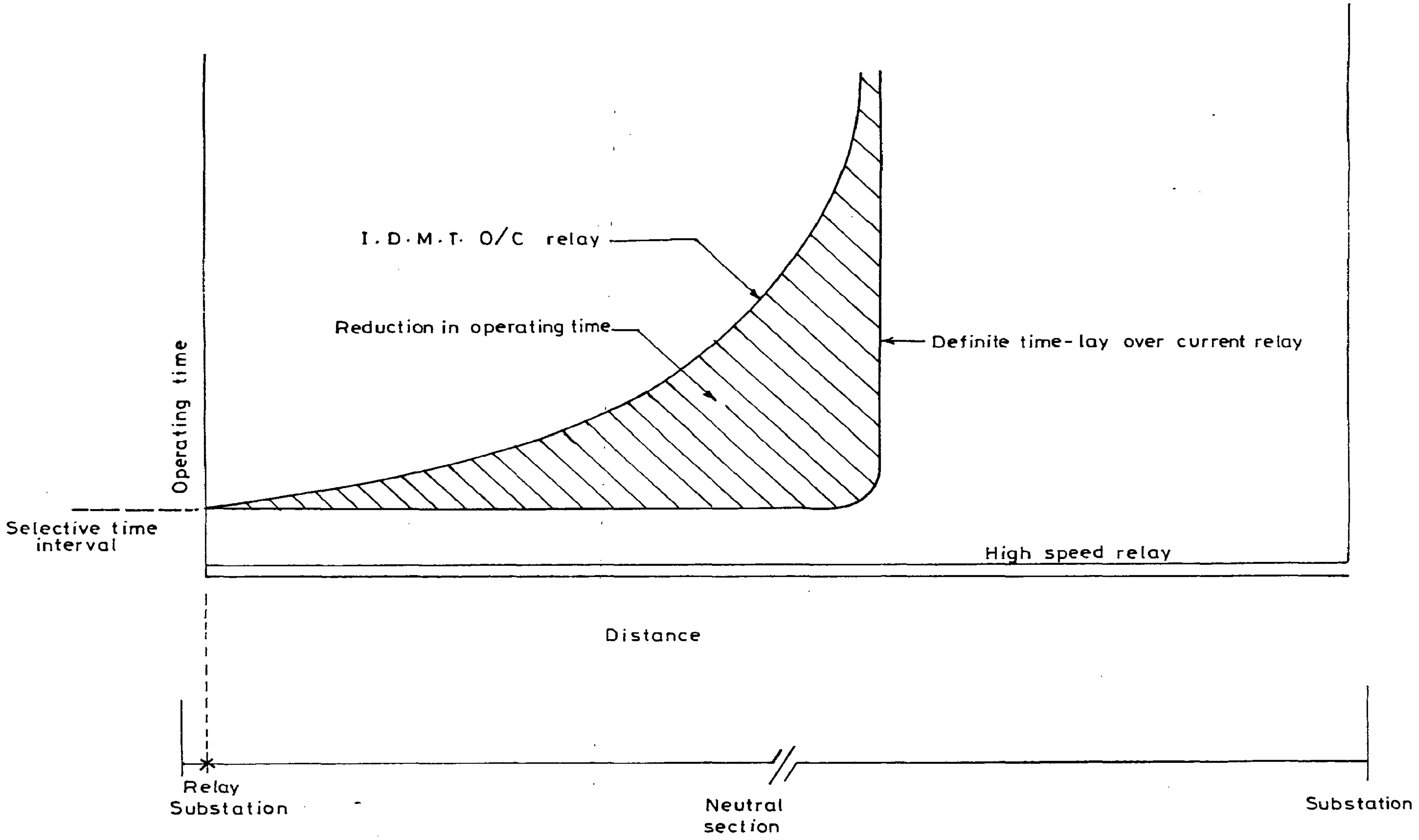

Fig. 2. 3 Back-up relay

2.2 DIGITAL FILTER ALGORITHM

The resistance and reactance seen at the relay location, which serve as the fault discriminants for earthfault and wrong phase coupling protection, need to be computed from the relaying signals. These relaying signals have d.c. offset and harmonics in post-fault condition, so these are required to be filtered for correct evaluation of fault discriminants. Filter algorithms based on Fourier, Walsh and Haar transforms can provide highly accurate estimate of fundamental frequency components. But signal processing based on these transforms involves some time consuming operations, specially multiplications, so these are not well suited to signal processing on microprocessor .

A technique based on cross-correlation with heptagonal waves[7] has been selected which involves a few additions substraction and rotation for computation of in-phase and 90° out of phase fundamental frequency components of the voltage and current signals. Frequency response of the fundamental frequency filter based on this technique is found to be almost as good as that of the filter based on the Fourier transform

2.2.1 Derivation

With a sampling rate of N samples per fundamental time period and an observation window of one full cycle, the cross correlation of a digital signal $\{x(n)\}$ with cosine and sine waves is expressed as:

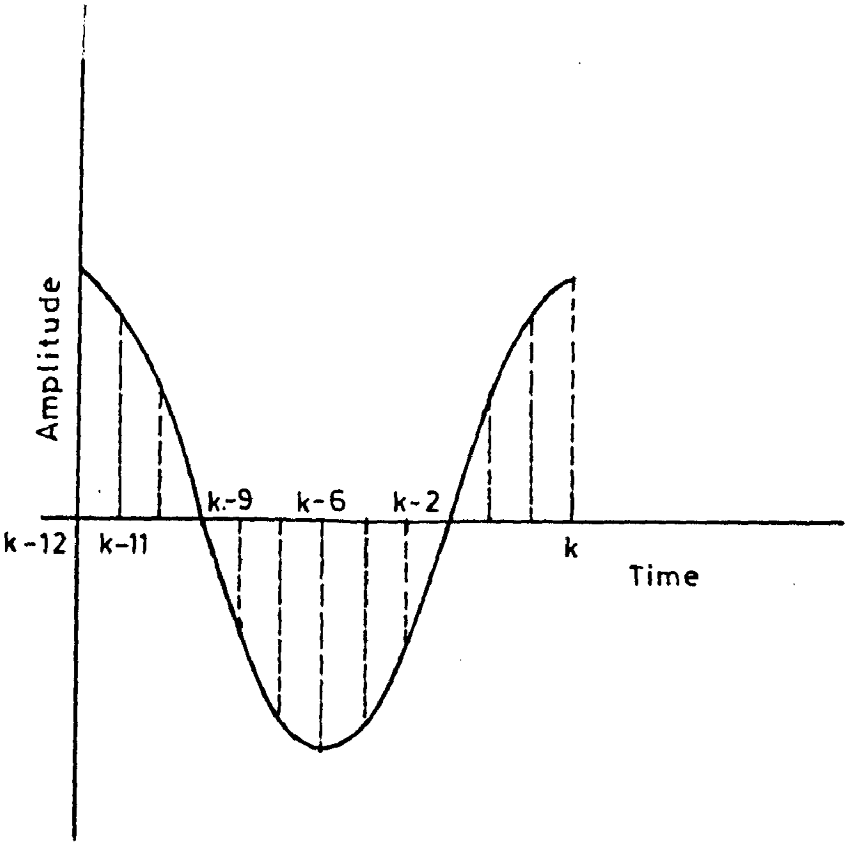

Fig. 2.4 Cosinusoidal wave of fundamental frequency

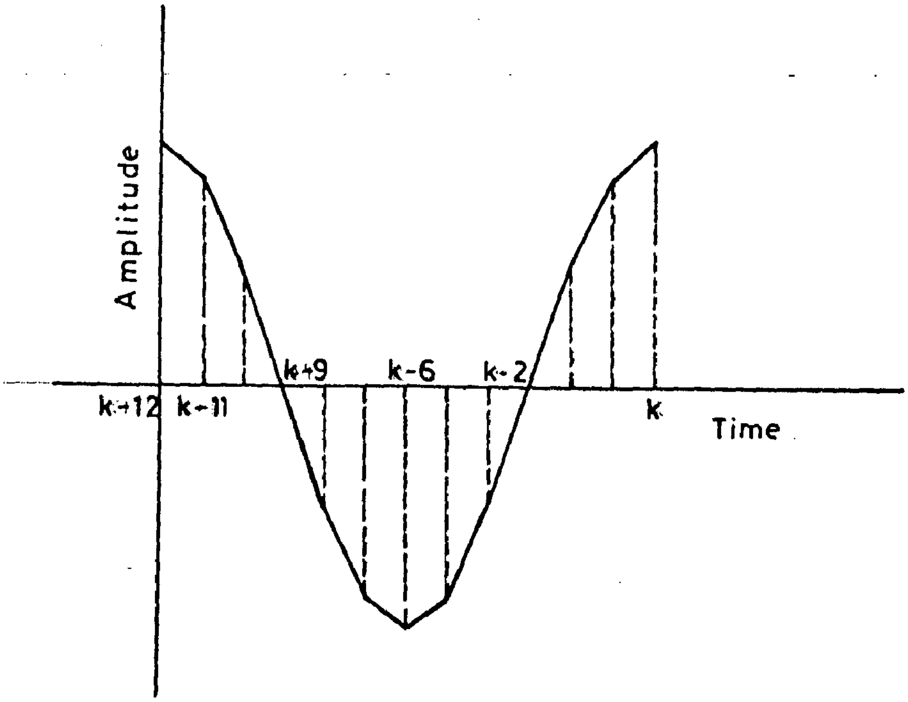

Fig. 2.5 Even heptagonal wave of fundamental frequency

$$y_{r1}(k) = \frac{2}{N} \sum_{n=0}^{N-1} x(k-n) \cos (k-n) \qquad .. (2.1)$$

$$y_{i1}(k) = \frac{2}{N} \sum_{n=0}^{N-1} x(k-n) \sin (k-n) \qquad .. (2.2)$$

Where cos (k-n) and sin (k-n) are the digital values of the cosine and sine functions of the fundamental frequency at $(k-n)^{th}$ sampling instant, and $y_{r1}(k)$ and $y_{i1}(k)$ are the cosine (real) and sine (imaginary) components of the fundamental frequency at the k^{th} sampling instant.

It is possible to compute resistance and inductance from the real components alone (of voltage and current signals). As such, only eq.(2.1) is of interest. The cosinusoidal function is shown in Fig. 2.4 . Expanding eq.(2.1) with the function values taken from Fig.2.4 , one gets,

$$\begin{aligned} y_{r1}(k) = \frac{1}{6} [x_k &+ 0.866\ x_{k-1} + 0.5\ x_{k-2} - 0.5\ x_{k-4} \\ &- 0.866\ x_{k-5} - x_{k-6} - 0.866\ x_{k-7} \\ &- 0.5\ x_{k-8} + 0.5\ x_{k-10} + 0.866\ x_{k-11}] \end{aligned} \qquad .. (2.3)$$

Rearranging equation 2.3

$$\begin{aligned} y_{r1}(k) = \frac{1}{6} [(x_k - x_{k-6}) &+ 0.866\ (x_{k-11} - x_{k-7} - x_{k-5} + x_{k-1}) \\ &+ 0.5(x_{k-10} - x_{k-8} - x_{k-4} + x_{k-2})] \end{aligned} \qquad .. (2.4)$$

2.2.2 Approximation

A very little approximation of changing the factor 0.866 to 0.875 in eqn.(2.4) is required to enable the equation to be implemented easily on microprocessors. The multiplication with 0.875 can be obtained simply through three binaryshifts and one substraction; factor 0.5 requires single binary shift operation. So the simplified equation

$$y_{r1}(k) = [(x_k - x_{k-6}) + 0.875(x_{k-11} - x_{k-7} - x_{k-5} + x_{k-1}) + 0.5(x_{k-10} - x_{k-8} - x_{k-4} + x_{k-2})] \quad .. (2.5)$$

Eqn. (2.5) may be seem to be the result of correlation with a heptagonal wave shown in Fig. 2.5 . Its corners coincide with the sampling instants and the magnitudes at these instants are 0, 0.5, 0.875 and 1.0, thus deffering with cosine wave only at one corner (0.875 for heptagonal and 0.866 for cosine wave).

Equation 2.5 represents the final filter algorithm used in the present work for extracting fundamental frequency real component of relaying signals.

Fig. 2.6 gives the frequency response of the filter given by equation 2.5.[7] It is clear that DC component in the signal is totally filteredout. 2nd, 3rd, 4th, 5th and 6th harmonics have very little remanant amplitudes.

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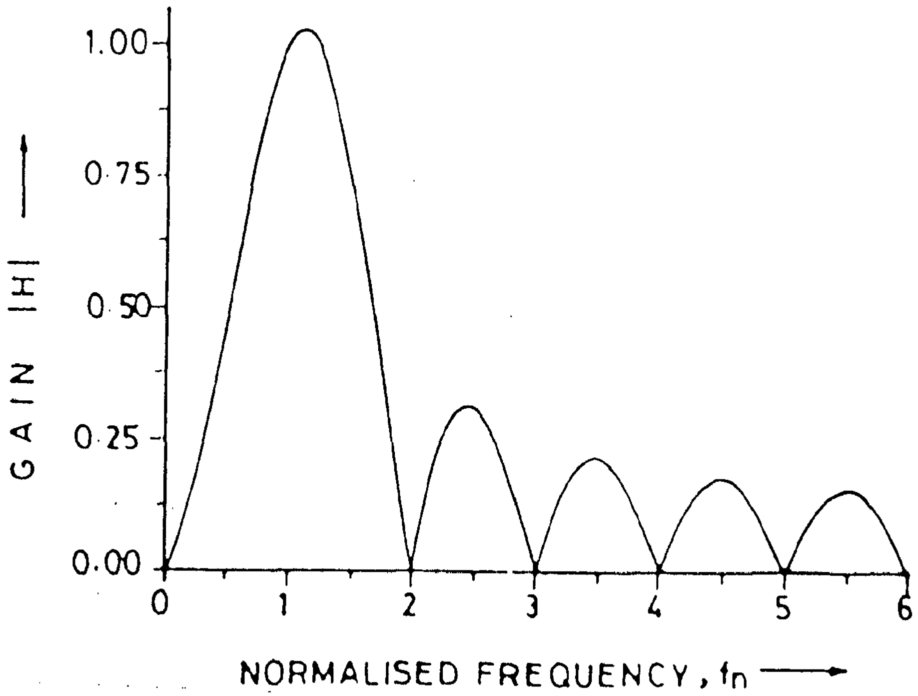

Fig.2.6 Frequency response of a filter based on cross-correlation with a heptagonal wave

CHAPTER - III

PROPOSED PRIMARY PROTECTIVE RELAYING SCHEME

Electromechanical relays used for the protection of overhead equipment, show poor selectivity and slow response and give rise to unecessary interruptions in the normal working of railway services as described in section 1.2. Modifications were put forth in section 2.1 to improve the performance of existing relaying. In all, four relays are required for the complete relaying of overhead equipment —— one for back-up and the rest for primary protective relaying.

The three relays required for primary protective relaying, with modified characteristics as proposed in the last chapter, have been realised through a system based around a microprocessor, 8085A. The principles of these relays alongwith software algorithms and hardware are presented in this chapter. Slight changes have been inducted into the characteristics of the distance relays to make the processing on the microprocessor faster; these are also dealt with here.

3.1 EARTHFAULT QUADRILATERAL DISTANCE RELAY

3.1.1 Principle

It has been explained in section 2.1.1 that quadrilateral characteristic would be most suitable for earth fault protective relaying of overhead equipment. The Quadrilateral characteristic, shown on the R-X plane in Fig.3.1, envelopes earth fault area and has some reasonable allowance outside the area. The characteristic can be seen as constituted of four straight line characteristics. The two

Where V_m and I_m are the amplitudes of the filtered fundamental voltage and current signals and ϕ_{vf} and ϕ_{if} are their respective phase angles. Filtered values at (k-1)th instant can be written for the sampling frequency of 12 samples per cycles as

$$V_{k-1} = V_m \cos(\phi_{vf} - \pi/6)$$

$$\text{and} \quad i_{k-1} = I_m \cos(\phi_{if} - \pi/6) \qquad .. (3.3)$$

From equation (3.3) quadrature components[8] can be calculated as below -

$$V_m \sin \phi_{vf} = V_{k'} = 1.732\ V_k - 2\ V_{k-1}$$

$$I_m \sin \phi_{vf} = i_{k'} = 1.732 i_k - 2 i_{k-1} \qquad .. (3.4)$$

The impedance seen by the relay is then given by:

$$Z = \frac{V_m}{I_m} \angle \underline{\phi_{vf} - \phi_{if}}$$

$$= \frac{V_m}{I_m} [\cos(\phi_{vf} - \phi_{if}) + j \sin(\phi_{vf} - \phi_{if})]$$

$$= \frac{V_m \cos \phi_{vf} \cdot I_m \cos \phi_{if} + V_m \sin \phi_{vf} \cdot I_m \sin \phi_{if}}{I_m^2} +$$

$$j \cdot \frac{V_m \sin \phi_{vf} \cdot I_m \cos \phi_{if} - V_m \cos \phi_{vf} \cdot I_m \sin \phi_{if}}{I_m^2} \qquad .. (3.5)$$

Real and imaginary part of the equation 3.5 denote resistance and reactance respectively. Hence, Electromechanical relays used for the protection of overhead equipment, show poor selectivity and slow response and give rise to unecessary interruptions in the normal working of railway services as described in section 1.2. Modifications were put forth in section 2.1 to improve the performance of existing relaying. In all, four relays are required for the complete relaying of overhead equipment —— one for back-up and the rest for primary protective relaying.

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3.1.1 Principle

It has been explained in section 2.1.1 that quadrilateral characteristic would be most suitable for earth fault protective relaying of overhead equipment. The Quadrilateral characteristic, shown on the R-X plane in Fig.3.1, envelopes earth fault area and has some reasonable allowance outside the area. The characteristic can be seen as constituted of four straight line characteristics. The two directional characteristics D1 & D2 make 80°and -10° angle with R axis. The ohm characteristic makes an angle of β and has an offset of R_o along R axis. Reactance characteristic has an offset of X_o from the origin.

Relaying voltage and current signal can be represented as:

$$V_i = V_m \sin wt$$

and $i_i = I_m \sin (wt-\emptyset)$; $\emptyset$ is the angle by which current lags the voltage.

For implementation of the above distance relay characteristics on μP, these signals are digitized using an ADC (analog to digital converter). Since an ADC needs voltage input signals, The relaying voltage and current are applied to it through an auxiliary VT of ratio K and a CT of ratio K' with a resistance of R ohm at the secondary output. Thus inputs to the ADC are

$$\begin{aligned} V_v &= K V_m \sin wt \\ \text{and} \quad V_i &= K' I_m R \sin (wt-\emptyset) \end{aligned} \qquad .. (3.1)$$

The signals expressed by equation (3.1) are sampled 12 times per cycle and filtered by cross-correlation technique described in section 2.2 to obtain in-phase fundamental components.

If V_k and i_k are the values of filtered fundamental frequency (in-phase components) at any sampling instant K, these can be represented as:

$$\begin{aligned} V_k &= V_m \cos \emptyset_{vf} \\ \text{and} \quad i_k &= I_m \cos \cos \emptyset_{if} \end{aligned} \qquad .. (3.2)$$

Where V_m and I_m are the amplitudes of the filtered fundamental voltage and current signals and ϕ_{vf} and ϕ_{if} are their respective phase angles. Filtered values at (k-1)th instant can be written for the sampling frequency of 12 samples per cycles as

$$V_{k-1} = V_m \cos(\phi_{vf} - \pi/6)$$

$$\text{and} \quad i_{k-1} = I_m \cos(\phi_{if} - \pi/6) \qquad .. \ (3.3)$$

From equation (3.3) quadrature components[8] can be calculated as below -

$$V_m \sin \phi_{vf} = V_{k'} = 1.732\, V_k - 2\, V_{k-1}$$

$$I_m \sin \phi_{vf} = i_{k'} = 1.732 i_k - 2 i_{k-1} \qquad .. \ (3.4)$$

The impedance seen by the relay is then given by:

$$Z = \frac{V_m}{I_m} \angle \underline{\phi_{vf} - \phi_{if}}$$

$$= \frac{V_m}{I_m} [\cos(\phi_{vf} - \phi_{if}) + j \sin(\phi_{vf} - \phi_{if})]$$

$$= \frac{V_m \operatorname{Cos} \phi_{vf} \cdot I_m \cos \phi_{if} + V_m \sin \phi_{vf} \cdot I_m \sin \phi_{if}}{I_m^2} +$$

$$j \cdot \frac{V_m \sin \phi_{vf} \cdot I_m \cos \phi_{if} - V_m \cos \phi_{vf} \cdot I_m \sin \phi_{if}}{I_m^2} \qquad .. \ (3.5)$$

Real and imaginary part of the equation 3.5 denote resistance and reactance respectively. Hence,

$$\text{Resistance} = r = \frac{V_k\, i_k + V_{k'}\, i_{k'}}{i_k^2 + i_{k'}^2} = A/c, \quad \text{say}$$

$$\text{Reactance} = x = \frac{V_{k'} i_k - V_k\, i_{k'}}{i_k^2 + i_{k'}^2} = B/c, \quad \text{say}$$

The values of A, B and C are calculated and used to decide for tripping of the quadrilateral relay (section 3.1.3).

3.1.2 Characteristic Simplification

Slight alternations can be made in the characteristic of the quadrilateral relay to reduce the calculatioons to be performed by the μP, as follows:

(i) Referring to Fig. 3.1 the line D1, the directional characteristic making about 80° with R axis (= 80°) is rotated to coinside with the x-axis. This eliminates one multiplication in decision making process.

(ii) In reference to the same figure, line D2, the directional characteristic having about -10° with R-axis is (= -10°) is turned to coincide with R-axis. This saves another multiplication .

(iii) Ohm characteristic will make an angle of 63.43 degrees. Tan 63.43 being equal to 2, the multiplication becomes less time consuming (it can be achieved as a single binary shift). The new (simplified) characteristic of quadrilateral relay is given in Fig. 3.2.

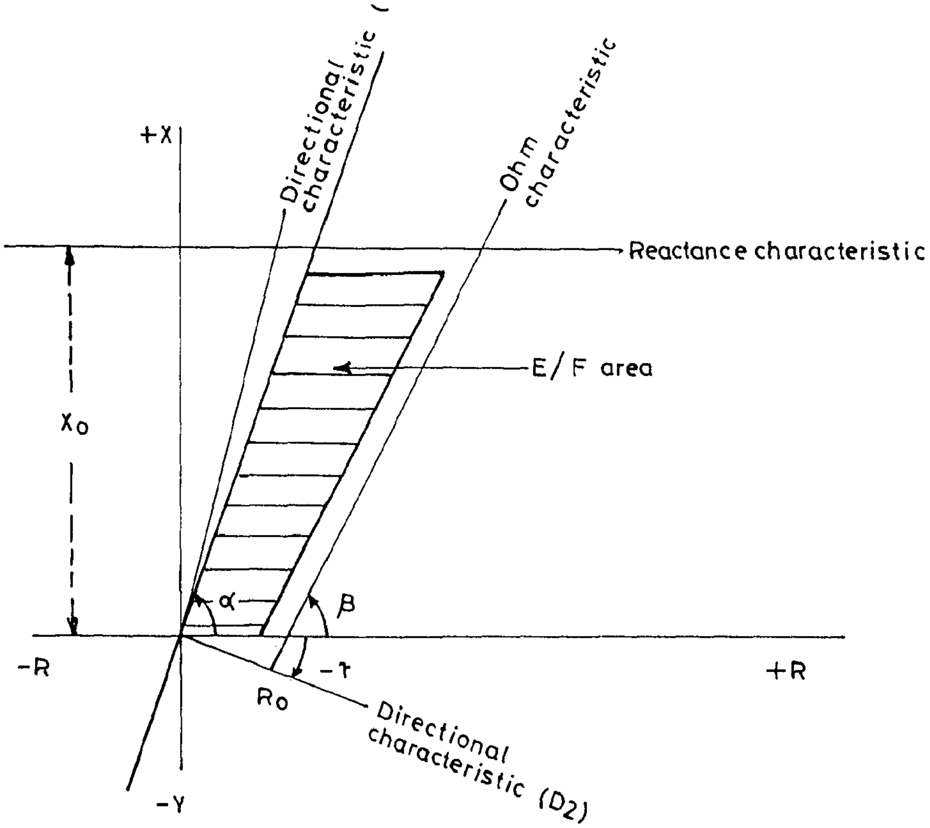

Fig. 3.1 Earth - fault quadrilateral characteristic

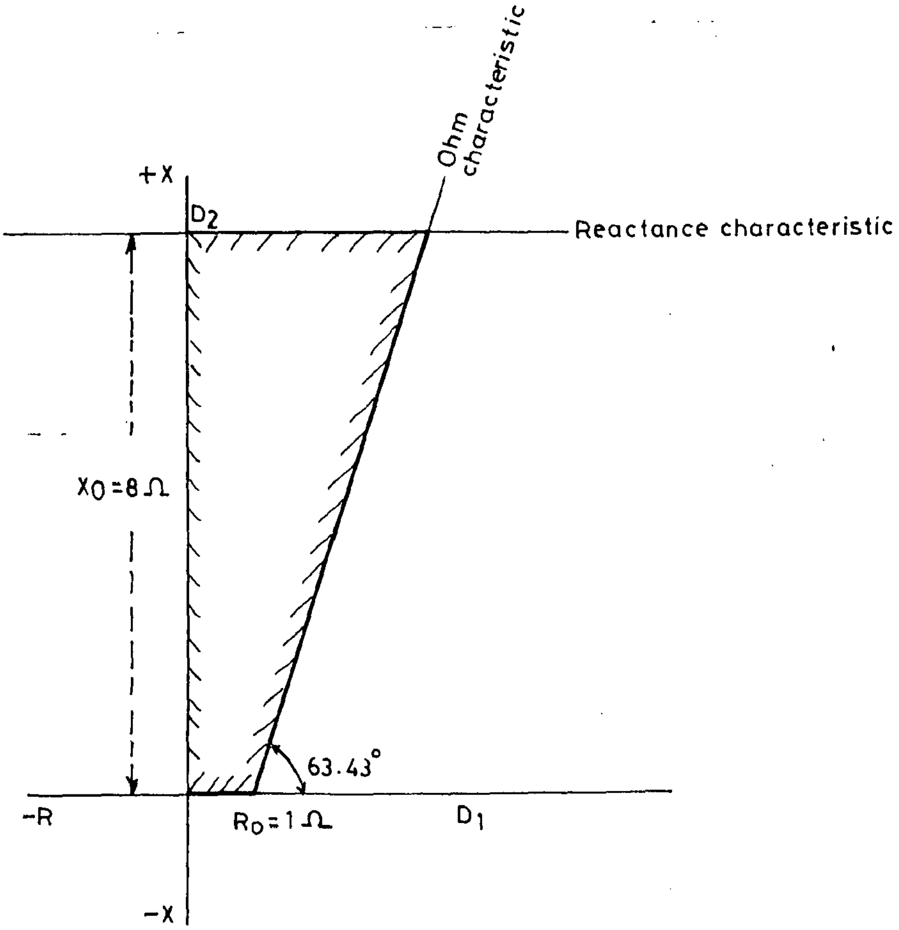

Fig. 3.2 Simplified characteristic

3.1.3 Relay Algorithm

To minimize the effect of transients in realisation of earth fault relay, a fault counter is incorporated. The decision to trip the C.B. is made only when the fault discriminants are found to lie in the fault area at two successive sampling instants. Thus, the implementation of earth fault distance relay characteristics on μP will use the following steps.

(1) Acquire the voltage and current samples

(2) Filter the in-phase components and compute quadrature components of voltage and current signal.

(3) Calculate $V_k i_k$, $V_{k'} i_{k'}$, $V_{k',Ik}$, $V_k i_{k'}$, i_k^2, $i_{k'}^2$,

$A = V_k i_k + V_{k'} i_{k'}$, $B = V_{k'} i_k - V_k i_{k'}$, $C = i_k^2 + i_{k'}^2$

(4) If the $B<0$ or $B>X_o C$, go to step 8.

(5) If $A<0$ go for wrong phase coupling check.

(6) If $(A-CR_o)<0$, increment fault counter and go to step 9.

(7) If $B-2(A-CR_o)>0$ increment fault counter and go to step 9.

(8) Reset trip counter, wait for next interrupt to go to step 1.

(9) If fault counter = 2 issue trip signal to C.B., reset fault-counter, set fault indicator, wait for the next interrupt to go to step 1.

3.2 WRONG PHASE COUPLING RELAY

3.2.1 Principle

For wrong phase coupling protection of overhead equipment, as observed in section 2.1.2 quadrilateral distance relay is more suitable than plain or offset mho relay. The characteristics of this relay is shown in Fig. 3.1.

The inclinations of two directional lines D1 & D2 are decided by wrong phase coupling points (Ae, Be, An and Bn) on R-X plane. The locations of these points[9] are dependent upon phase difference, various impedances between the coupled voltages and can be calculated as follows:

Let the relay be located at substation P and wrong phase coupling occurs with phase of substation Q, the substation volttages being $\overline{E}_p = E_p\angle\delta$ and $\overline{E}_q = E_q\angle 0$ and source impedances $\overline{Z}_p$ and $\overline{Z}_q$, respectively. Due to the fault, two phases get interconnected with impedance $\overline{Z}_{pq}$ where

$\overline{Z}_{pq} = \overline{Z}_p + \overline{Z}_q + \overline{Z}_l$; $\overline{Z}_l$ is OHE impedance between the coupled substations.

The fault current is

$$\overline{I}_f = (\overline{E}_p - \overline{E}_q) / \overline{Z}_{pq} \qquad ..(3.6)$$

The voltage at relay location is

$$\overline{V}_r = \overline{E}_p - \overline{I}_f . \overline{Z}_{pq} \qquad ..(3.7)$$

and the impedance seen by the relay is

$$\overline{Z}_r = \overline{V}_r / \overline{I}_f = \frac{\overline{Z}_{pq} . \overline{E}_p}{\overline{E}_p - \overline{E}_q} - \overline{Z}_m \qquad ..(3.8)$$

Magnitude of the voltage at two substations may be assumed to be equal. Hence,

$$\overline{Z}_r = \frac{\overline{Z}_{pq} \angle\delta}{\angle\delta - 1} - \overline{Z}_p \qquad ..(3.9)$$

Solving equation (3.9)

$$\overline{Z}_r = \left(\frac{\overline{Z}_{pq}}{2} - \overline{Z}_p \right) - j . \frac{\overline{Z}_{pq}}{2} \cot \delta/2 \qquad .. (3.10)$$

Equation (3.10) clearly shows that tip of the Z_r is a point on right angled bisector of phasor $\overline{Z}_{pq}$. For the same values of impedances $\overline{Z}_{pq}$ and $\overline{Z}_p$, δ can assume four values and thus gives rise to four wrong phase coupling points on the R-X plane. In emergency feed condition. $\overline{Z}_{pq}$ changes as $2\overline{Z}_1$ replaces $\overline{Z}_1$ in equation (3.6) and this results in four more points on the R-X plane.

In the event of wrong phase coupling, the realy at the lagging substation alone operates. Therefore, four points out of the total of eight points corresponding to local voltage lagging the voltage of other substation by 120° or 60° are relevant in deciding the relay characteristic. The operating angle range of the relay should be selected in a way to enclose all the four points with appropriate allowance at either side to accomodate various errors in the system data, C.T., V.T. and relay.

3.2.2 Characteristic Simplification

Following are the simplifications used in the relay characteristic:

(i) Multiplication in the comparision process can be eliminated by merging the directional characteristic D_2 with X-axis.

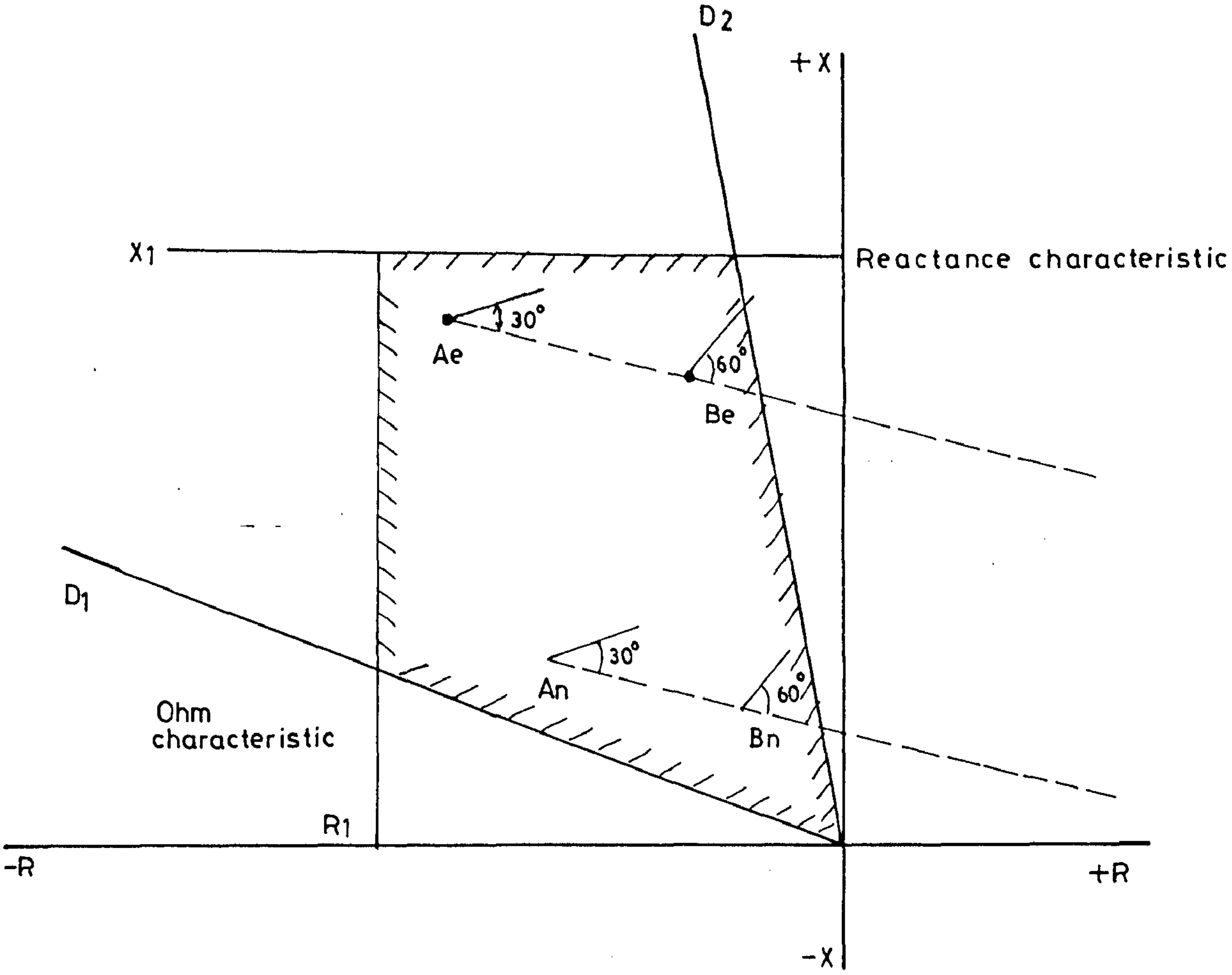

Fig.3.3 WPC Quadrilateral characteristic

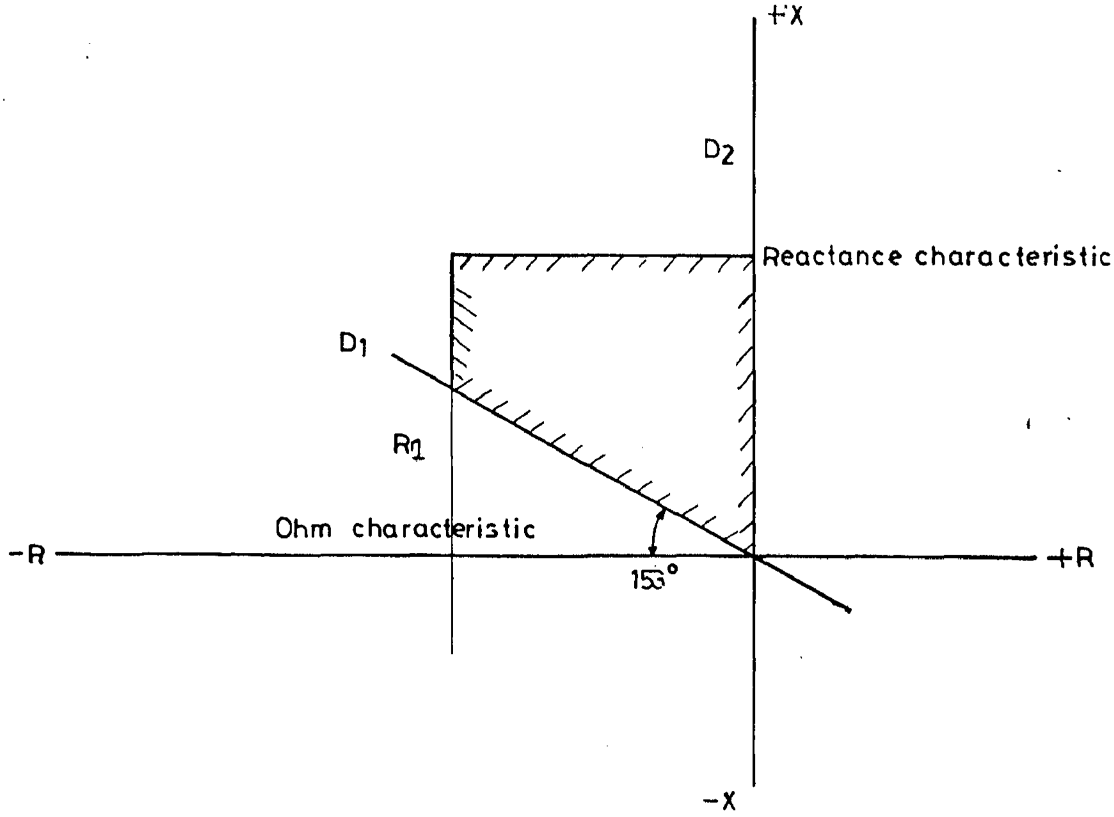

Fig.3.4 Simplified WPC Quadrilateral characteristic

(ii) The line D_1 in the characteristic can assume any inclination in between 140° to 160°. Here 153° has been chosen because tangent 153° is 0.5 and needs only one binary shift ooperation in implementation on µP.

(iii) To avoid the operations due to spurious signal, the area bounded by the two directional characteristic D_1 & D_2 should be enclosed, say, by a circular characteristic. But the circular characteristic will be very difficult to implement on microprocessor. So one ohm and one reactance characteristic are selected to close the said area on the R-X plane, making the WPC relay characteristic a quadrilateral one and easier to realize on microprocessor. The simplified characteristic is given in Fig. 3.4.

3.2.3 Relay Algorithm

For the reasons given under the earth fault distance relay, a fault counter is incorporated in WPC relay also. Following steps are carried out to realize the relay:

(1) Acquire relaying signal samples (voltage and current).

(2) Filter the in-phase components and calculate quadrature components.

(3) Calculate $v_k.i_k$, $v_{k'}.i_{k'}$, $v_{k'}.i_k$, $v_k.i_{k'}$, i_k^2, $i_{k'}^2$,
$A = v_k i_k + v_{k'} i_{k'}$, $B = v_{k'} i_k - v_k i_{k'}$, $C = i_k^2 + i_{k'}^2$

(4) If $B \nless X_1C$ go to step (8)

(5) If $A \nless R_1C$ go to step (8)

(6) If $A \nless 2B$ go to step (8)

(7) Increment fault counter; if fault counter = 2, issue trip signal to C.B., reset fault counter, set fault indicator and wait for next interrupt to go to step 1.

(8) Reset-fault counter; fault, indicator and wait for next interrupt to go to step 1.

3.3 INSTANTANEOUS OVERCURRENT RELAY

The relay is required to operate as the current signal attains an average value corresponding to the relay setting. The average is taken over one half cycle so that the maximum operating time of the relay is 10 ms. Following sequence of operations is carried out to realize overcurrent relay.

(1) Take the average of the latest 6 samples.

(2) If the average value is less than the relay setting go to step 4.

(3) Issue trip signal to C.B. set fault indicator and wait for the next interrupt to go to step 1.

(4) Wait for the next interrupt to go to step 1.

3.4 RELAYING SCHEME

The general block schematic of the primary protective relay scheme is shown in Fig 3.5 The relaying signals obtained from main CT and VT are not suitable for direct application to solid-state circuits. Therefore, they are stepped down with the help of aux. CT and VT to the proper value. Singals are then applied to input signal preprocessor which performed two functions as given below:

(i) The current signal is converted to a voltage signal by connecting a resistance at the output of secondary of CT because inputs to AD convertor must be a voltage.

(ii) The relaying signals obtained from the system contain varying degrees of dc and harmonics, which are filtered by a digital filter which extracts the in-phase component of fundamental frequency as described in section 2.2. The harmonics having frequency above them 300 Hz are filtered by a 4-pole low pass filter.

An analog multiplexer constitutes the ADC interface and the processed signal goes through it to ADC which digitizes the signals for the microprocessor.

3.4.1 Hardware

The hardware of the primary relaying scheme has been shown in Fig. 3.6. Two 741C operational amplifiers are used to

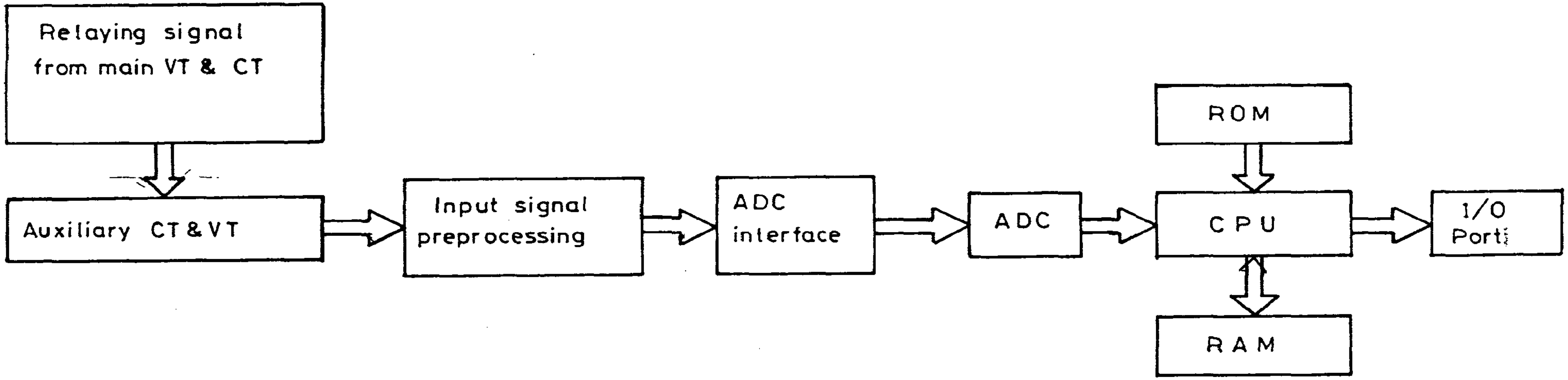

Fig. 3.5 General block schematic of primary protective relaying

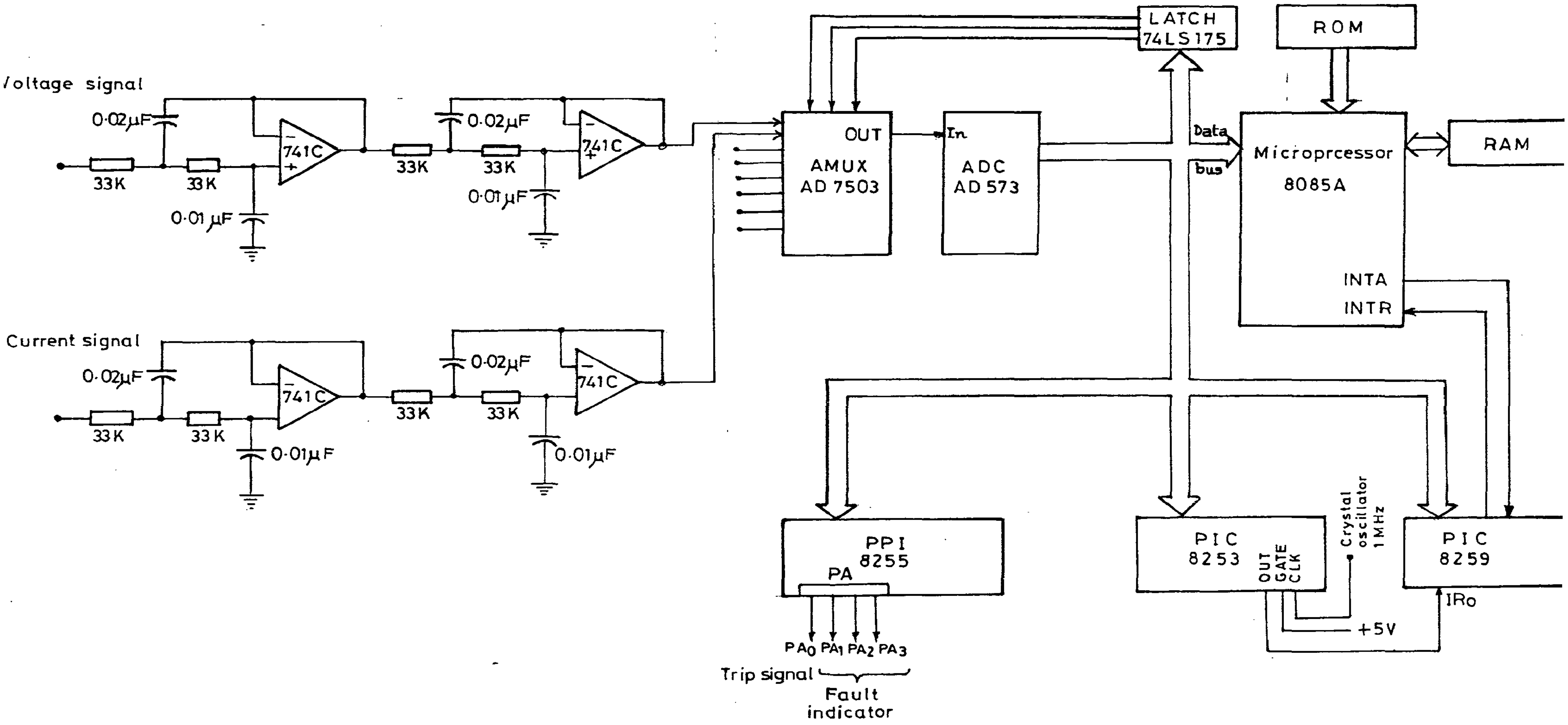

Fig. 3.6 Hardware diagram of Primary protective relay

make the 4-pole low pass filter. The cutoff frequency of the filter is set to less than half the sampling frequency (600 Hz). for the signal to eliminate alising. It has been selected as 250 Hz. Analog multiplexer (AD7503) passes one of the two filtered relaying signals at a time to 10 bit analog to digital converter AD573. The ADC has 20 μs conversion time and can be configured for ±5V or 0-10V; the former configuration has been used here. There is also facility of configuring it for differential mode which is necessary in noisy environment. This ADC can be directly connected to microprocessor without any port except an address decoding logic circuitry. A 74LS138 is utilized for this purpose.

A programmable counter (counter 0 of 8253) produces square wave of 1.67 ms time period duration. This output of the counter is connected to IR0 of an 8259 (programmable interrupt controller). The 8259 is configured for edge triggered interrupts and interrupt the microprocessor at every 1.67 ms. The microprocessor input voltage and current samples and checks if they represent any fault. At the condition of fault one port line (PA_0) of an 8255 is made high (trip signal) and one of he lines PA_1, PA_2 or PA_3 made high to indicate the type of fault (fault indication signal).

3.4.2 Software

The flowchart of primary protective relaying software is given in Fig.3.7. It starts with the initialization of programmable peripheral interface (PPI:8255), programmable timer counter (PTC:8253), programmable interrupt controller (PIC:8259) and software counters. On receiving an interrupt (which is generated at every 1.67 ms time interval) the microprocessor issues channel selection logic to the analog multiplexer (AD7503). The conversion period is utilized for rearranging the memory locations where voltage and current samples are stored. Although the ADC used here is of 10-bit size, only higher 8-bits are input and two least significant bits are discarded because if whole of the 10-bits are input the computation cannot be completed in 1.67 ms. After the samples of voltage and current signals have been taken, the instantaneous overcurrent relay logic starts. For this, the sum of the latest 6 samples (half cycle) is [redacted] taken and compared with the relay setting to take an overcurrent trip decision. The streps involved are shown separately in the flow chart in Fig. 3.9. Using the latest 12 samples, the fundamental frequency in-phase and quadrature components of the relaying signals, v_k, i_k and $v_{k'}$, $i_{k'}$, are calculated. Subsequently, the μP calculates $v_k i_k$, $v_{k'} i_{k'}$, $v_{k'} i_k$ and $v_k i_{k'}$ and using them it computes A, B and C. With the values of A, B, and C, few steps as described in section 3.1.3 & 3.2.3 are carried out to check earthfault and wrong phase coupling conditions. These steps are presented systematically in the form of two flow charts in Figs. 3.7(a), 3.8 .

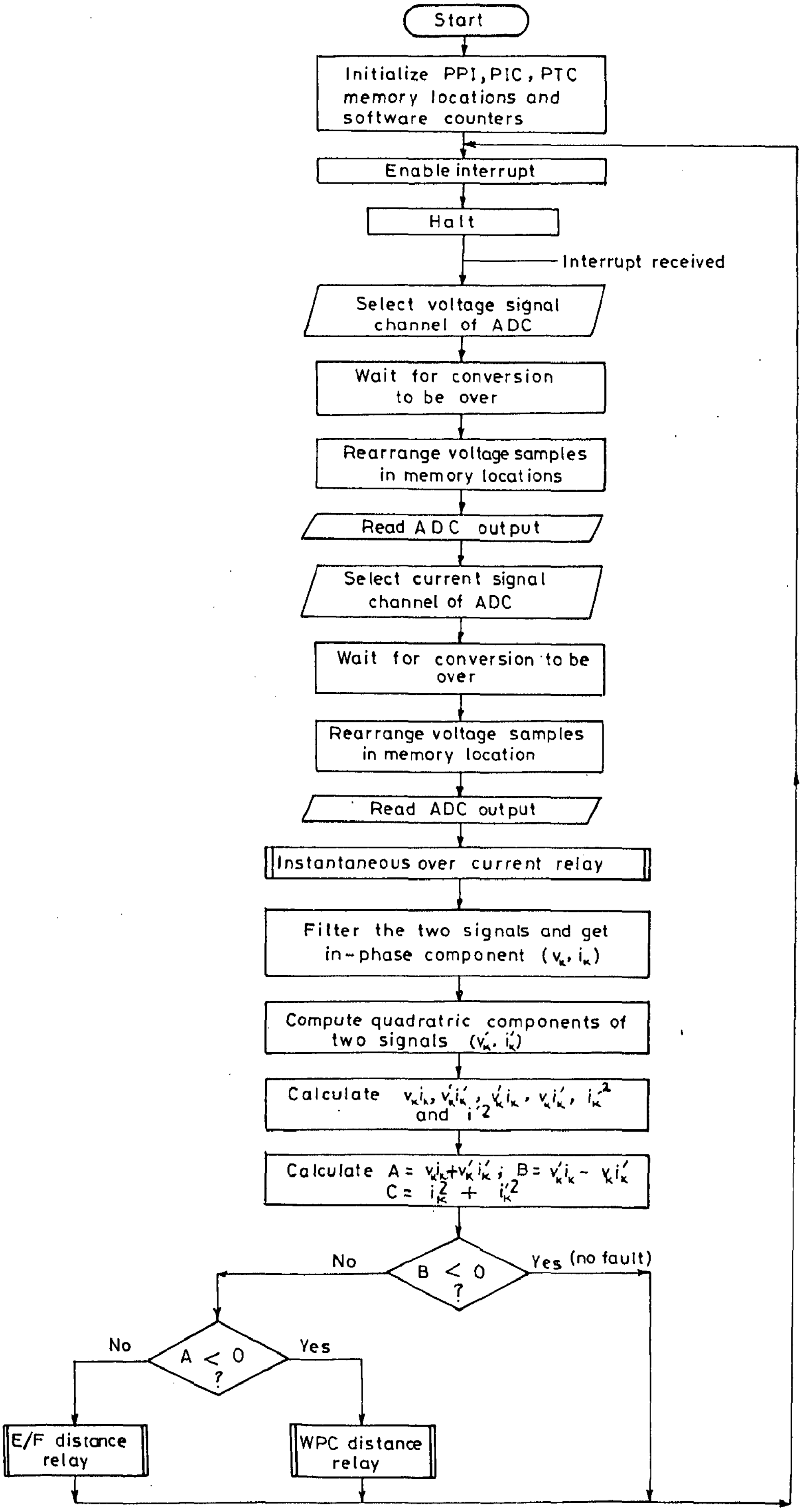

Fig. 3.7 Flow chart for primary protective relay

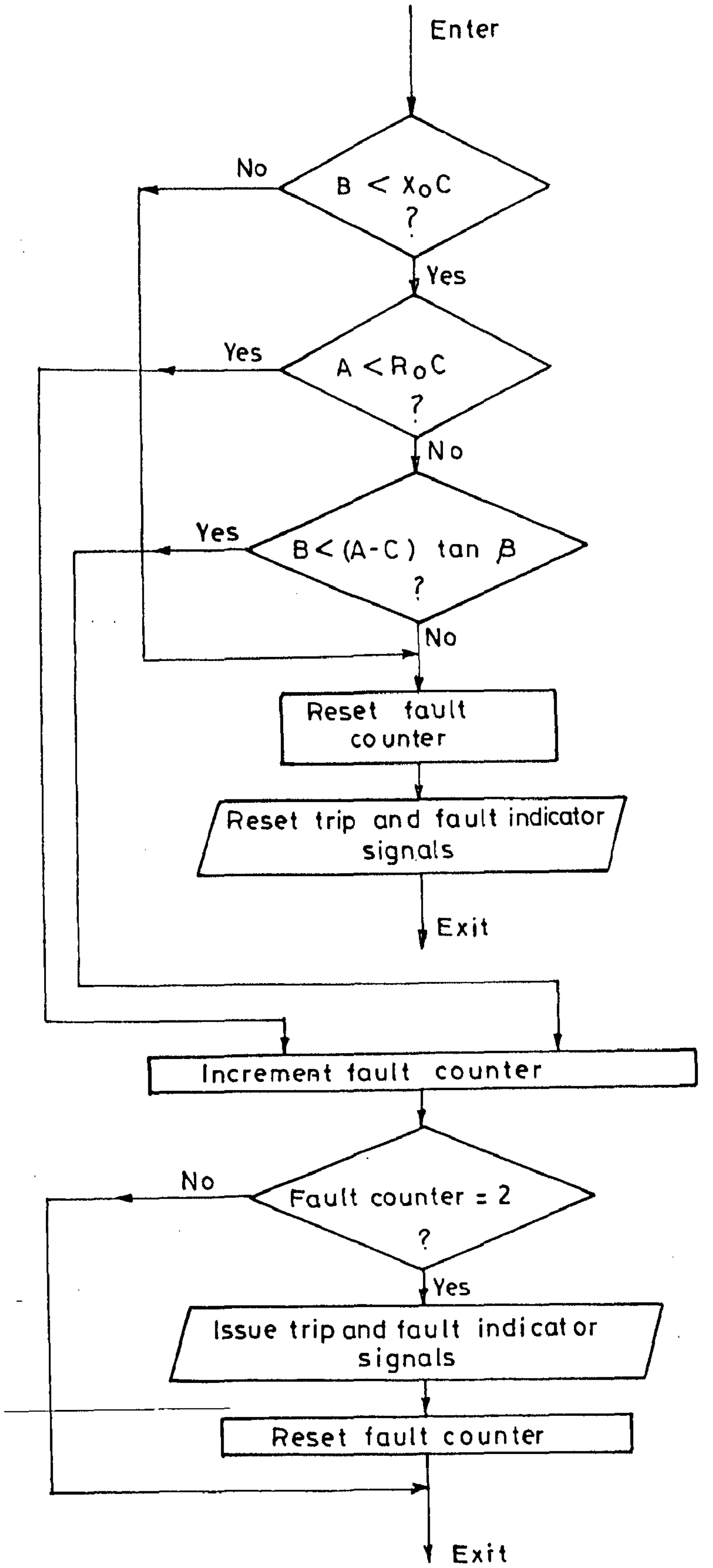

Fig. 3.7(a) Detailed flow chart for E/F distance relay

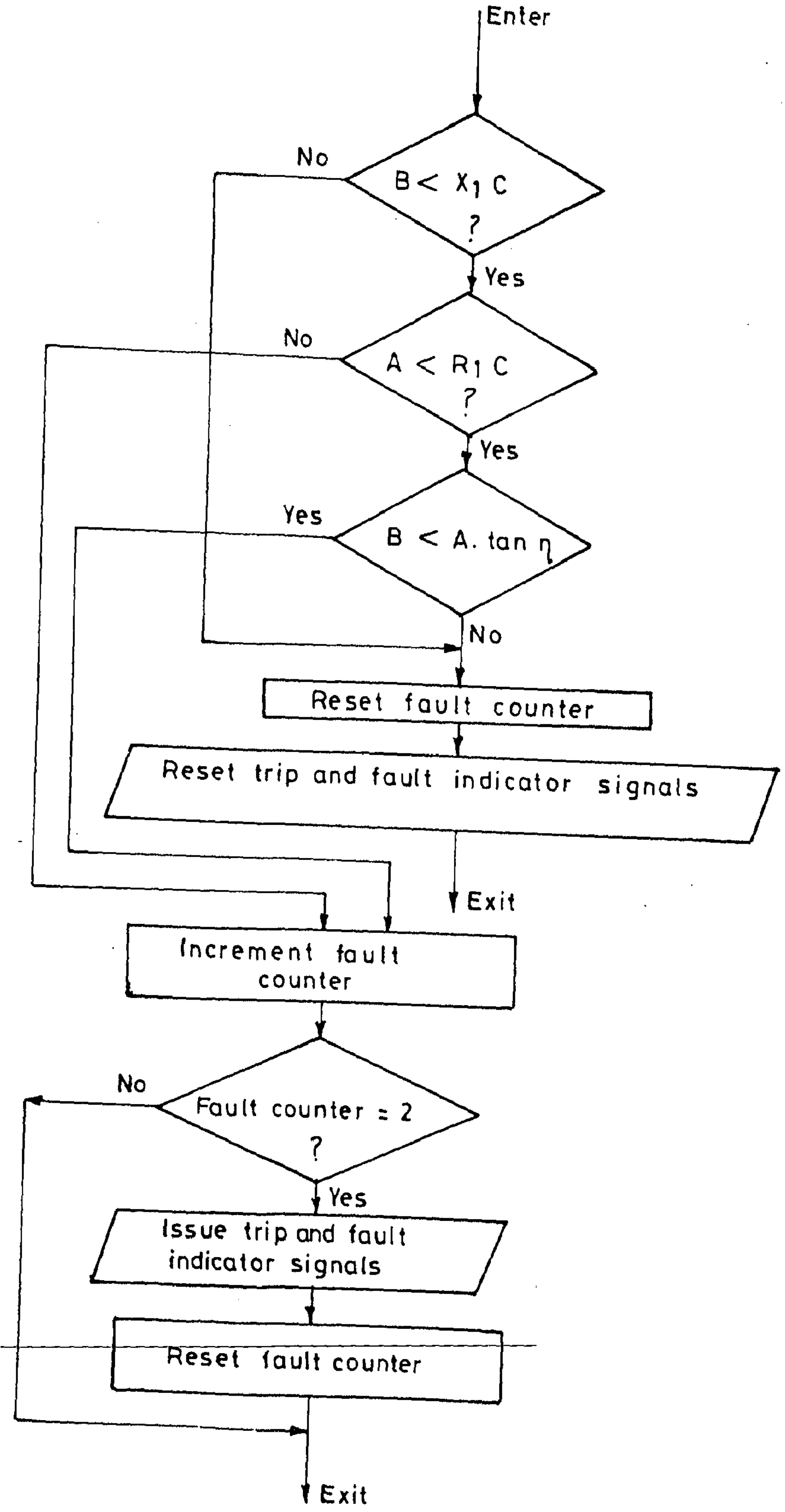

Fig.3.8 Detailed flow chart for WPC distance relay

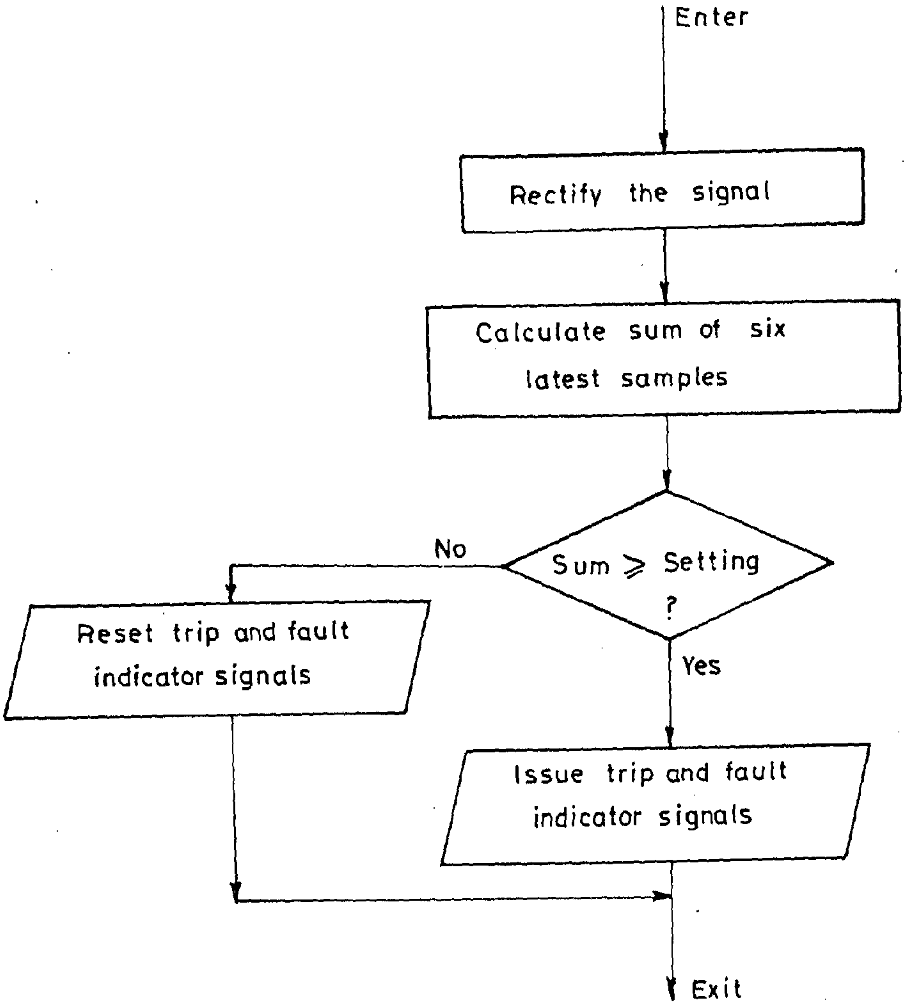

Fig. 3.9 Detailed flow chart for instantaneous over current relav

3.5 LABORATORY TESTING OF THE SCHEME

The foregoing relaying scheme has been tested for its steady state and dynamic state performances. In this section, the experimental characteristics of the relays have been plotted from the data obtained by steady state performance testing. The variation of the resistance and reactance as calculated by the μp during the transient conditions has also been determined.

3.5.1 Steady State Performance Tests

(a) Earth Fault Relay:

Steady state testing for earthfault relay requires two pure sinusoids, with variable amplitudes and phase angle (0 to 90°) one as voltage signal and another one as current signal. These signals should have the same source. Therefore, a osciallator (HIL 2961) generating a sinusoidal signal was selected. The signal is given to all pass filter for phase angle variation and to potentiometers for amplitude variation. The test circuit diagram is shown in Fig.3.10. Amplitude of the voltage signal is fixed. For any phase angle, the amplitude of the current signal is recorded for which the relay just operates. Fig. 3.11 shows the characteristics of the relay so obtained.

The experimental characteristics shows a few disparities with the designed characteristic and are listed below:

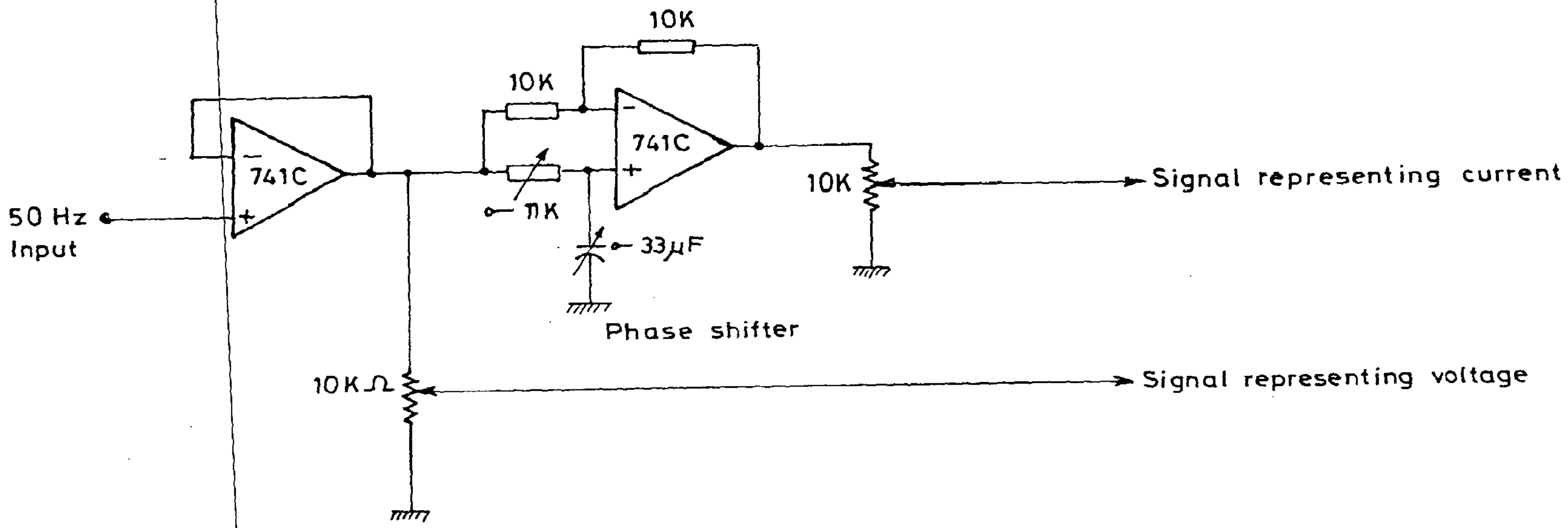

Fig. 3.10 Testing circuit

(i) The reactance line (X_o) has a drooping tone and initial offset at the +x axis is 8.3 ohms against a designed offset of 8 ohm.

(ii) The line D1 makes an angle of 2° with +x axis.

(iii) The ohm characteristics has an offset of 1.2 ohm along the R-axis against the designed offset of 1 ohm and an angle of 62° against the designed angle of 63.43° .

The aforesaid disparities can be attributed to the fact that the simulated relaying signals have been taken from oscillator and have large degree of harmonics. The phase difference given by all pass filter in the testing circuit is different for different harmonics. So total phase difference produced would be different than the calculated by taking value of R & C in the all pass filter circuit. The capacitance (C) has tolerance of 10% which will result an additional error. Moreover, the measurements of the signals are done at the terminals (before any filtering) using an average responding digital voltmeter, so these measurements are not very accurate.

(b) <u>Wrong Phase Coupling Relay:</u>

Steady state testing of the WPC relay requires the same set-up as for the earth fault relay with phase angle variation between the two signals in range of (90°-180°) because WPC characteristic fully lies in second quadrant of R-X plane.

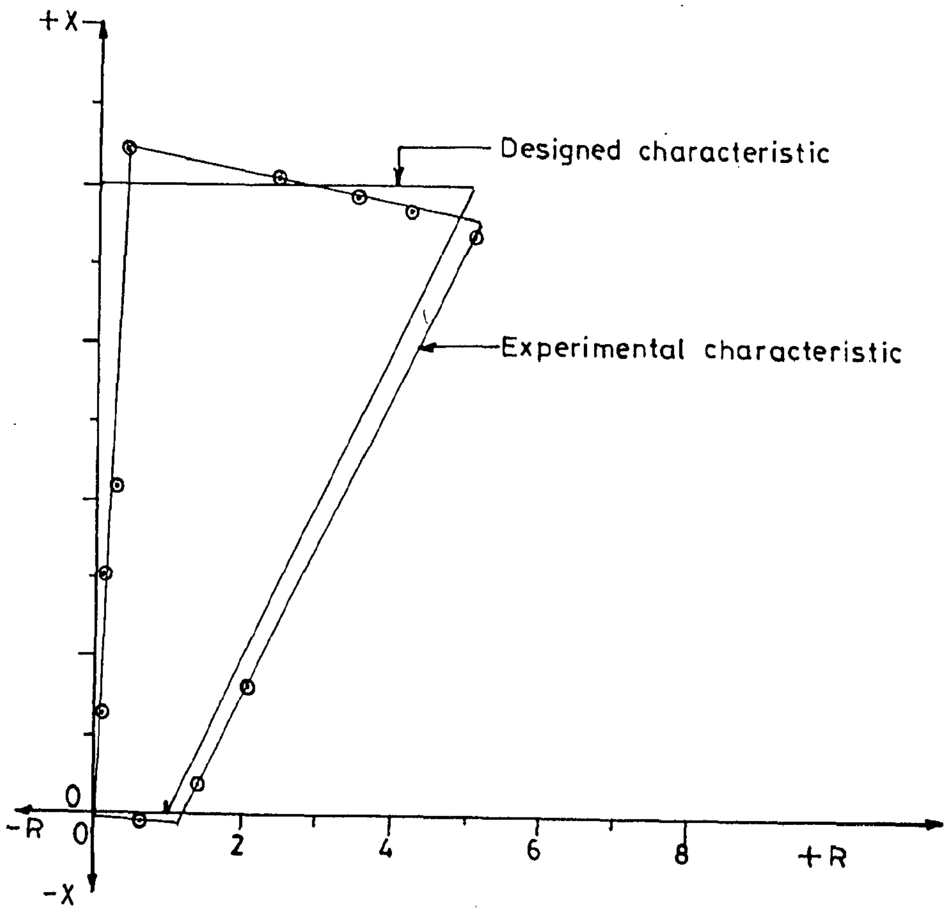

Fig.3.11 Earth fault relay characteristic

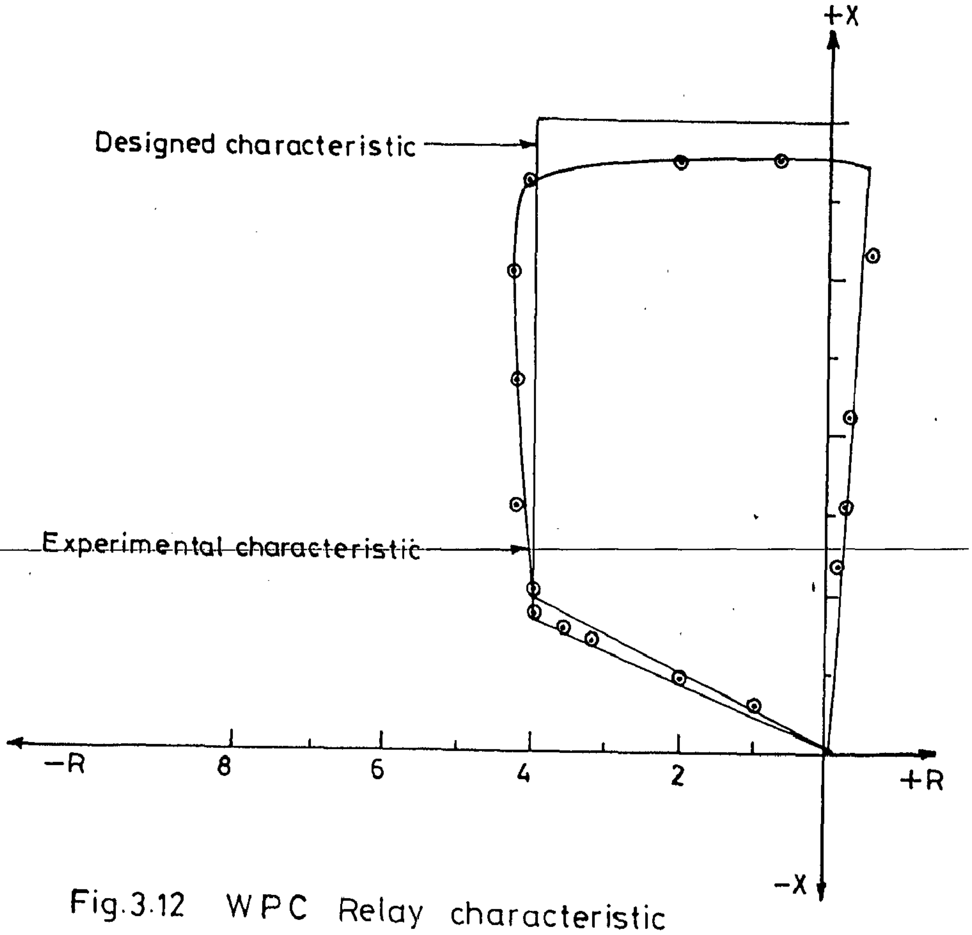

Fig.3.12 WPC Relay characteristic

Amplitude of the voltage signal is fixed and at different phase angles amplitude of the current signal is obtained for which the relay just operates. The characteristics obtained is given in Fig. 3.12. The experimental characteristic has a few differences with the designed characteristic which are listed below:

(i) The line D_2 makes 5° angle with the + X-axis.

(ii) The offset of reactance characteristic (X_1) is 7.5 ohm (designed value is 8 ohm).

(iii) The Ohm characteristic (R_1) has an offset of 4.2 ohm with the origin (design value 4 ohm).

As the testing circuit in this case is the same as used with the earth fault relay, so the factors producing errors in that case are also applicable here.

3.5.2 Dynamic Testing

The distance relays have been tested for their dynamic performance to estimate the transient overreach. For this, a decaying dc components (time constant = 100 ms) is superimposed with the sinusoidal current signal. There was found to be no effect of this d.c. component over the relay reach.

Computations of resistances and reactances by the microprocessor when no fault condition is suddenly change to fault condition have also been taken and plotted in Fig.3.13. This shows that calculations of resistance and reactance have oscillatory nature up to one cycle time period. These oscillations in the calculation fully justify the application of a fault counter in relay algorithms.

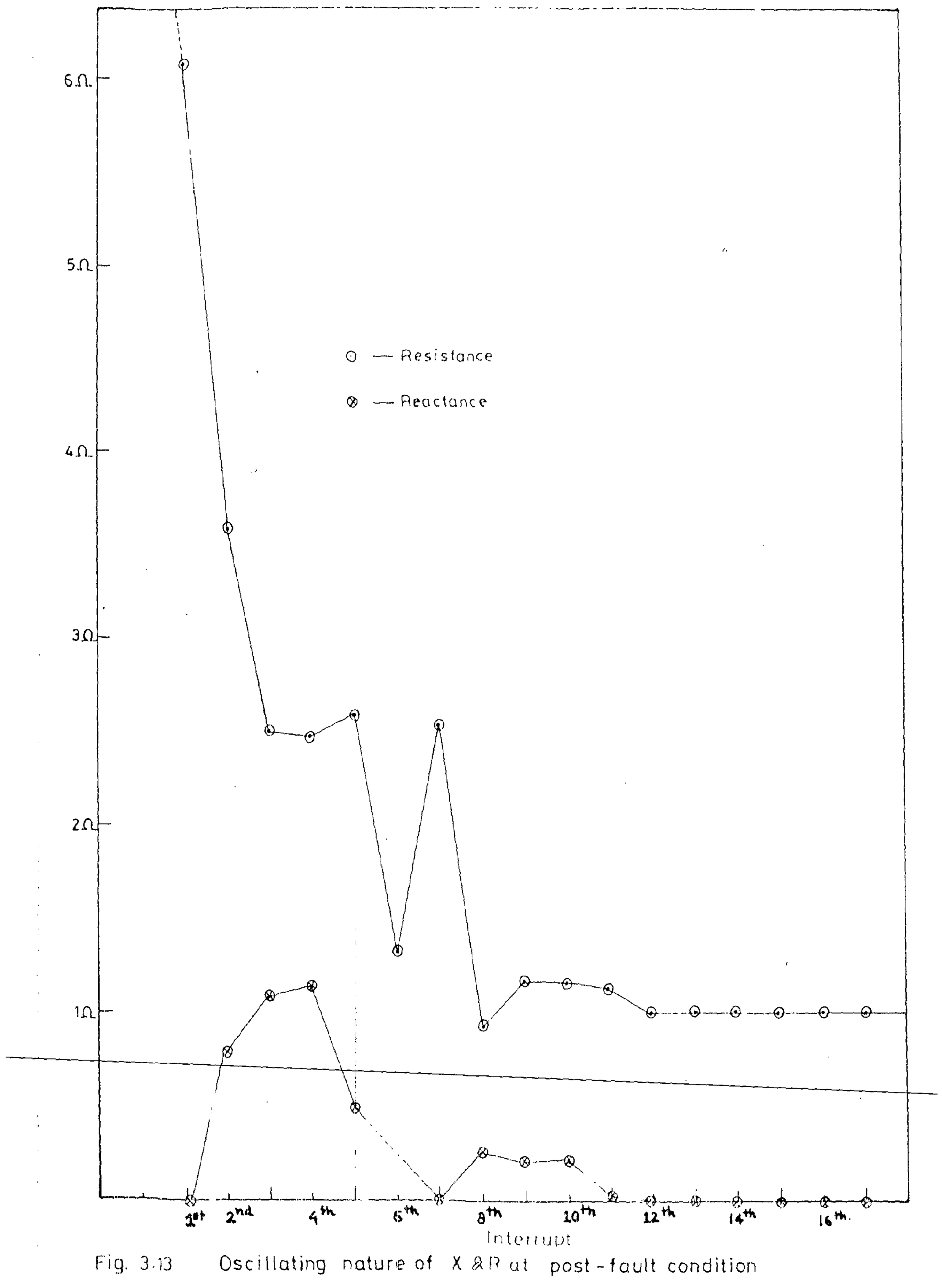

Fig. 3.13 Oscillating nature of X & R at post-fault condition

3.5.3 Instantaneous Overcurrent Relay Testing

Laboratory testing of instantaneous overcurrent relay requires a single simulated as current signal. Setting of the relay is kept at 1A. The time current-characteristic is plotted in Fig.3.14. The operating time of the relay decreases as the current increases. The minimum operating time was found to be 3 ms (at 5 times the setting) and the maximum time to be 8.35 ms (at 1.05 times the setting). At the current setting, the relay did not operate.

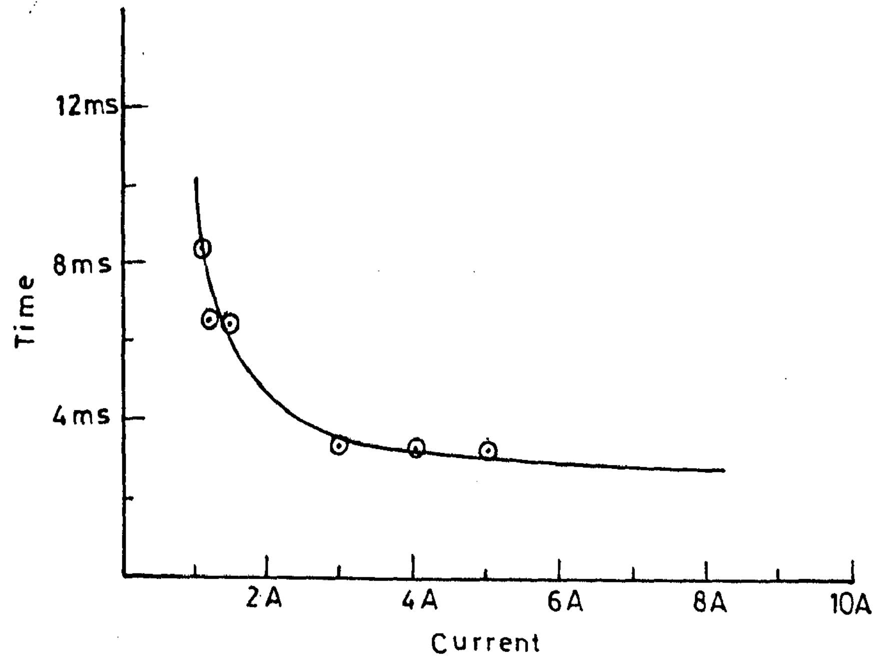

Fig.3.14 Time - Current characteristic of instantaneous o/c Relay

CHAPTER - IV

PROPOSED BACK-UP RELAYING SCHEME

In Chapter-II, it was reasoned that the IDMT overcurrent relay should be discarded in favour of a definite time lag overcurrent relay on the grounds of simplicity of realization and faster operation. The definite timelag overcurrent relay has been implemented on a system based around 8085A. The source of relaying signals for back-up should be different from the one used for sourcing the primary relay to avoid a simultaneous failure of the two relays. Therefore, a CT other than the one used in primary protective relaying has been employed in back-up protection.

4.1 PRINCIPLE

This relay operates when the average of current samples for a full cycle (12 samples) exceeds a preset value and this condition persists continuously for the period of a preset delay. Therefore, at every interrupt, the microprocessor calculates the average of the latest 12 samples. If it is found to be in excess of the preset value, a counter is started for giving the desired delay. During this time if the average value of latest 12 samples goes below the set value, the counter is reset. Otherwise a trip signal is generated at the end of the delay and the process is started again.

4.2 HARDWARE

The same circuitry as described in section 3.4.1 is used for implementation of the definite timelag overcurrent relay with a few minor differences described below:

(1) A voltage signal proportional to the line current is the only input signal for implementation of this relay, therefore, only one channel of the analog multiplexer is used.

(ii) Only one line of port A is used to indicate the type of fault.

4.3 SOFTWARE

The flowchart of the software is given in Fig. 4.1. It starts with initialization of PPI (8255), PTC(8253), PIC (8259) and software counter. A counter of the 8253 interrupts the microprocessor at every 1.67 ms (counter 0 of 8253 produces square wave of 1.67 ms and connected to IR_O of 8259 which is configured for edge triggered interrupts) and microprocessor samples the current signal through ADC. Sum of latest 12 samples is now compared with the preset value by the microprocessor and if sum is greater than the preset value a software counter starts decrementing. If this condition persists for more than 0.1 seconds (preset delay), then the fault indication and trip signals are made high, otherwise the counter is reset to it initial value.

4.4 LABORATORY TESTING

For testing the relay, its setting is kept at 1A. A

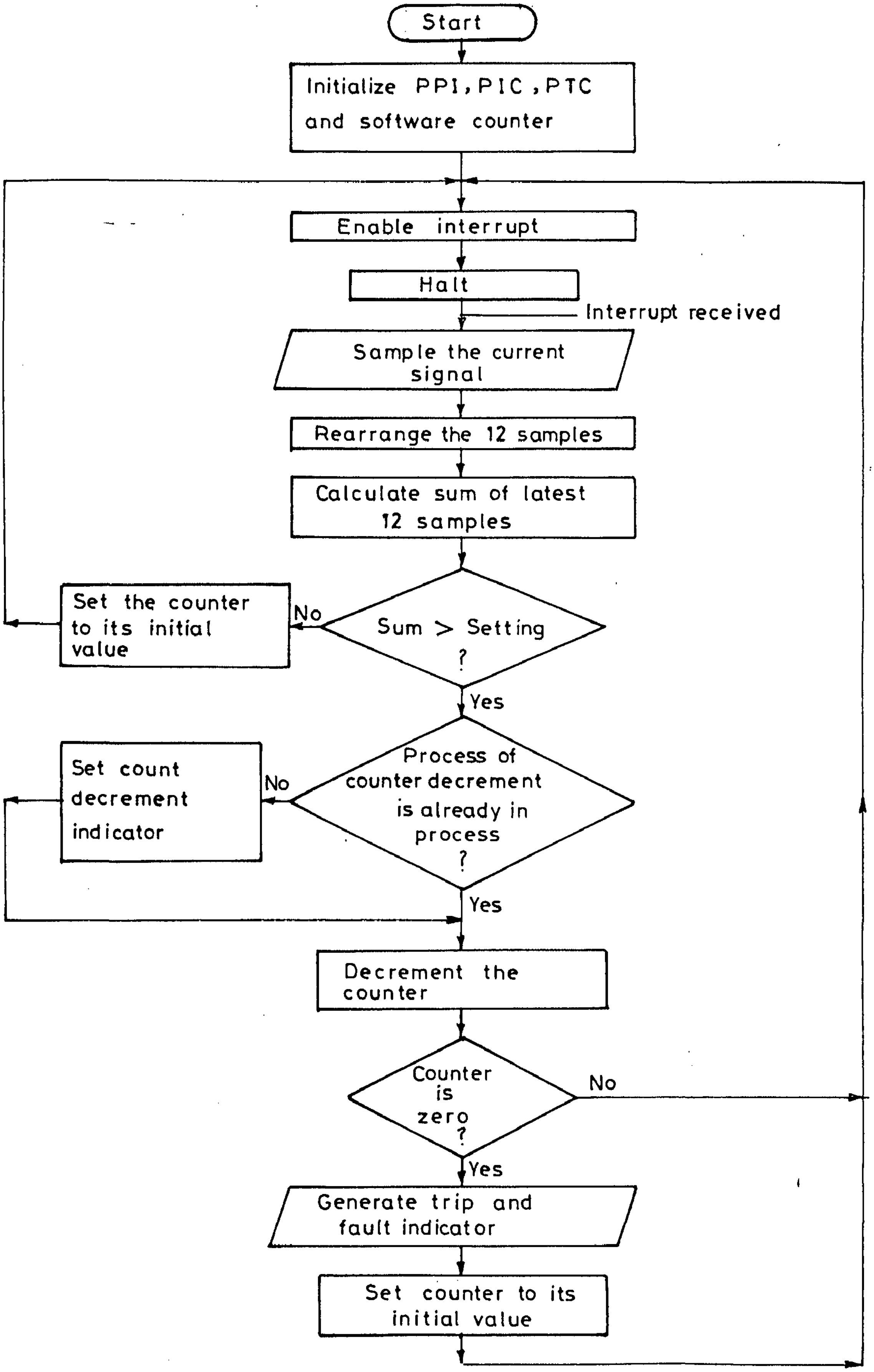

Fig.4.1 Flow chart for Back-up protective relaying

current signal of varying amplitudes is given to the ADC and the time delay provided by the relay is measured. Results are plotted in Fig.4.2. The time delay provided by this relay is found to be equal to the preset time. A small variation in the time can be noted from the experimental characteristic. The fault is sensed faster as the fault current is increased.

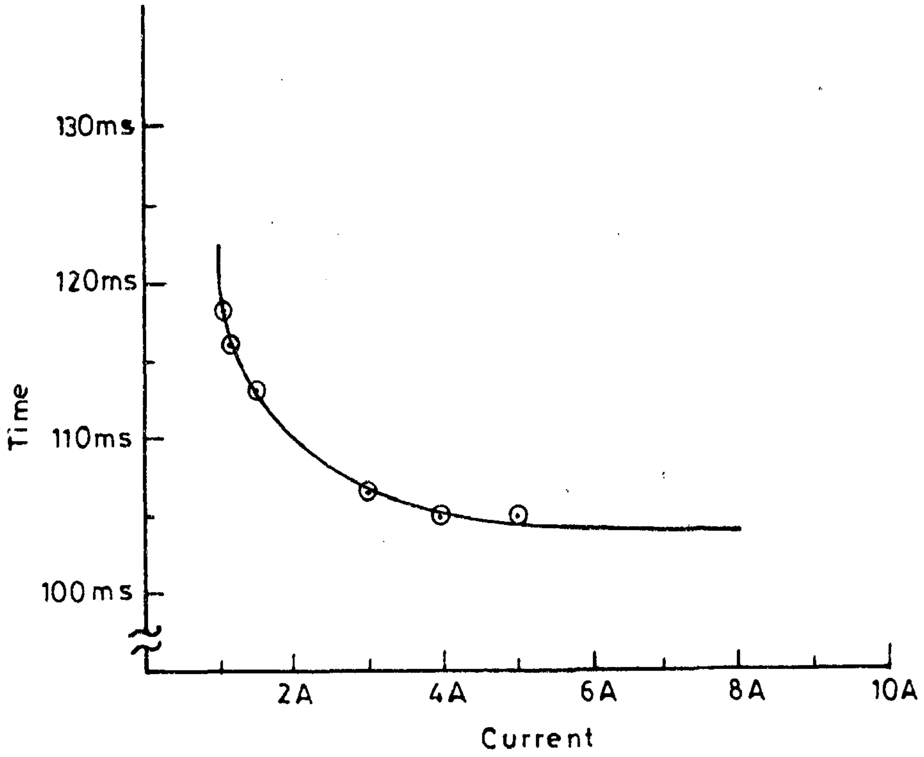

Fig.4.2 Time-Current characteristic of time lag o/c relay

CHAPTER-V

CONCLUSIONS AND FURTHER SCOPE

5.1 CONCLUSIONS

The following conclusions can be drawn on the work reported in last 4 chapters:

(1) The relay characteristics used in the conventional protection of 25 KV, 1-∅ traction overhead equipment need modifications. Firstly, the inadvertant trippings can be eliminated by using a quadrilateral characteristic matching the earth fault area in place of the present mho characteristics of the earth fault distance relay and discarding the non-offset mho relay for wrong-phase-coupling protection. Secondly, another distance relay with quadrilateral characteristic in the the second quadrant can replace the present offset mho characteristic. Thirdly, a definite time, instead of the present inverse definite minimum time, of the overcurrent relay can make the back-up protection considerably faster.

(2) Microprocessor based relays form a desirable substitute to the present electromechanical relays because of the relative ease with, which the new characteristics can be realized, faster operation, flexibility and other usual advantages of microprocessor-based systems.

(3) In the protection scheme two microprocessor are used. One microprocessor performs of all high speed relaying

functions while the other performance timelag overcurrent relaying. They do not share any electronic hardware or software and obtain signal from different CTs. This approach ensures that the failure of high speed relaying system due to failure of microprocessors, associated electronic hardware or the current transformer or any snag in its software does not simultaneously fail the back-up relaying.

(iv) For distance protection the resistance and reactance seen at the relaying location which serve as the fault discriminants, need to be computed from voltage and current signals at that location. If these signals are assumed to be pure sinusoids all the time, it will lead to highly inaccurate results, especially in post-fault condition. So two filters are incorporated in the scheme. One is active filter and eliminates the frequencies above 300 Hz. Second is digital filter and eliminates d.c. and frequencies other than fundamental.

A filter based on cross-correlation with haptagonal wave is selected as digital filter. This filter requires a few substractions, additions and binary shifts, in its realization. Therefore, it is easier to implement on microprocessor.

(v) The distance relays have been tested for their steady state characteristics. The characteristics are plotted and found to be tallying their respective designed characteristics except a few disparities which can justifiably, be attributed to measurement errors and error in phase angle calculations.

(vi) The distance relays have also been put to dynamic testing. The transient overreach is found to be negligible. In steady no fault condition suddenly a fault is created, the resistance and reactance calculated at each interrupt, is plotted which shows an oscillatory pattern upto one cycle time period in post-fault condition. This justifies the use of fault counter in relay algorithms.

(vii) The time-current characteristics of overcurrent relay have been plotted. It shows that the operating time of the relays decreases as fault current increases.

(viii) The quadrilateral distance relay developed for earth fault protection of the traction OHE has potential to be applied on power lines. Setting of X_o, R_o and inclination of ohm characteristics with +R axis can be changed to suit the system easily through software.

(ix) The definite timelag overcurrent relay, like quadrilateral earth-fault distance relay, can be used as back-up relay in power lines specially where IDMT relay is functioning as a back-up relay. Time relay provided by this relay can be changed by modifying the value of the software delay counter.

5.2 SUGGESTIONS FOR FURTHER WORK

(i) The relaying in the present work has been accomplished with 8085A microprocessor. A further improvement is possible by using a faster microprocessor like Intel 8086 or Motorola 6800. This will reduce considerably the data processing time. Therefore, it will lead to larger flexibility of modifying characteristics of all the relays, offset of reactance, ohm characteristics and characteristic line angles of the distance relays.

(ii) If a faster ADC is used in place of AD573 it will increase the cost of the system without any significant advantages in performance. But an ADC of higher resolution can replace it if a faster microprocessor is used with the advantage of an improved accuracy.

(iii) A faster microprocessor can also provide protective relaying to entire substation including protection to OHE, traction transformers and capacitor banks. Relaying of traction transformer includes differential relay, IDMT relay (for both HV and LV), restricted earth fault relays and high speed inter-tripping relay. Protective relaying of capacitor bank consists of a current comparison relay and a voltage relay.

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