AUTOMATED TEST EQUIPMENT
FOR
DYNAMIC TESTING OF PROTECTIVE RELAYS

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 declare that the work presented in this dissertation entitled **"AUTOMATED TEST EQUIPMENT FOR DYNAMIC TESTING OF PROTECTIVE RELAYS"** submitted in partial fulfilment of the requirement for the award of Degree of **MASTER OF ENGINEERING** with specialization in **MEASUREMENT AND INSTRUMENTATION**, in the Department of Electrical Engg., University of Roorkee, Roorkee is an authentic record of my own work carried out from October 1998 to March 1999 under the guidance of **Dr. H. K. Verma**, Professor and **Dr. R. P. Maheshwari**, Asstt. Professor, Electrical Engg. Deptt., University of Roorkee, Roorkee.

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

Date : 31st March, 1999

Place : Roorkee

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CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of our knowledge and belief.

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ABSTRACT

This dissertation work presents the design and development of a personal computer (IBM PC/ AT compatible) based scheme for testing protective relays. Precise and comprehensive testing of relay is essential to make sure that the protective gear always operates reliably on faults. Due to standardization of PCs, their low cost and the availability of software and hardware support, a PC based relay test scheme enables comprehensive testing of relays, quite accurately and in short time. The test procedure simulates realistic relaying signals corresponding to dynamic state operating conditions.

A PC based data acquisition card has been used to test static relay circuits. Single phase as well as 3-phase relay testing scheme has been developed. Distance relay testing is chosen as typical example for implementing this scheme. Complete software is written using C language and for making characteristic plots, Graphics has been used. On-line parameter display and on-line plotting are the key features of this scheme.

CONTENTS

INTRODUCTION

This dissertation work realizes an automated test equipment for protective relay testing. Power system includes large impressive units like generating stations, transformers, high voltage lines etc. Protective relays are very basic and important feature of any power system, and are essential for protection of power system in case of fault conditions, so their testing needs great attention.

1.1 SIGNIFICANCE OF RELAY TESTING

An electric power system should ensure the availability of electrical energy without interruption to every load connected to the system. The high voltage transmission lines carrying bulk power could extend over several hundred kilometers. Since all these lines are generally overhead lines and exposed, there are many chances of their breakdown due to storm, falling of trees, these may result in short circuit which produces a sudden and sometimes violent changes in system operation. Protective relays and relaying systems detect abnormal conditions like faults in electrical circuits and operate automatic switch gear to isolate faulty equipment from the system as quickly as possible. This limits the damage at the fault location and prevents the effects of the fault spreading into the system [1].

Protective relays are intended to protect expensive electrical equipment with proper care they will perform this duty, but when neglected they may become inoperative and could become a hazard in themselves. Since the reliability is the most important quality of protective relays it follows their maintenance be first class [2].

To make sure that protective relay operates appropriately and accurately at times when it is needed. Proper testing of protective relays is very much necessary.

1.2 CLASSIFICATION OF RELAY TESTING

Tests are carried out to show that :

(i) the relay operates correctly to clear a fault,

(ii) the relay will remain inoperative on faults outside its specified zones.

Tests can be grouped into following four classes [3] :

(i) Manufacturer's tests,

(ii) Acceptance tests,

(iii) Commissioning tests,

(iv) Maintenance tests.

1.2.1 MANUFACTURER'S TESTS

A newly designed relay is subjected to a series of through tests by the manufacturer before it is manufactured on large scale. Almost every possible aspect about relays is determined in these tests. Such tests are carried out on few relays of each type. After the complete exhaustive type tests the manufacturer decides whether to go ahead with manufacture of the relay or some modifications are necessary in the design.

1.2.2 ACCEPTANCE TESTS

Acceptance tests are generally performed in the laboratory. Acceptance tests fall in two categories :

(i) On new relays which are to be used for first time. On such products intensive testing is desired to prove its characteristics and to gain information about it.

(ii) On relay types which have been used earlier, only minimum checks should be made. Acceptance tests are performed in presence of the customer or by the customer.

1.2.3 COMMISSIONING TESTS

While testing the protective system at site the protection system for each zone should be tested separately to begin with and then the protective system for the neighbouring protective system should be coordinated as per the plan for entire plant.

The objective of site testing are to ensure that :

- connections are correct
- settings are correct
- individual protection system is functioning satisfactorily
- the co-ordination between various protection systems is as per broad plan given by designers.

1.2.4 MAINTENANCE TESTS

Periodic maintenance after the installation and commissioning of protective gear is of utmost importance. Although the relay may be in sound condition when first put into service, many troubles can develop due to infrequent operation, moisture and dust etc. It is therefore essential to test and inspect relays at suitably chosen intervals.

1.3 IMPORTANCE OF AUTOMATED RELAY TESTING

Relay operates in fault conditions under which system dynamics gets changed. This introduces transients in voltage and/or current signal which may make relay performance quite different than what is expected. So, for testing relays abnormal conditions have to be simulated first, and then tests can be carried out on relays. This imposes great difficulties on testing of relays.

The conventional testing approach involves massive test benches and artificial transmission lines, which can simulate steady state and dynamic conditions under which relay has to operate.

Conventional test procedures have many limitations. Some of these limitations are [6]:

(i) It will be highly expensive if realistic relaying signals representing the transient behaviour of the power system have to be simulated.

(ii) Lack of flexibility and limited range in which it can model the power system.

(iii) Test procedure is time consuming.

Apart from these jobs of setting test parameters, taking readings, observations and making plots and graphs are done by manual operator which may introduce some errors.

So in this dissertation work, a computer based automated scheme has been developed for dynamic testing of relays. This scheme being a software approach is very flexible and fast. Test signals are simulated by computer, sent to relay. Relay status is checked by computer. Results are shown on CRT screen and kept in computer storage. This whole procedure consumes very less time and is very flexible.

1.4 REVIEW OF EARLIER WORK

Some important works in this field are as follows :

A paper by G.W. Swift, et al. [4] discusses an automated approach for testing distance relays. A mini computer based approach was developed for both steady state and dynamic conditions. Programs for steady state were written in assembly language, for dynamic state programs were written in BASIC language.

Another paper by R.K. Aggarwal et al. [5] discusses about a PC based system for relays. They have used Programmable Transmission Line (PTL), for testing protective relays. Electro Magnetic Transient Programs (EMTP) have been used for generating test signals for protective relays.

Another paper by U.S. Shenoy et al. [6] discusses about a microprocessor based approach for testing over current relays.

Another paper by M. Kezunovic and Galijasevic [7]. They introduced a WIN95/NT software for automated transient testing of protective relays.

1.5 ORGANIZATION OF THE DISSERTATION

Chapter 1, introduces different types of tests which are done on relays and sets forth the motive behind the present work, namely, to make an automated test equipment for the testing of protective relays.

Chapter 2 highlights the basic approach to dissertation work and presents the hardware requirements for the test equipment.

Chapter 3 describes about the user interface and prepares some preliminary background for testing sequences, i.e., it introduces few algorithms in the form of subroutine which are common almost to every testing sequence.

Chapter 4 starts with highlighting importance of distance scheme and ends with computer solutions and results of different characteristics of single phase distance relay.

Chapter 5 presents algorithm developed for testing 3-phase distance relay.

Chapter 6 presents conclusions and the future directions in which this work can be advanced, improved or modified.

HARDWARE OF A.T.E. FOR RELAY TESTING

This chapter introduces the basic concepts for testing static relays and the hardware components required for the purpose. This A.T.E. (Automated Test Equipment) is capable to simulate the operating conditions under which protective relays are intended to work.

From understanding point of view, static relays may be considered as analog to binary converters. For relay testing, analog signal of varying amplitude is applied to the relay input and the relay status is continuously monitored. Relay output is TTL compatible, i.e., it is either high (+5 volts) or low (below 0.8 volts) depending on whether relay has tripped or not.

For electronic relays the system needs only provide information, i.e., signals and this leads to a different approach in testing namely use of computer generated low power level signals. Hardware requirements of this automated test equipment for static relays is as follows :

- Personal computer
- Timer
- Digital to Analog Converters
- Filters

Complete schematic is shown in Fig. 2.1.

2.1 PERSONAL COMPUTER

First and foremost requirement of this A.T.E. is a personal computer. Steady state testing requires appropriate sinusoidal testing signal to be applied to the relay input. In dynamic testing sinusoidal signal with certain degree of offset is required.

So for generating low power test signal, a 486 processor based PC was used. This PC is equipped with V.G.A. card facility and coloured monitor for display of various characteristics and test signals. Mass storage capacity of this personal computer is used to keep results/data pertaining to different test sequences on relays.

2.2 TIMER

Test signals are generated by personal computer. These signals are generated in the form of discrete sample values by PC. For creation of analog signal these discrete sample values are transferred through digital to analog converters at proper time interval. Throughout this dissertation, time interval of one millisecond is used. So between any two consecutive samples transfer a time delay of 1 millisecond is kept.

For obtaining time delay either software approach or hardware approach can be used. But software approach suffers on account of following disadvantages :

(i) Any addition or deletion of instructions may produce different time delay.

(ii) Time delay will be processor clock dependent.

So for obtaining consistent and precise time delay irrespective of programming instructions and PCs, hardware approach for obtaining time delay is preferred. A timer card from **Vinytics VPC-2T2I0** was used, which uses 8253 timer chips.

2.3 DIGITAL TO ANALOG CONVERTERS

For relay testing analog test signals are required at the input terminals of the relay. The computer generated digital signal has to be converted into analog form by a digital to analog converter. So for conversion into analog form a high performance high speed digital to analog conversion card **PCL-726** from **Dynalog** was used.

This PCL-726 card has multichannel (6 channels) 12 bit monolithic D/A converters. For single phase distance relay only two channels, one for voltage signal and another for current signal, have been used. For 3-phase distance relays all 6 channels have been used. 3 channels for 3-phase voltages and remaining 3 for 3 phase currents were used. The reference level and mode of operation (either unipolar or bipolar) for this card can be selected by proper setting of jumpers [8]. For present work, internal reference voltage of -5 Volts, and bipolar mode of operation was used.

Analog output signal obtained from a DAC channel is as shown in Fig. 2.2. The DAC output is not pure sinusoidal. It has high frequency components in it. Application of this signal on relay will not give true operation due to presence of higher harmonics. If sinusoidal is generated using A samples per cycle, harmonics occur at frequencies of

$(AB \pm 1)$ 50 Hz

where $B = 1, 2, ...$

with corresponding amplitudes.

$1 / (AB \pm 1)$ [4]

2.4 FILTERS

As mentioned in previous section DAC output contains significant high frequency components, to filter out these high frequency components from the signal low pass filter with appropriate cut-off frequency are employed.

If 20 samples per cycle, i.e. 1000 samples/sec. are to be transferred, then the harmonics can be filtered out using low pass filter with cut-off frequency 220 Hz. Fourth order Butterworth low-pass filters have been used to filter out the harmonics [9]. Two stages of second order Butterworth low-pass filters are cascaded to obtain one fourth order low pass filter for each channel. This low-pass filter is shown in Fig. 2.3.

The cut off frequency of the filter is decided by the R & C components and is given by

$$\omega_c = 1/RC$$

where

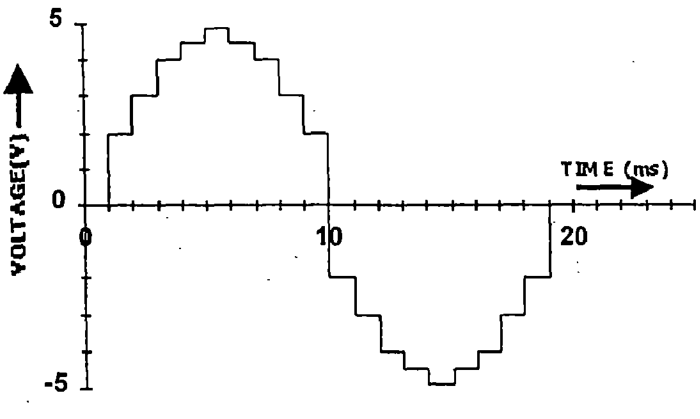


Fig. 2.2 : Output waveform of D/A Converter

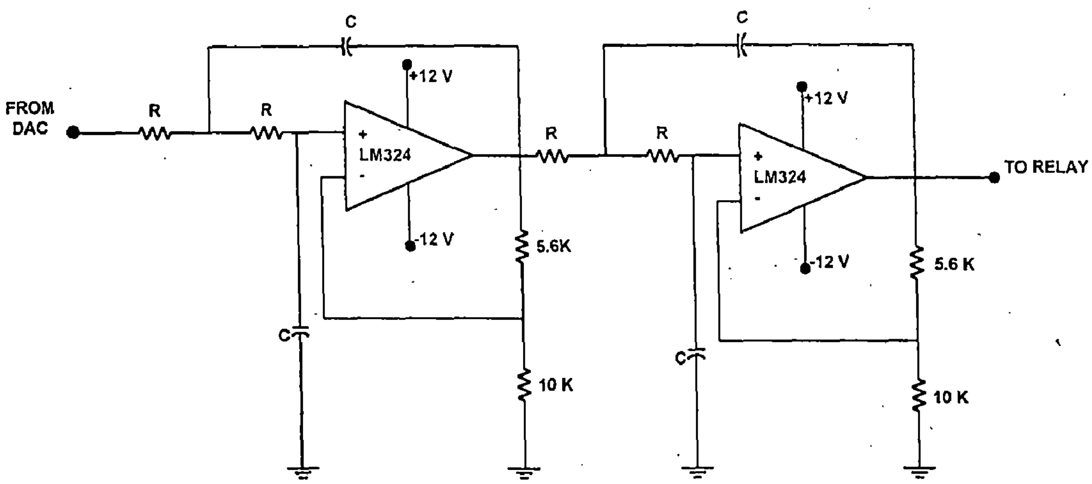


Fig. 2.3 : Filter Circuit

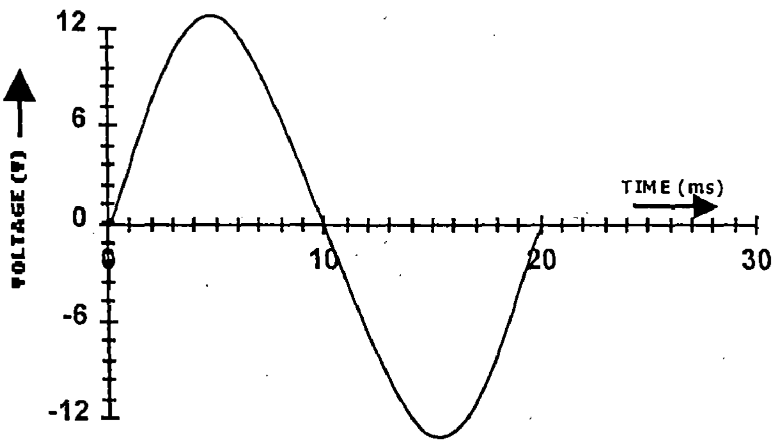


Fig. 2.4 : Signal After Filtereing

G.U.I. AND TEST SIGNAL GENERATION

A.T.E. for protective Relay Testing includes both hardware and software contributions. Hardware schematic has already been discussed in the previous chapter. The software portion includes subroutines for waveform generation, testing procedures, characteristic plots. These subroutines are written in 'C' language for plots/displays different utilities of graphics have been used.

3.1 GRAPHICAL USER INTERFACE (G.U.I.)

This dissertation work is aimed to develop a computerised test system for protective relays. To make this test system more user friendly and interactive a graphical user interface has been provided for the system. With this objective, all the testing programs have been put into one main menu program. This user interface makes selection of particular options for relay/testing condition/testing approach/characteristics easily approachable.

This user interface is built around various inbuilt library functions available in graphics. A tree structure showing different options is in Fig. 3.1. To make this interface operational, certain special keys are put into use.

Up Arrow key	: is for upward movement in the menu option list.
Down Arrow key	: is for downward movement in the menu option list.
Enter key	: For selecting a particular option.
Esc key	: For moving back among different option lists.

A screen display showing different facilities is in Fig. 3.2.

3.2 TEST SIGNAL GENERATION

First step in testing, is the proper generation of test signal. Testing of relays will be accurate, only if test signals are accurate. Therefore, test signal generation holds primary importance in the relay testing.

Since PCL 726 card is having 12 bit D/A converters, to generate sinusoidal output from D/A such as

$$V(t) = V_{peak} \, Sin\omega t \tag{3.1}$$

where

$V(t)$ = Instantaneous value of test signal

V_{peak} = Peak value of test signal.

ω = Frequency of test signal in radian/sec.

The expression needed to be entered for D/A converter is

$$V(t) = 2047\left(1 + \frac{V_{peak}}{V_{ref}} \sin\omega t\right)$$

where

V_{ref} is reference voltage chosen for D/A conversion and,

V_{peak} should be less than V_{ref}.

3.2.1 Software for Computation of Sample values for Steady-State

In steady state condition only sinusoidal waveform is needed. For waveform generation sample values have been calculated first. Samples have been computed with angle/step size of 18° for current channel output. Samples for voltage channel output have been calculated with angle/step size of 1°.

The eqn. (3.1) is used for sample value computations under steady-state conditions.

Flowchart for sample value computation is shown in Fig. 3.3 and algorithm written below :

(i) First of all, peak value V_{peak} for the sine function, eqn. (3.1) is chosen. Angle is initialized to zero.

(ii) Angle in degrees converted into radians and placed in eqn. (3.1).

(iii) Compute the function value and increment angle.

(iv) Store the sample value in a data file. Check the condition for angle, if it is less than or equal to 360° repeat the procedure from Step-II else stop the program.

3.2.2 Mathematical Model for Dynamic Conditions

Steady state testing of protective relays require the signals which are pure sinusoidal in nature. But the actual conditions [Fault conditions] under which relay has to work are quite different than the steady state conditions. In actual condition system parameter [i.e., voltage, current, phase] differ quite considerably, what we have assumed in the steady state condition. Dynamic testing is the performance evaluation of relay under actual (fault) conditions.

In fact when a fault occurs both the voltage and current suddenly change in amplitude and/or angle and, because of the reactive components of the system impedances, the current and voltage go through some transient values before settling down to the values corresponding to the fault condition of the system [4].

So to generate transient voltage and transient current signals a mathematical model of transmission line is chosen which is shown in Fig. 3.4.

Some assumptions made are as follows :

(i) Capacitance to ground is neglected, thus the relay sensitivity to higher order harmonics is not determined.

(ii) A no load condition exists prior to the fault (t < 0).

Nomenclature and Circuit Solution

Refer to Fig. 3.4. Before the fault (t < 0)

$$V_s(t) = V_{peak}\,\mathrm{Sin}(\omega t + \theta) = V(t) \quad (3.2)$$

and $i(t) = 0$ (3.3)

where,

$V_s(t)$ = Source voltage, Volts

V_{peak} = Peak value of source voltage, Volts

ω = System frequency, rad/sec.

$v(t)$ = Voltage at relay terminals.

$i(t)$ = Relay current.

θ = Angle of v at which the fault occurs.

The impedances shown are

$Z_s \angle\alpha = R_s + j\omega L_s$ = Source impedance, ohm

$Z_l \angle\beta = R_l + j\omega L_l$ = Line impedance, ohms

Total impedance

$Z = R + jX$

$$= (R_s + R_l) + j\omega(L_s + L_l) = |Z|\angle\phi^0 \quad (3.4)$$

The solution of the circuit, then for t > 0 is

$$i(t) = \frac{V_{peak}}{|Z|}\left[-e^{-(R/L)t}\,\mathrm{Sin}(\theta-\phi)+\mathrm{Sin}(\omega t+\theta-\phi)\right] \quad (3.5)$$

and $V(t) = V_{peak}\,\mathrm{Sin}(\omega t + \theta) - R_s i - \frac{L_s V_{peak}}{|Z|}$

$$\left[R/Le^{-(R/L)t}\mathrm{Sin}(\theta-\phi)+\omega\mathrm{Cos}(\omega t+\theta-\phi)\right] \quad (3.6)$$

In eqn. (3.5), the right hand term represents the steady state fault condition and the left hand term the transient component which exists only during the transition from normal to fault condition.

Inspection of the left hand term in current expression will show that it is a d.c. offset which decays exponentially. Its size depends upon moment the fault strikes and the duration increases with the X/R ratio of the system.

The maximum amplitude of the offset component in current expression is $\frac{V_{peak}}{|Z|}$ which is the same as the peak value of the steady state current. This occurs when $\mathrm{Sin}(\theta - \phi) = 1$, i.e., when $\theta - \phi = 90$.

Voltage expression (eqn. 3.6) also has steady state as well as transient components. There will be no voltage transient if the system impedance Z is of uniform phase angle (homogeneous) and also if $\theta = \phi$, removing the current transients [2].

These above mentioned facts about the current and voltage wave transients are shown in Figs. 3.6(a)-(c) as a part of A.T.E. displays.

(a) Software for Computation of sample values for single phase relays

For single phase relays, voltage and current samples are obtained using eqn. 3.5 and eqn. 3.6. For every cycle 20 samples for each voltage and current signals are computed. Algorithm is as follows and flow chart is shown in Fig. 3.5 and algorithm given below :

(i) Various parameters such as V_{peak}, source impedance Z_s, , source angle α, Line impedance Z_l, line angle β, number of samples, and display status are passed from main function.

(ii) No. of samples is initialized to zero. According to eqn. 3.5 and eqn. 3.6 current and voltage samples are computed for required number of samples.

(iii) Depending on display status disp_stat, current and voltage waveform are displayed on screen or not.

(b) Software for Computation of sample values for 3-phase relays

Prefault voltage and current for 3-phase system can be taken as :

For R-phase

$$V_R(t) = V_{peak} \sin(\omega t + \theta) \quad (3.7)$$

$$i_R(t) = 0 \tag{3.8}$$

For Y-phase

$$V_Y(t) = V_{peak} \, Sin(\omega t + \theta - 120) \tag{3.9}$$

$$i_Y(t) = 0 \tag{3.10}$$

and for B-phase

$$V_B(t) = V_{peak} \, Sin(\omega t + \theta - 240) \tag{3.11}$$

$$i_B(t) = 0 \tag{3.12}$$

On the basis of analysis given earlier, voltage and current signals for t > 0 are :

For R-phase

$$i_R(t) = \frac{V_{peak}}{|Z|}\left[-e^{-(R/L)t} Sin(\theta - \phi) + Sin(\omega t + \theta - \phi)\right] \tag{3.13}$$

$$v_R(t) = V_{peak} Sin(\omega t + \theta) - R_s i_R - L_s \frac{V_{peak}}{|Z|}\left[R/Le^{-(R/L)t} Sin(\theta - \phi) + \omega Cos(\omega t + \theta - \phi)\right] \tag{3.14}$$

For Y-phase

$$i_Y(t) = \frac{V_{peak}}{|Z|}\left[-e^{-(R/L)t} Sin(\theta - \phi - 120) + Sin(\omega t + \theta - \phi - 120)\right] \tag{3.15}$$

$$v_Y(t) = V_{peak} Sin(\omega t + \theta - 120) - R_s i_Y - L_s \frac{V_{peak}}{|Z|}\left[R/Le^{-(R/L)t} Sin(\theta - \phi - 120) + \omega Cos(\omega t + \theta - \phi - 120)\right] \tag{3.16}$$

For B-phase

$$i_B(t) = \frac{V_{peak}}{|Z|}\left[-e^{-(R/L)t} Sin(\theta - \phi - 240) + Sin(\omega t + \theta - \phi - 240)\right] \tag{3.17}$$

$$v_B(t) = V_{peak} Sin(\omega t + \theta - 240) - R_s i_B - L_s \frac{V_{peak}}{|Z|}\left[R/Le^{-(R/L)t} Sin(\theta - \phi - 240) + \omega Cos(\omega t + \theta - \phi - 240)\right] \tag{3.18}$$

Flowchart for 3-phase sample computation is shown in Fig. 3.7 and algorithm discussed below :

(i) First of all, parameters like peak voltage value V_{peak}, Z_s, α, Z_l, β, θ, disp_stat, three trip status trip_stat R, trip_stat Y, trip_stat B for R, Y and B phase are passed to this function.

(ii) From the given parameters, R_s, L_s, R_l, L_l are calculated and from eqn 3.4, $|Z|$ and ϕ are calculated.

(iii) Trip status for R phase trip_stat R is checked if it is zero, phase R current and voltage sample values are calculated using eqn. 3.13 and 3.14 for required number of samples.

(iv) Successively step (iii) is repeated for phase Y and phase B depending on their trip status and with the help of eqn. 3.15 and eqn. 3.16. For phase Y, and with eqn. 3.17 and 3.18 for phase B.

(v) In the end depending on display status current and voltage waveforms are displayed on screen or not.

These 3-ϕ signals are displayed in Fig. 3.8.

3.2.3 Software for Time Delay

As mentioned earlier, test signal is obtained by transferring sample values through respective DAC channels at an interval of 1 milli second. This one milli-second time interval is obtained by hardware (i.e., timer card).

First of all, timer is initialized to give square-wave o/p of 1 kHz frequency so as to have individual pulse of one milli-second duration. This initialization of timer is done in main program. Now to obtain one milli-second time interval following procedure is followed and shown in Fig. 3.9.

(i) First, timer o/p status is read at specified port.

(ii) Step (i) is repeated untill one transition from high to low is obtained.

3.2.4 Software for Transfer of Samples Through D/A Converters

Sample values are transferred through different DAC channels. For single-phase relay, only two channels Ch#0 and Ch#1 have been used while for 3-ϕ relay, all 6 channel from Ch#0 to Ch#5 have been used. Two separate subroutines for sample transfer have been made.

(a) Transfer of samples through D/A converters for single-phase relay

Fig. 3.10 is used for single phase samples transfer and algorithm is discussed below :

(i) Both current and voltage samples are received from main program.

(ii) Mask higher bytes of voltage and current sample.

(iii) Again take original current and voltage sample values.

(iv) Mask lower bytes of voltage and current samples.

(v) Transfer current higher byte to channel # 1.

(vi) Transfer voltage higher byte to channel # 0.

(vii) Increment channel address of both Ch#0 and Ch#1 by 1.

(viii) Send lower current and voltage bytes to respective channels.

(b) Transfer of samples through D/A converters for three-phase relay

Flowchart shown in Fig. 3.11 is used for 3-ϕ relays and algorithm is discussed below:

(i) First of all, 6 quantities, 3 voltages V_R, V_Y, V_B and three currents i_R, i_Y, i_B are received from main program

(ii) Mask higher bytes of all six signals and store them.

(iii) Again take all 6 original quantities.

(iv) Now mask lower bytes of all six quantities.

(v) Transfer higher bytes of all six signals to the respective channels, sequentially.

(vi) Increment all six channel address by 1.

(vii) Transfer lower bytes of all six signals to the respective channels, sequentially.

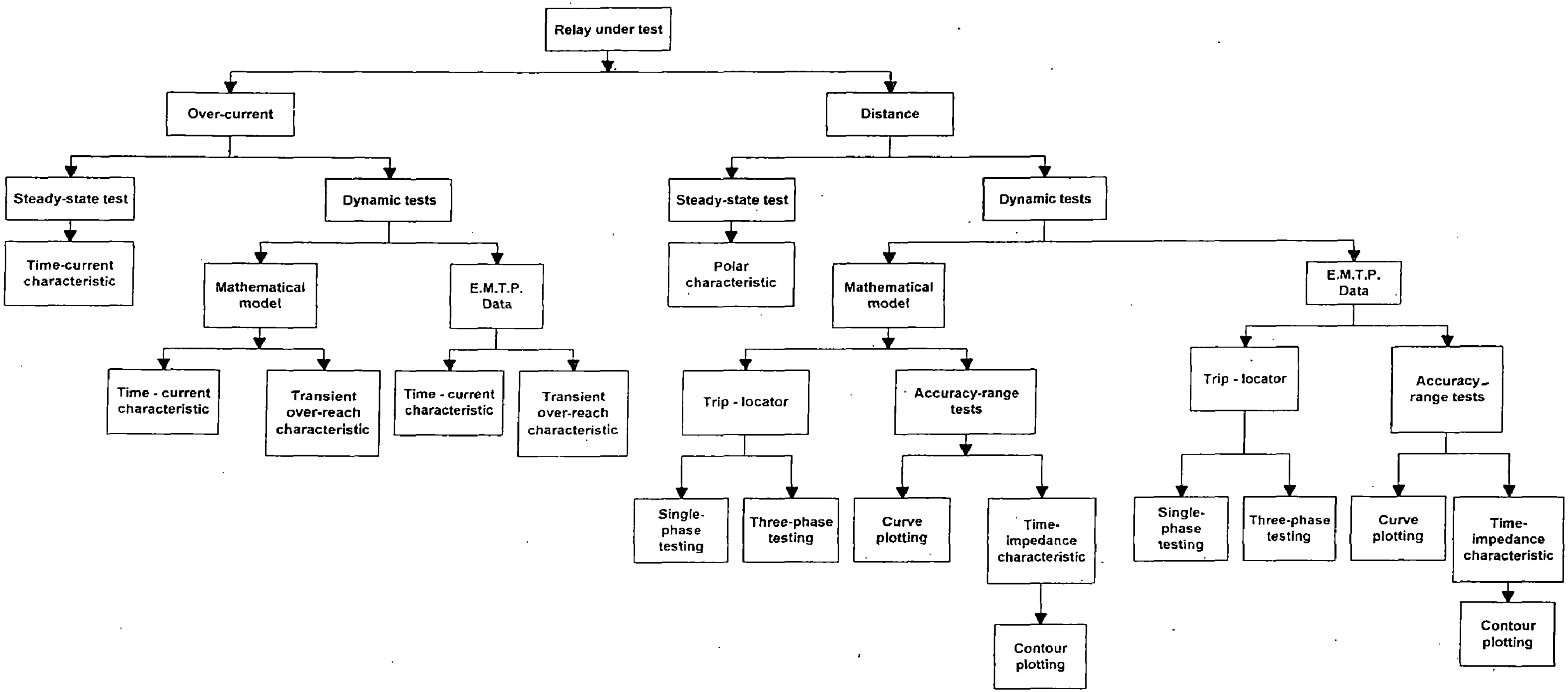


Fig. 3.1 : Tree Structure of User Interface

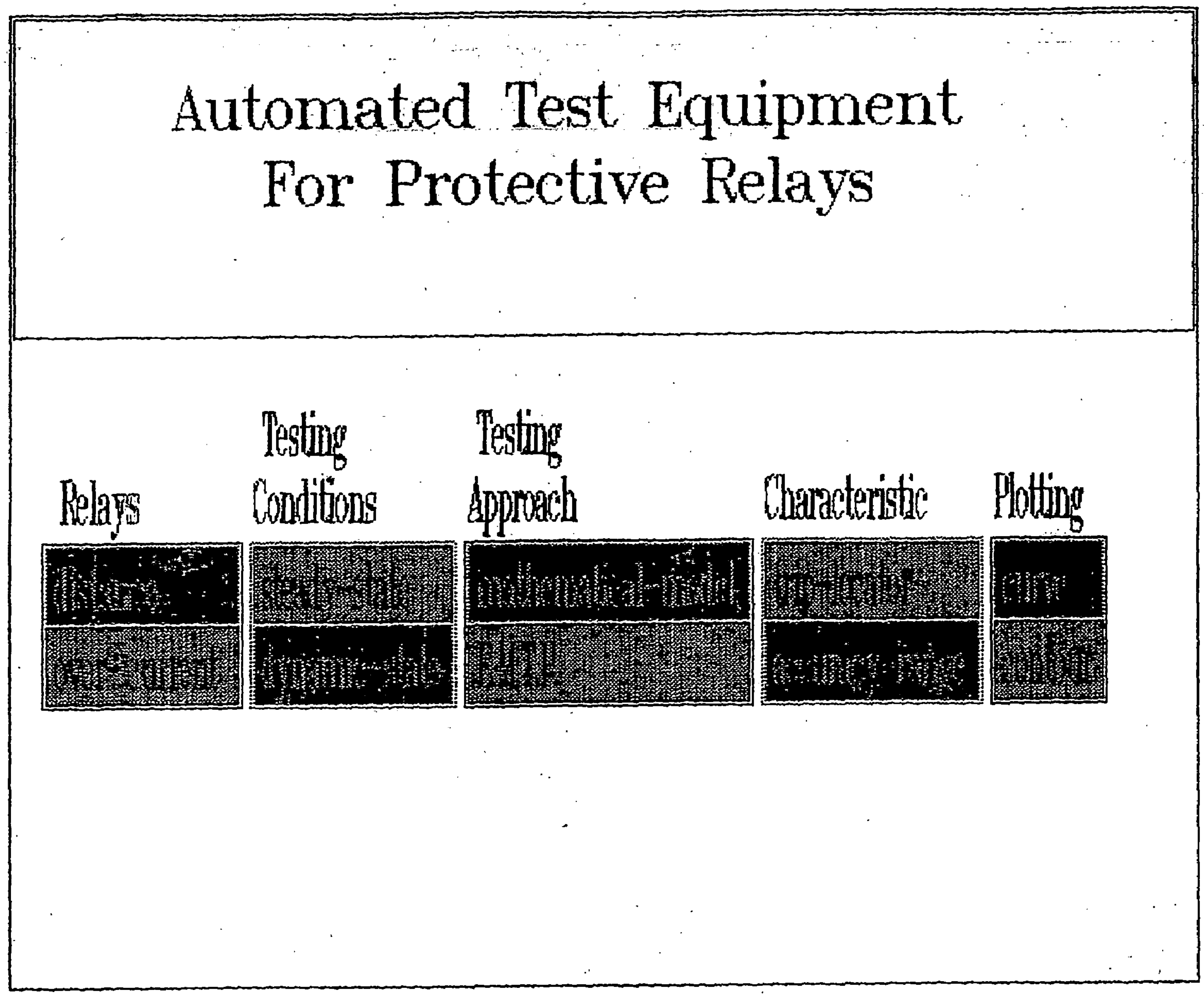


Fig. 3.2 : Screen Display of User Interface

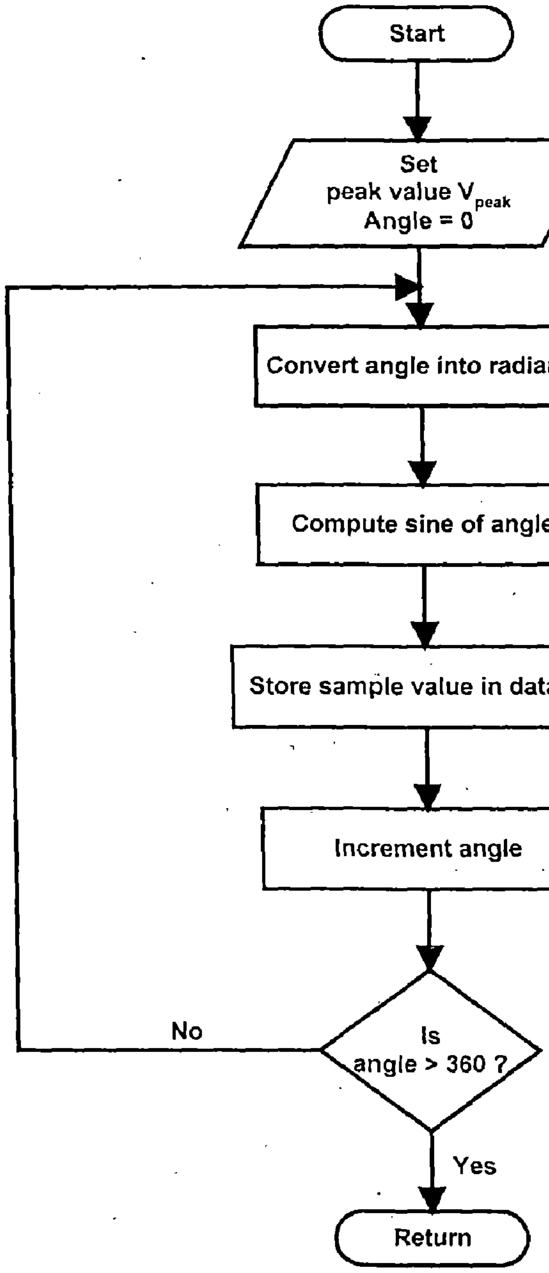


Fig. 3.3 : Flowchart for Sample Value Computation under Steady-State

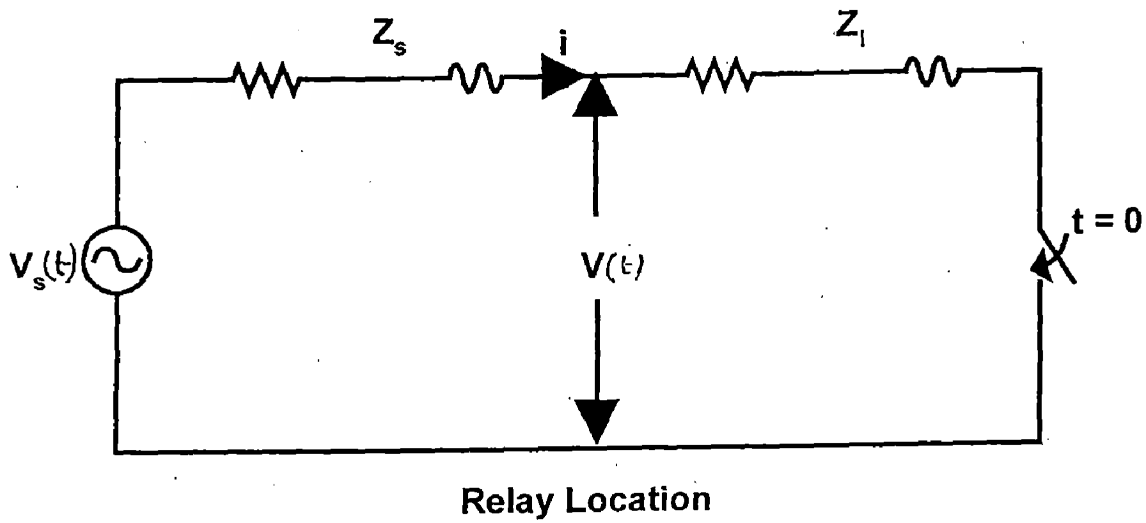


Fig. 3.4 : System Diagram for Dynamic Test

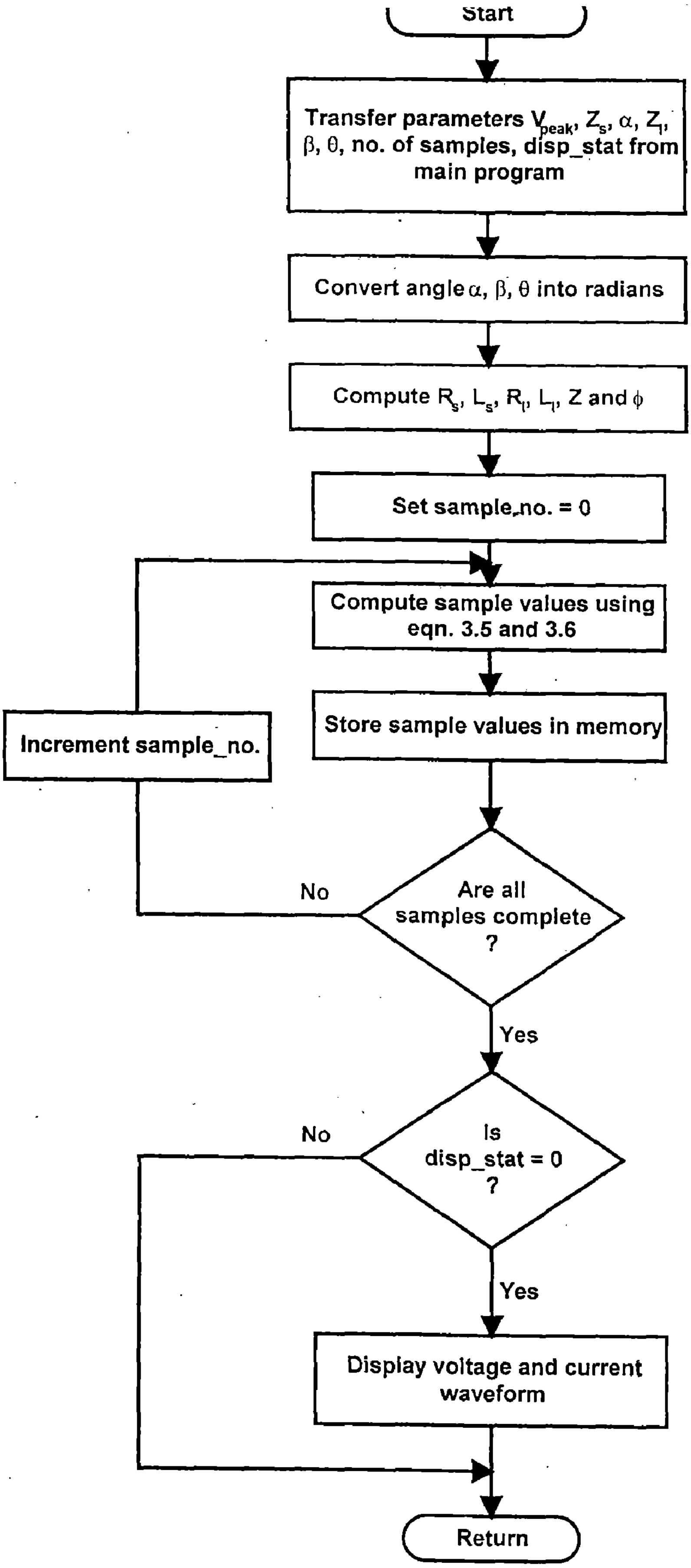
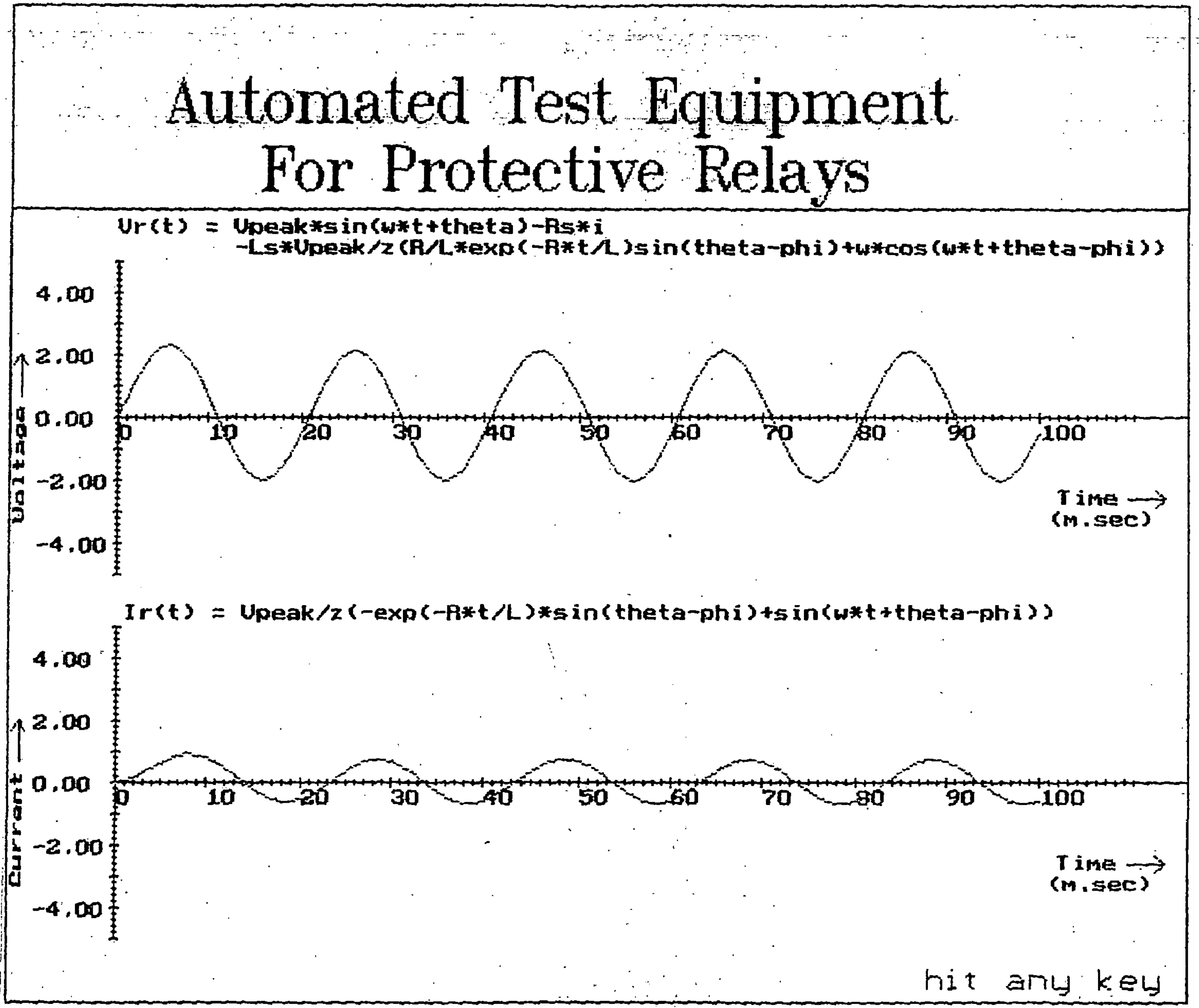
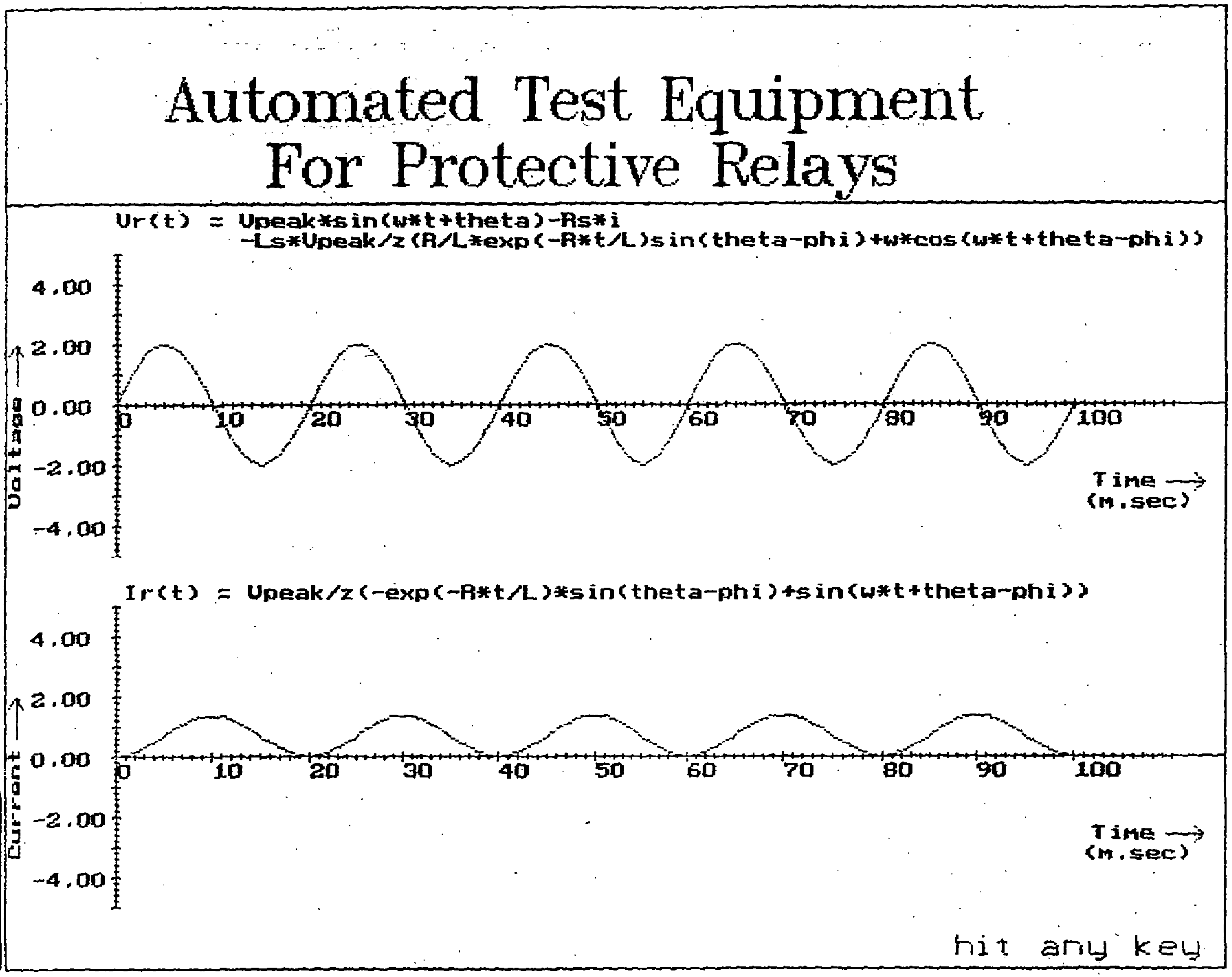


Fig. 3.5 : Sample Value Computation for Single-Phase Under Dynamic Condition



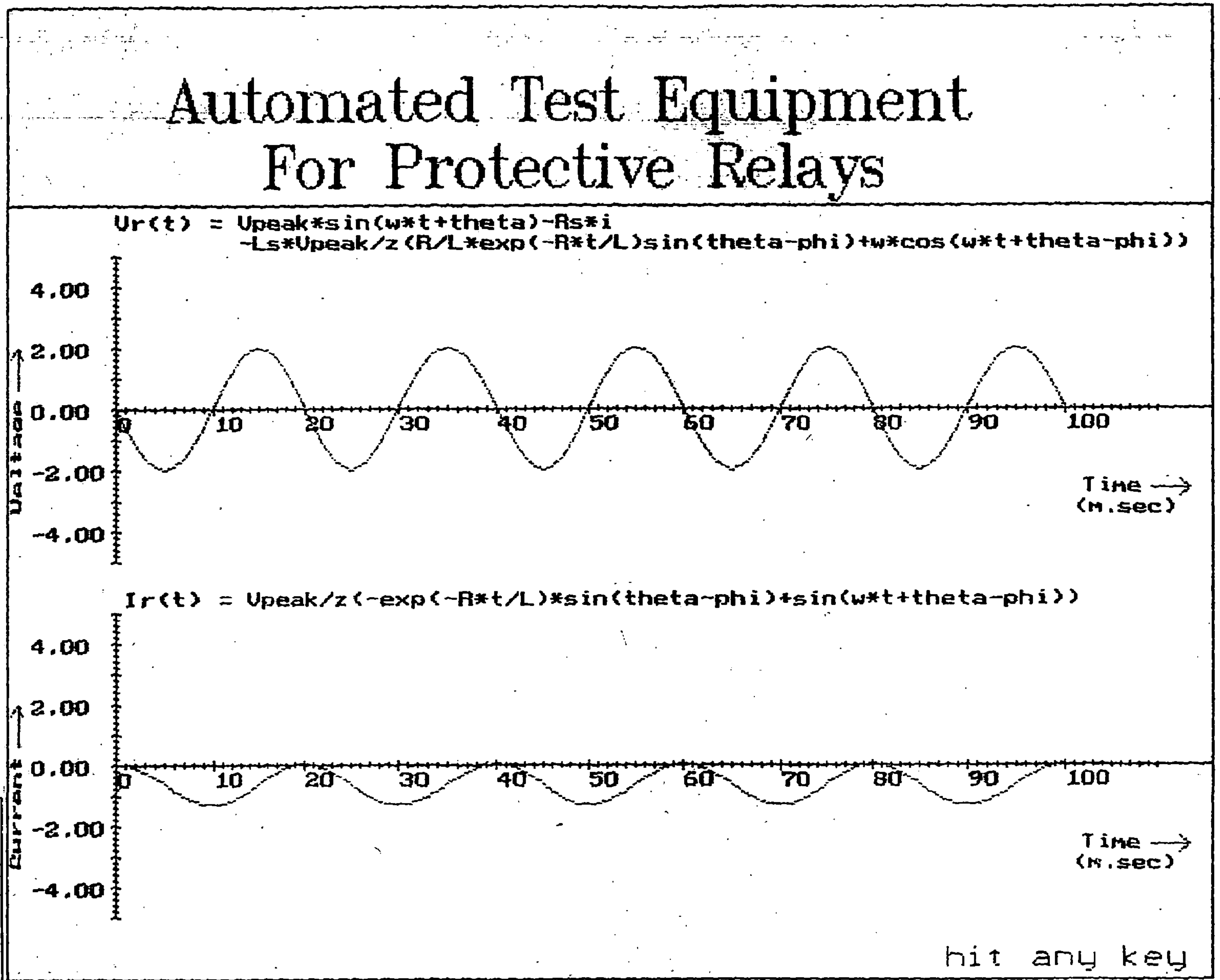
Z_s	$= 3\ \Omega$
α	$= 80^o$
Z_l	$= 3\ \Omega$
β	$= 50^o$
θ	$= 0^o$
V_{peak}	$= 4$ V

Fig. 3.6(a) Waveform Display for Single-Phase.



Z_s	= 3 Ω
α	= 90°
Z_l	= 3 Ω
β	= 90°
θ	= 0°
V_{peak}	= 4 V

Fig. 3.6(b) Waveform Display for Single-Phase.



Z_s	= 3 Ω
α	= 90°
Z_l	= 3 Ω
β	= 90°
θ	= 180°
V_{peak}	= 4 V

Fig. 3.6(c) Waveform Display for Single-Phase.

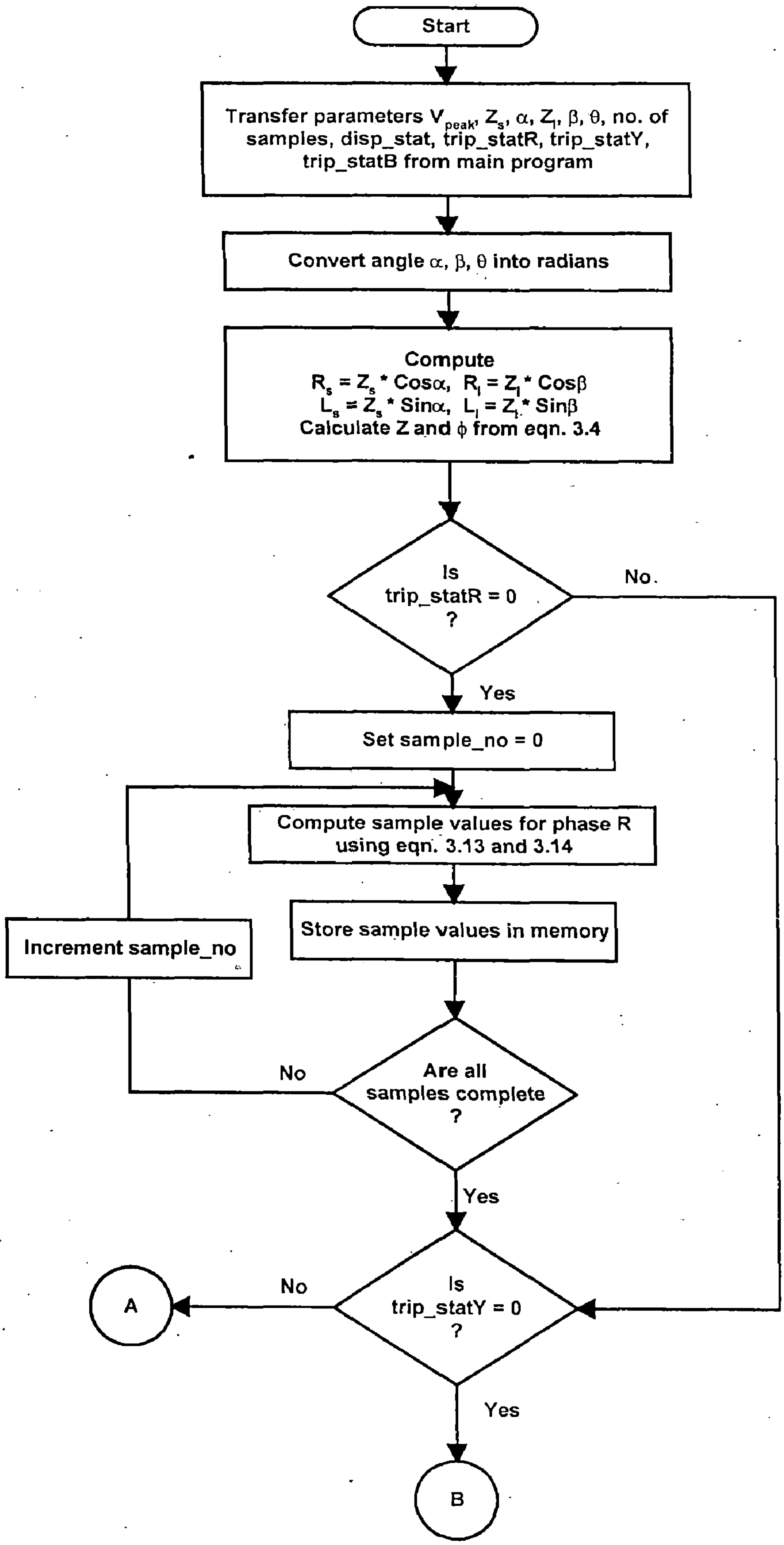


Fig. 3.7 : Flowchart for Sample Computation for 3-Phase under Dynamic Conditions (Contd.

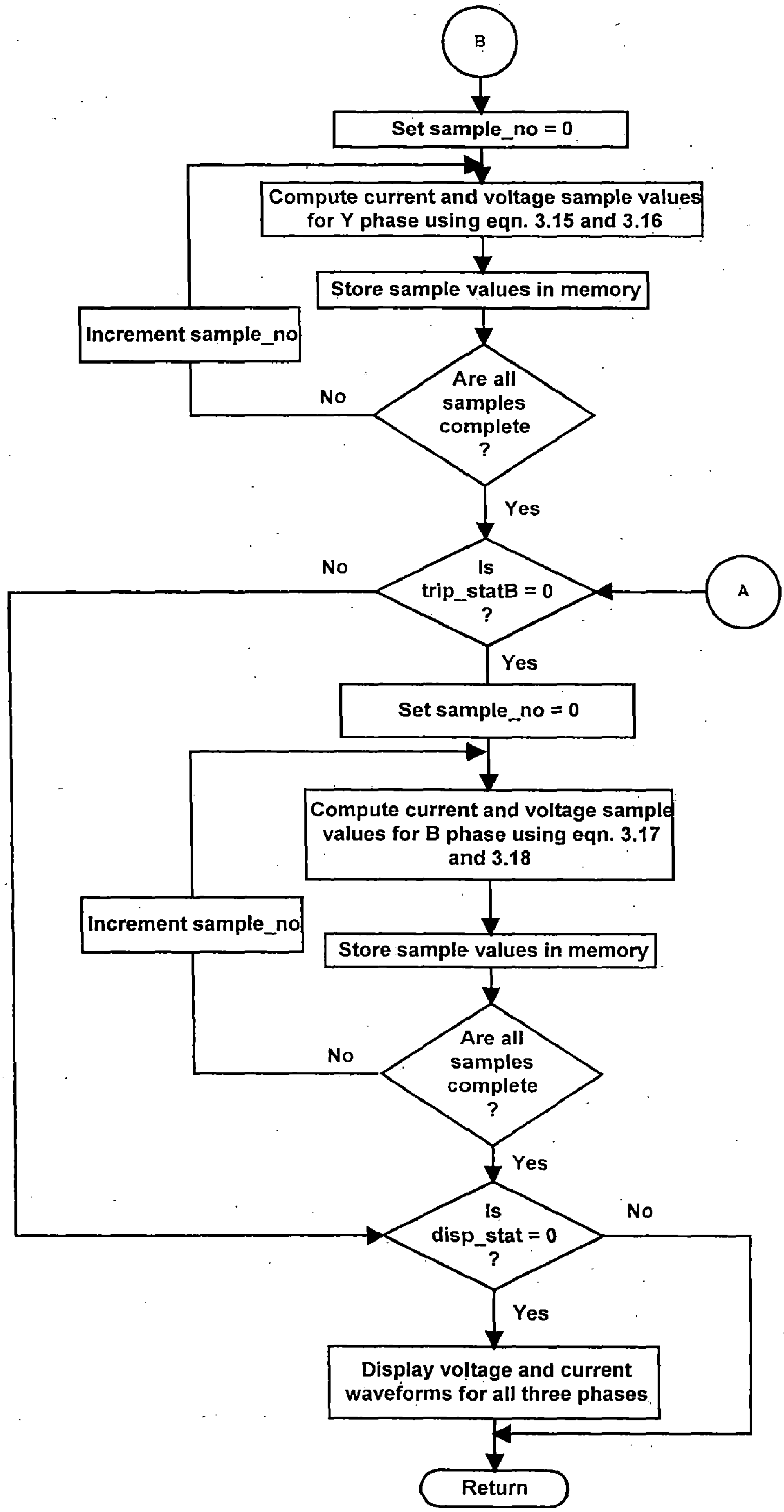
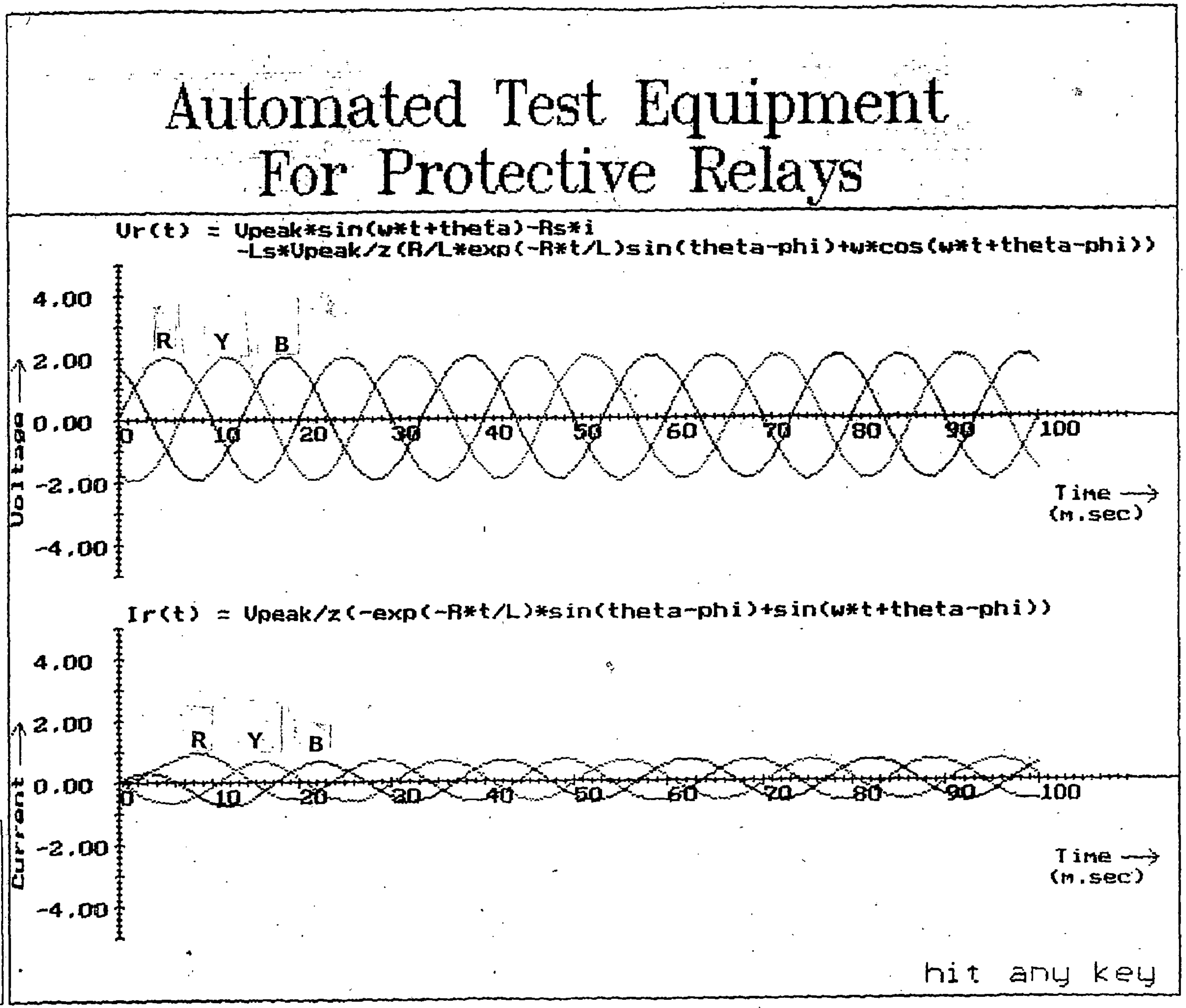


Fig. 3.7 : Flowchart for Sample Computation for 3-Phase under Dynamic Conditions



Z_s	$= 3\ \Omega$
α	$= 70°$
Z_l	$= 3\ \Omega$
β	$= 70°$
θ	$= 0°$
V_{peak}	$= 4\ V$

Fig. 3.8 : Waveform Display for Three-Phase.

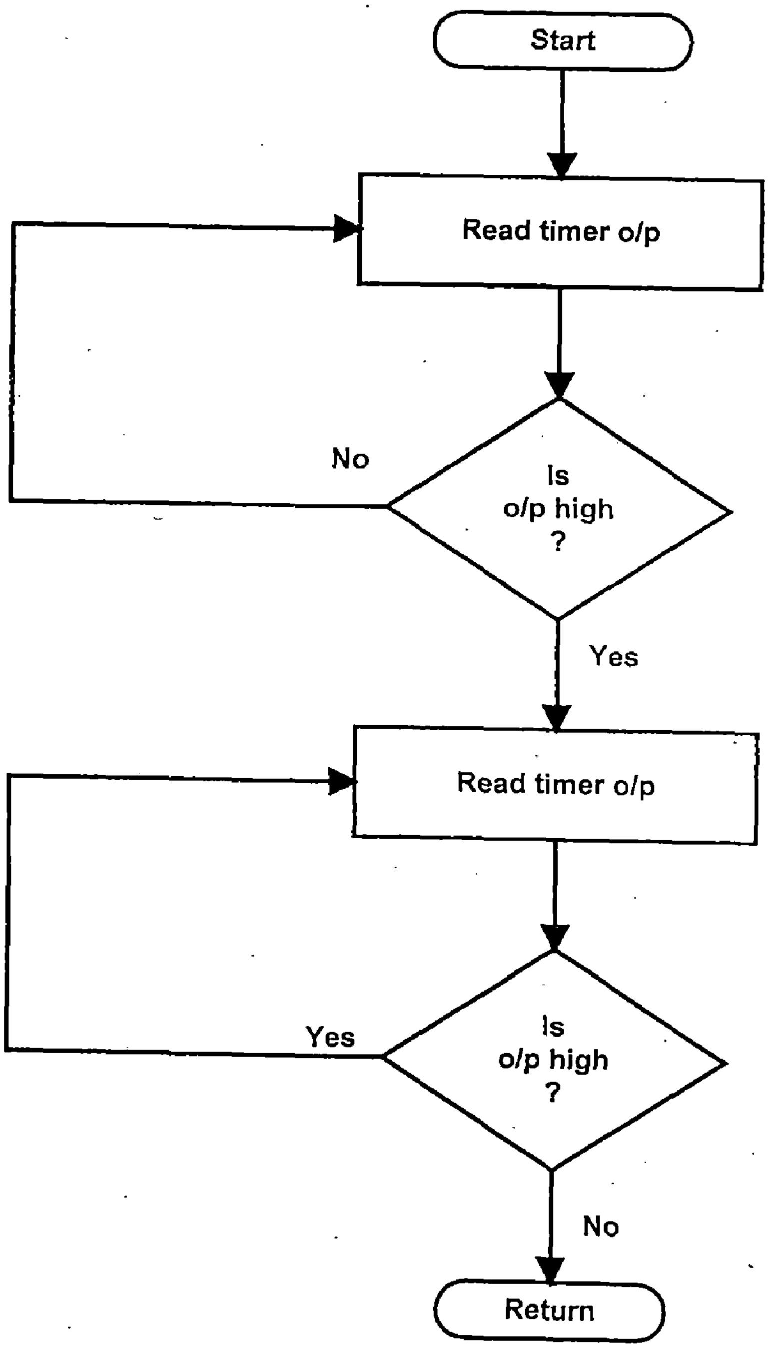


Fig. 3.9 : Flowchart for Time Delay

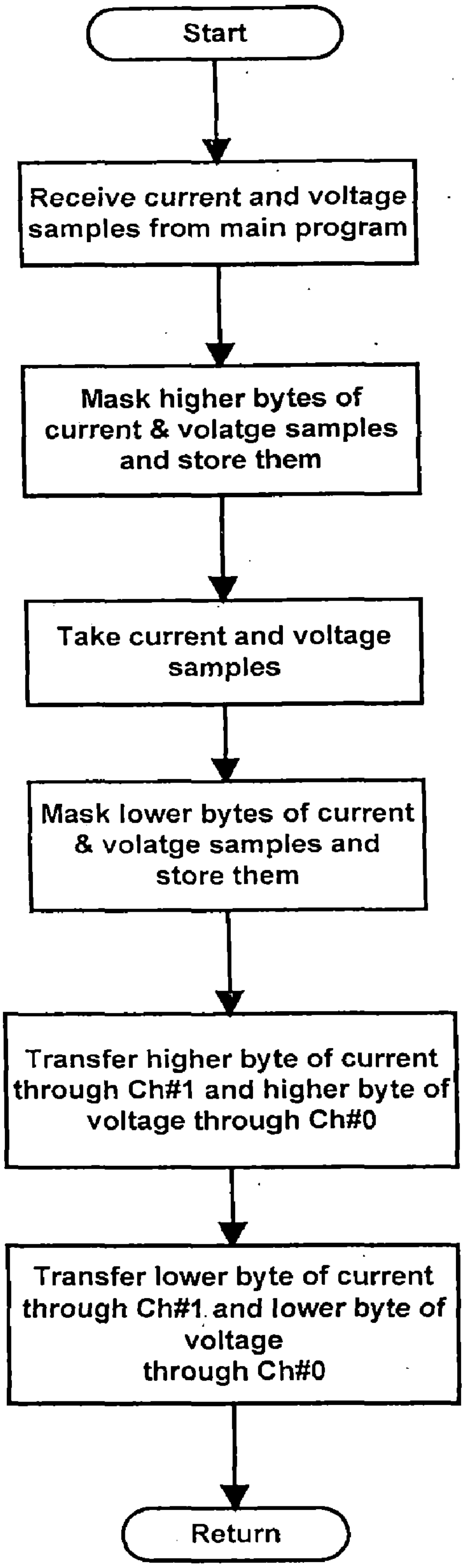


Fig. 3.10 : Flowchart for Single-Phase Samples Transfer through D/A Converters

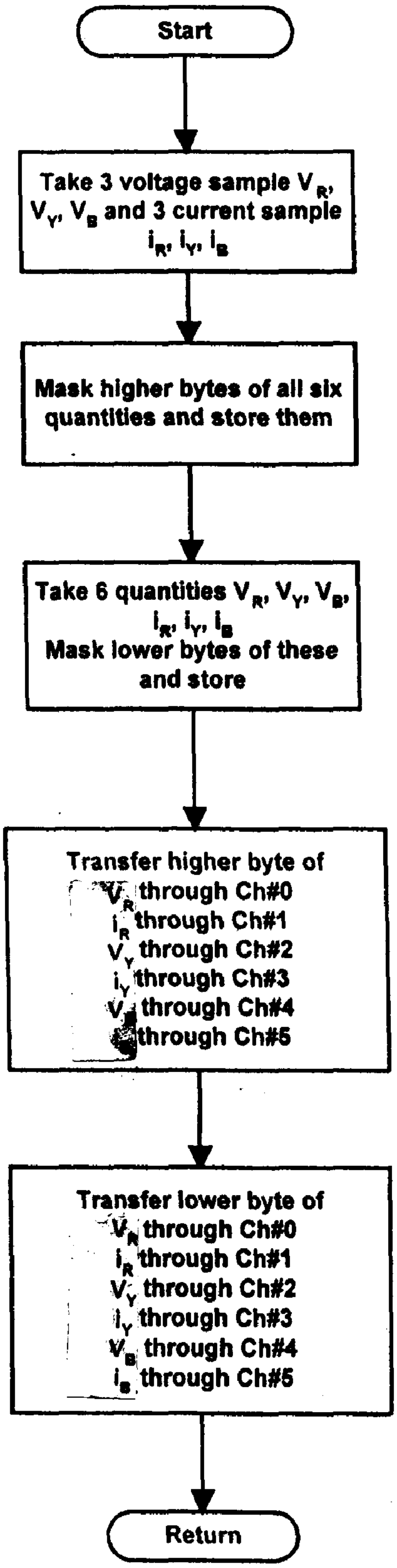


Fig. 3.11 : Flowchart for 3-Phase Samples Transfer through D/A Converters

TESTING OF SINGLE-PHASE DISTANCE RELAYS

In this dissertation work, detailed testing of single phase distance relays have been carried out. Different characteristics of distance relays have been obtained. This chapter presents the testing algorithms for different types of tests needed for distance relays. Mho relay is chosen as typical example of distance relay for testing.

4.1 IMPORTANCE OF DISTANCE RELAYS

Present day power system is very complex, requires faster clearing times. Because of the difficulty in grading time/overcurrent relays with increasing number of switching stations, the use of high speed distance relays has become an obvious choice. It is a non-unit form of protection offering considerable economical and technical advantages on medium and high voltage feeders. Being of the non-unit type, distance schemes automatically provide backup protection to adjacent feeder sections. Selectivity is offered by a directional feature which is either inherent to the distance relay itself or is provided by supplementary relays.

The performance of distance relay is governed by the ratio of voltage to current at the relay location. Now the impedance or the reactance of the circuit between the relay and the fault is proportional to the distance between them provided the relay actuating quantities (voltage and current) are properly chosen. This is the reason why such a relay is known as a distance relay [1].

Distance relays are very selective in nature, so their operating characteristics have to be very accurate and the relay should behave reliably on fault conditions under their operating zone of transmission line, if it fails to operate successfully then this may create severe damage to the equipments and to the lives which in turn will many fold increase the outage time. So there is a greater use of very prompt and precise testing of distance relay which is attempted here by computer.

4.2 OPERATING CHARACTERISTICS OF DISTANCE RELAYS

For estimating the performance of distance relay certain criterion/ characteristics are defined for these relays. These criterion judge the relay performance under different conditions. These characteristics evaluate the relay behaviour with reference to the expected performance. Before going for detailed test algorithm, following lines describe the operating characteristics of a distance relay.

4.2.1 Steady-State Characteristic

The locus of points where the operating and restraining quantities are equal is described as the boundary characteristic of the distance relay and since it is a ratio of voltage and current it can be plotted on R-X diagram.

The R-X diagram of impedance relay is as shown in Fig. 4.1. In the diagram, Z_R is the relay setting, which is the radius of circle shown. This relay setting is an indication of the distance of the line which is to be protected by the relay. Relay remains inoperative if the fault impedance is greater than the relay setting Z_R. As soon as fault impedance decreases and falls below this relay setting, relay becomes operative.

Fig. 4.2 is the polar characteristic of a mho relay. As can be seen the relay setting of a mho relay depends on the angle between voltage and current phasor. ϕ is the maximum sensitivity angle of the relay, relay operates only for the faults which lie in the stated operating zone.

4.2.2 Dynamic-State Characteristics

The relay should definitely be tested under dynamic conditions. Satisfactory performance of the relay under dynamic conditions will ensure reliable and satisfactory performance of the relay under actual fault conditions. Under dynamic condition relay is tested for different system parameters. Single point testing on different line angle is performed. Under transient conditions, fault current has a dc offset which is decaying in nature. Percentage of dc offset depends on the point at the voltage wave, when the fault occurs.

The tendency of a distance relay to operate at impedances higher than its setting is known as over-reach [10]. Under fault conditions, the fault current is an exponentially decaying sinusoid, with its momentary, instantaneous value being quite offsetted and larger than its steady state value. Under dynamic conditions, therefore, the relay sees an impedance much less than what it would see under steady state conditions. This may lead to sudden maloperation of the relay, resulting in over-reach of the relay. This impairs the accuracy and selectivity of the relay which is undesirable. This over-reach is decided by many factors, such as operating time, design, system parameters etc.

Under dynamic conditions the performance of distance relay is ascertained by all or some of the following curves/family of curves.

(a) Accuracy-Range Curve

The performance of a distance relay is usually presented in terms of accuracy versus range curves. The quantities given below are referred to the relay terminals. Accuracy is defined as [10].

$$x = \frac{\text{Impedance just causing operation of relay}}{\text{Impedance setting } Z_R}$$

The range is defined as

$$y = \frac{\text{System source impedance } Z_s}{\text{Impedance setting } Z_R}$$

Theoretically, the relay accuracy should be independent of the source impedance, but in practice the source impedance affects the magnitude of fault current and thus in turn impairs the relay accuracy. A typical curve is shown in Fig. 4.3. The fall in the curve after a certain range is due to the voltage at the relay terminals drops to less than that required for maintaining the accuracy.

(b) Accuracy-Range Contour

The accuracy range curve shown in Fig. 4.3 is a particular contour curve in which the operating time is infinite, the operation is marginal. Similar curves are plotted for finite operating times and these will have almost the same shape. The outside curve represents the boundary between operation and non-operation and this shows cut-off impedance. Successive curves approaching the origin give decreasing operating times as the inputs to the relay are increased. Accuracy-range contours are shown in Fig. 4.4.

In addition to these, curve showing operating times for different line impedances (i.e., fault impedance for a fixed range) can also be very useful for determining relay performance.

4.3 TESTING PROCEDURES FOR SINGLE-PHASE DISTANCE RELAYS

Distance relays require both voltage and current inputs. Either of these is used as reference quantity and other is used as operating quantity, depending upon the type of characteristic being realised. Hence, the relay should be subjected with both voltage and current signal simultaneously for testing. This section describes testing procedures which were adopted for testing distance relays in both steady state and dynamic state. Since a particular point on the impedance plane does not imply a unique voltage-current pair, but rather their ratio, it must be decided to vary, (I) both voltage and current in some rational way, (ii) fix the current and vary the voltage, or (iii) fix the voltage and vary the current. In steady state testing, the approach to vary voltage and fix the current was applied. While for dynamic testing, both voltage and current signals were set to vary according to a mathematical relation.

4.3.1 Testing Procedure under Steady-State

For steady state testing, voltage signal starts with higher magnitude V_{peak} the magnitude is slowly decremented until relay operates or voltage magnitude reaches near zero. To obtain variable phase difference (even to obtain resolution of 1^0 angle) voltage samples were taken at an interval of 1^0 angle according to eqn. 3.1 and stored in a data file. Current samples with angular displacement of 18^0 were computed [refer eqn. 3.1] and stored in another data file. The flow chart for testing distance relay is given in Fig. 4.5 and explained below :

(i) Number of cycles b for which amplitude of voltage cycles has to be decremented is read.

(ii) Number of cycles c with constant amplitude to be applied, are read.

(iii) Stepsize for incrementing phase angle is entered.

(iv) File for storing results is opened.

(v) Current samples are copied down into an array X [ ], phase angle phi is initialized to zero.

(vi) A check is provided if phase is greater than 360^0, if true then results are displayed on CRT screen and program terminates.

(vii) If condition in step (vi) is false then voltage samples are copied down from data file into an array Y [ ].

(viii) 10 cycles of both normal voltage and current signal are sent to DAC channel 0 and 1 respectively.

(ix) A counter j representing the number of cycles with decreasing amplitude is initialized to zero.

(x) Another counter k, representing the test cycle number at constant amplitude is initialized to one.

(xi) Counter i is initialized to phase angle phi, this will provide the correct voltage sample number in voltage sample array Y [ ].

(xii) Counter q represents the correct sample number in the current sample array X [ ], initially it is set to zero.

(xiii) Time delay of one milli second is provided. Now current sample and voltage sample are sent through Ch # 1 and Ch # 0 respectively.

(xiv) Relay status is checked if it is low then counters q and i are incremented, cnt is set to 10.

(xv) A check is provided if all 20 samples have been sent to DAC channels. If not, process repeats from step (xiii) else counter k is incremented for next cycles operation.

(xvi) If k is greater than c, then voltage array is modified by decrementing amplitude of characteristic signal (voltage signal) V_{peak} to 0.98 times of the earlier amplitude, otherwise next cycle with the same amplitude is repeated.

(xvii) Counter j is incremented and compared against counter b, if it greater than b,phase angle gets advanced by an angle phi-step and control is transferred to step (vi).

(xviii) If condition in step (xvii) is false then process is repeated from step (x).

(xix) If relay status in step (xiv) is high, condition for valid trip is checked. A valid trip is considered when 10 successive tips are obtained. If it is not a valid trip then q and i are incremented and operation from step (xv) continues.

(xx) If valid trip is obtained in above step impedance with resistance and reactance is calculated and these are stored in file along with trip time and phase angle.

(xxi) Further phase angle is incremented and operation repeats from step (vi).

4.3.2 Testing Procedures under Dynamic-State

For dynamic testing as mentioned earlier in chapter 3, mathematical model was used. For generation of test signal, required system parameters are entered externally. Three programs investigating different aspects of distance relays under dynamic conditions have been presented here.

(a) Dynamic Trip-Locator

This program locates the path of trip point on R-X plane undr dynamic conditions. This is a single point testing, it is carried out on a specific line angle. System parameters and number of cycles for operation are entered by the user. This program shows the comparison of relay performance between both dynamic and steady state conditions on a particular line angle on R-X plane.

Flowchart is shown in Fig. 4.6 and algorithm discussed below.

(i) First of all, various parameters such as source impedance Z_s, source impedance angle α, line impedance Z_l which is equal to the relay setting, line angle β, fault incidence angle θ, peak value V_{peak} of voltage is entered.

(ii) Number of cycles for which relay operation is to be tested is entered as variable C.

(iii) Steady state test result file of the relay is opened. Timer is initialised to give 1 KHz square wave o/p.

(iv) Starting impedance value from which relay testing starts with, is taken 1.5 times of relay setting.

(v) Least impedance value upto which relay operation may be tested is taken as 5% of the relay setting.

(vi) Prefault voltage and current samples are computed using eqn. 3.2 and 3.3 for one cycle.

(vii) Fault current and fault voltage samples are computed using eqn. 3.5 and 3.6. Number of samples are taken equal to 20 times of requested number of cycles plus one. Generated waveform is displayed or not depending on display status disp_stat as discussed in section 3.2.2(a).

(viii) Before applying first fault voltage and current sample to relay for a particular impedance, 10 cycles of prefault voltage and current signals are applied to the relay input.

(ix) After applying every fault voltage and current sample relay status is checked. If it is a valid trip (i.e., cnt = 0, showing 10 successive trips), result is stored in a data file and display subroutine shows this information (i.e., locus of trip point) alongwith the trip time.

(x) If in step (ix), it is not a valid trip then sample number is incremented and a check is made for completion of all samples. If sample number is less than the last sample, then step (ix) is repeated and if all samples are complete then informations such as present impedance, line angle etc. alongwith the locus of operating point is displayed.

(xi) Impedance Z_l is lowered by multiplying it with 0.98.

(xii) A check is provided whether Z_l is greater than limiting value, i.e., ed_point or not. If it is, then steps from step (vii) are repeated for new decremented value of Z_l. Else a message showing that no valid trip obtained is displayed on the screen.

(b) Accuracy-Range Curve

This program determines accuracy of relay at different ranges. Range is incremented in steps depending on maximum range as provided by the user. On-line display of line impedance and source impedance alongwith the accuracy-range curve is provided. Accuracy is determined for the last trip giving range or upto the maximum value of range entered by the user.

This testing is usually performed on line angle which is equal to the maximum sensitivity angle of static relay or maximum torque angle of electromechanical relays. Flowchart for this is shown in Fig. 4.7 and algorithm given below ;

(i) First of all, line impedance Z_l equal to the setting of relay, and line angle β, equal to the m.s.a. of relay is entered, fault incidence angle θ, number of cycles c, and peak voltage V_{peak} are entered.

(ii) Maximum range upto which relay accuracy is to be determined is entered as k_{max}. K_{step} by which the range K is to be incremented is taken equal to or greater than k_{max} / 10 for curve plotting purpose.

(iii) Once again Z_l_set is made equal to the relay setting. Starting impedance value is chosen to be 1.5 times of the relay setting. Last value of impedance Z_l is chosen to be 10% of the relay setting. Range k is initialized to zero.

(iv) Source impedance Z_s is taken equal to the range multiplied by relay setting.

(v) Prefault voltage and current samples for one cycle are calculated by using eqn. 3.2 and 3.3.

(vi) A condition of Z_l, whether it is greater than last value, i.e., ed_point is checked if this happens to be true then fault voltage and current samples for requested number of cycles are computed using eqn. 3.5 and 3.6.

(vii) Ten cycles of prefault voltage and current are applied to relay.

(viii) Required number of cycles of fault voltage and current are applied and in between transfer of any two voltage-current samples relay status is checked.

(ix) If relay status is high and if this is a valid trip then present impedance value of Z_l on per unit basis is considered to be the accuracy of the relay for that particular range. Entries are made for accuracy-range curve.

(x) Range k is incremented in step size of k_{step} and if present range is less than the maximum range k_{max} then procedure is repeated from step number (iv) else program terminates.

(xi) If for a particular range no valid trip is obtained then the last value of range for which valid trip may be obtained is traced by lowering step size k_{step} equal to 2.

(c) Accuracy-Range Contours

As mentioned in section 4.2.2, accuracy-range curve plot shows the boundary between no operation and operation for different ranges. The operating time may be considered to be infinite. If we want accuracy-range curves for finite operating time, impedance Z_t is further decremented and operating times are recorded for every value. Contour is obtained by joining points with different accuracies (of different ranges) but of same tripping time.

Flowchart for this is shown in Fig. 4.8.

The procedure remains almost same as discussed in previous program except the operating time for every point is taken upto the last limiting value ed_point, for a given range. Operation times for every point, from the first tripping point to the last tripping point alongwith impedance are recorded in a data file and displayed on screen, this plot is operating time Vs impedance characteristic of the relay.

Finally, when range k reaches maximum value k_{max} contour display subroutine is invoked.

This subroutine is shown in Fig. 4.9 and discussed below :

(i) First of all, two different times, time1 and time2, for which contour is required are entered, time band for these times is entered.

(ii) Data file obtained from Fig. 4.8 is opened

(iii) For range zero, sorting of points for time1 is done. For sorting all such accuracies which lie in the operating time band size, time1 $\pm$ time band are selected, number of such points are calculated.

(iv) Average accuracy for all such points obtained in step (ii) is calculated.

(v) For time2 same procedure is repeated from step (iii).

(vi) Average accuracies obtained in above steps is plotted on y axis against appropriate range on x-axis.

(vii) Now range k is incremented by k_{step} and if range is less than k_{max} steps from (iii) are repeated else program gets terminated.

4.4 CASE STUDY : TESTING OF SINGLE-PHASE MHO RELAY

As mentioned earlier for testing distance relay mho relay is chosen as typical example of distance relay. For carrying out tests mho relay comparator was developed in laboratory, and tests were carried out over that relay comparator.

Mho relay comparator tested (shown in Fig. 4.10) in laboratory comprises filter circuit alongwith level detector circuit. For making distance relay comparator either amplitude comparator or phase comparator may be used. In the laboratory an amplitude comparator was fabricated for which operating quantity is IZ_R and restraining quantities is $KV-IZ_R$. Inputs for different relay characteristics are shown in Table 4.1.

Table 4.1 : Inputs for various relay characteristics.

S. No.	*Characteristic*	*Inputs to phase comparator*		*Inputs to amplitude comparator*	
		Operating	***Restraining***	***Operating***	***Restraining***
1	Impedance	IZ_R - V	IZ_R + V	IZ_R	KV
2	Mho	IZ_R - V	V	IZ_R	KV - IZ_R
3	Directional	IZ_R	V	IZ_R + V	V - IZ_R

For static relays to operate both operating as well as restraining quantities should be either voltage or current [10]. Hence in this work both signals are voltage signals.

Phase shifting circuit provides a lagging phase shift at its output. This can be done to obtain different maximum sensitivity angle ϕ of the relay. Restraining input $V-IZ_R$ and operating input IZ_R are rectified and filtered by precision rectifier and filter unit of the relay. This unit is shown in Fig. 4.11. Comparator compares two inputs if $|IZ_R| / R > \frac{|V - IZ_R|}{R}$, then comparator output is high, and if not comparator output is low.

The steady state characteristic of this Mho relay on per unit basis is shown in Fig. 4.12. This relay has m.s.a. of 70°.

The dynamic trip-locator for above mentioned relay showing path traced by tripping point on R-X diagram is shown in Fig. 4.13.

The on-line accuracy-range curve with on-line display of source impedance Z_S is presented in Fig. 4.14.

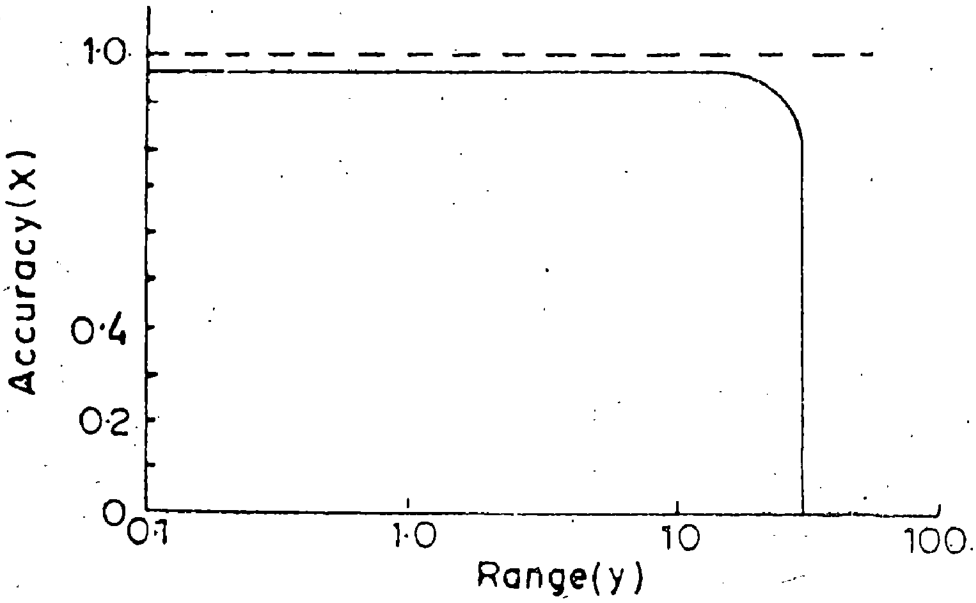


Fig. 4.3 : Accuracy-Range Curve

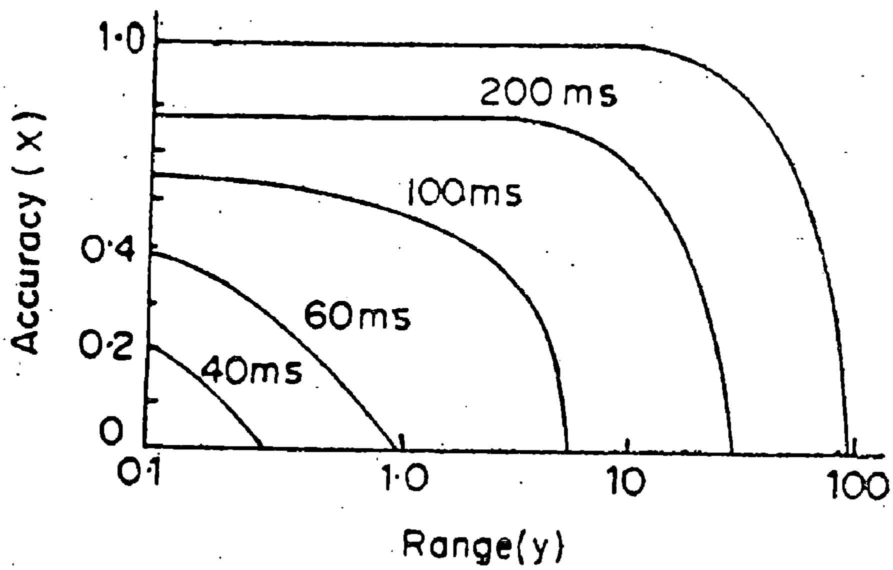


Fig. 4.4 : Accuracy-Range Contour

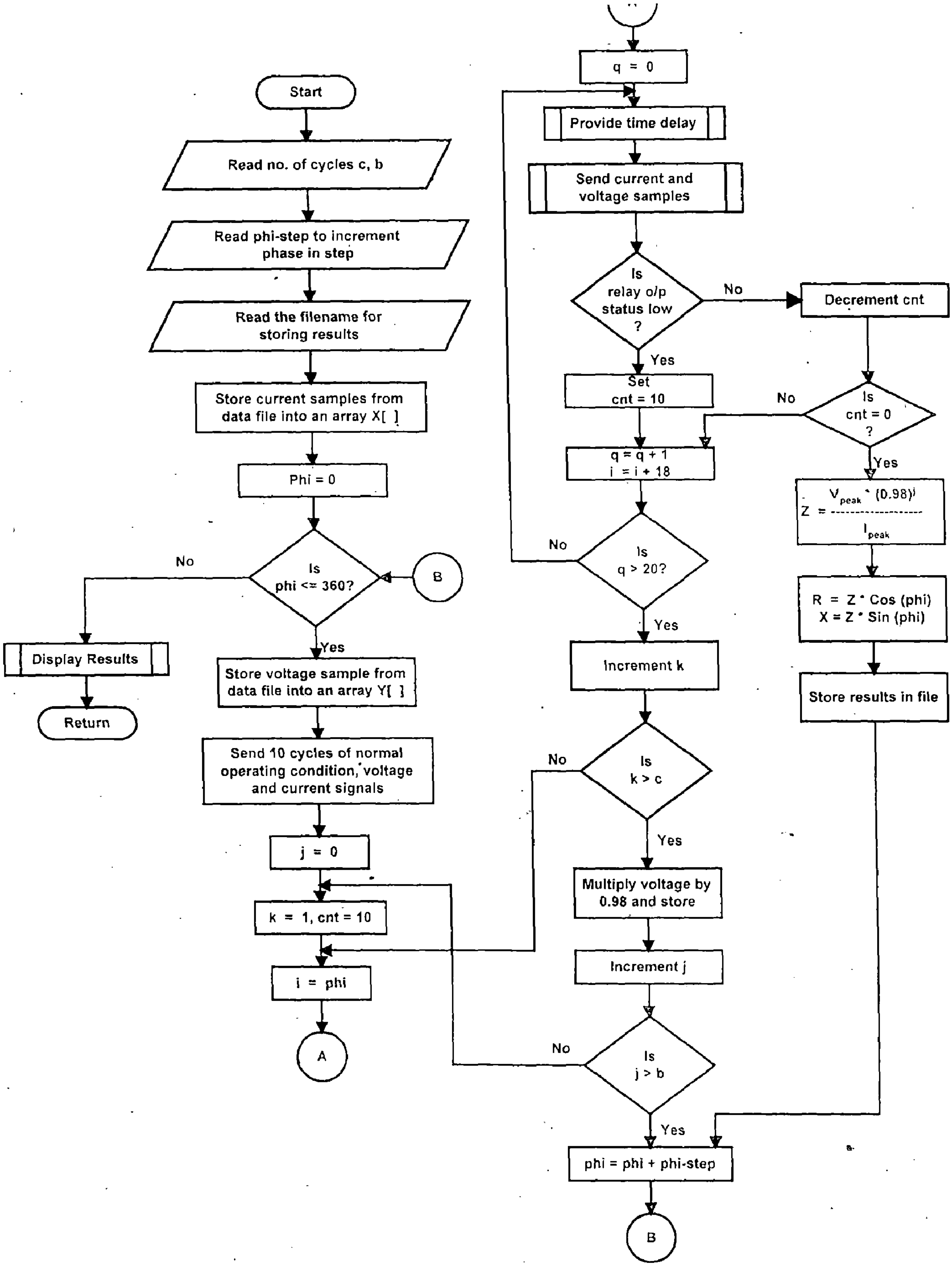


Fig. 4.5 : Flowchart for Steady-State Testing

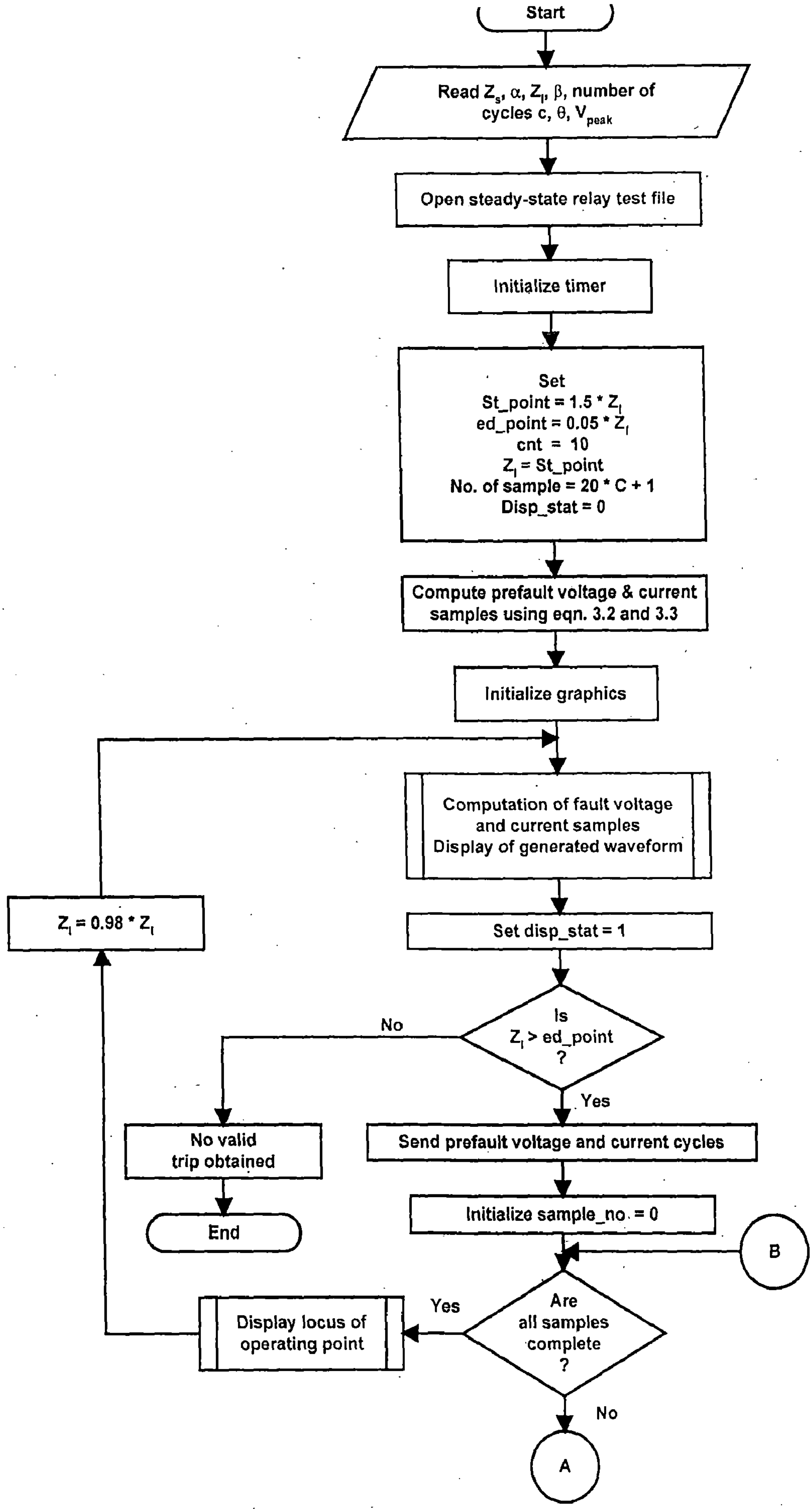


Fig. 4.6 : Flowchart for Dynamic Trip-Locater (Contd.)

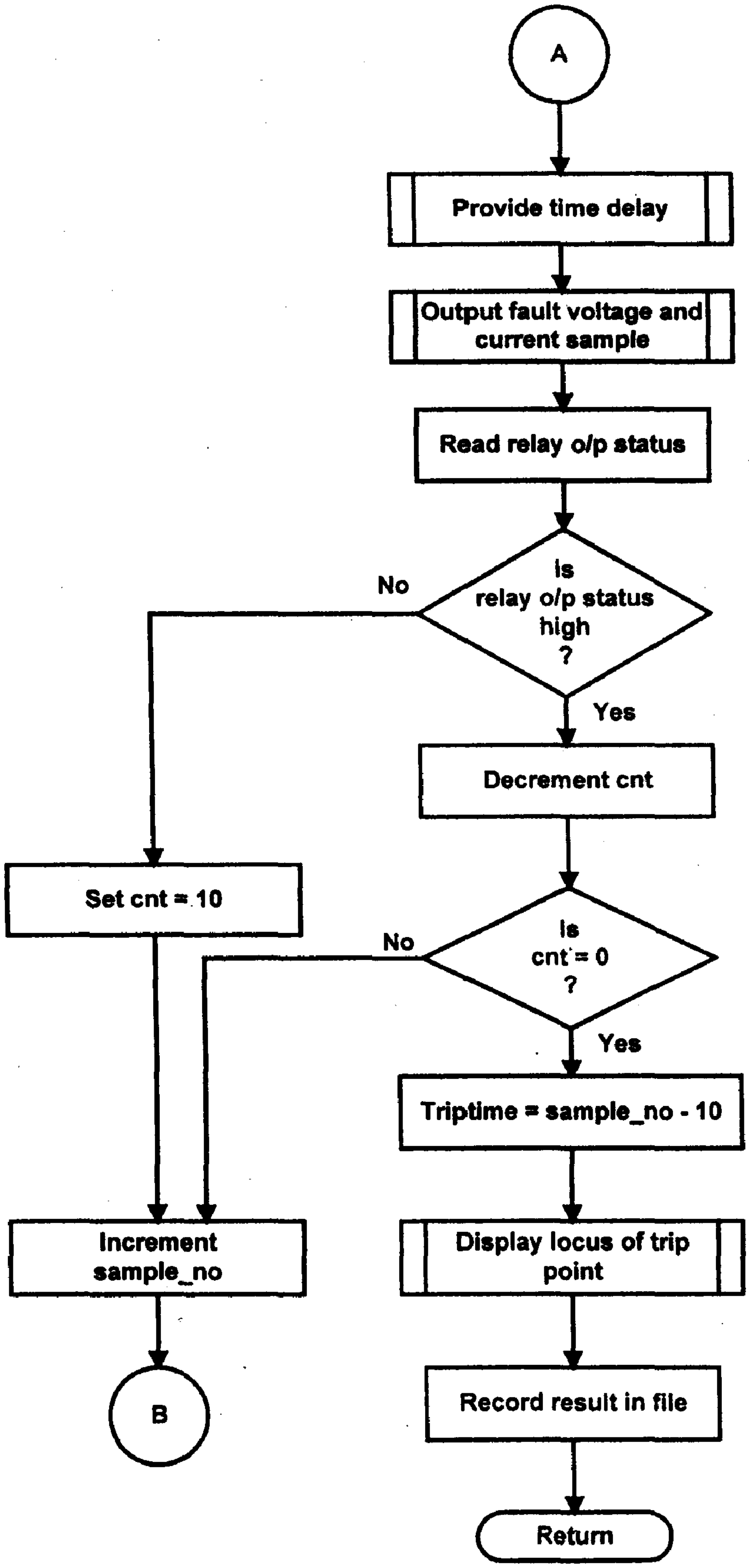


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Fig. 4.6 : Flowchart for Dynamic Trip-Locater

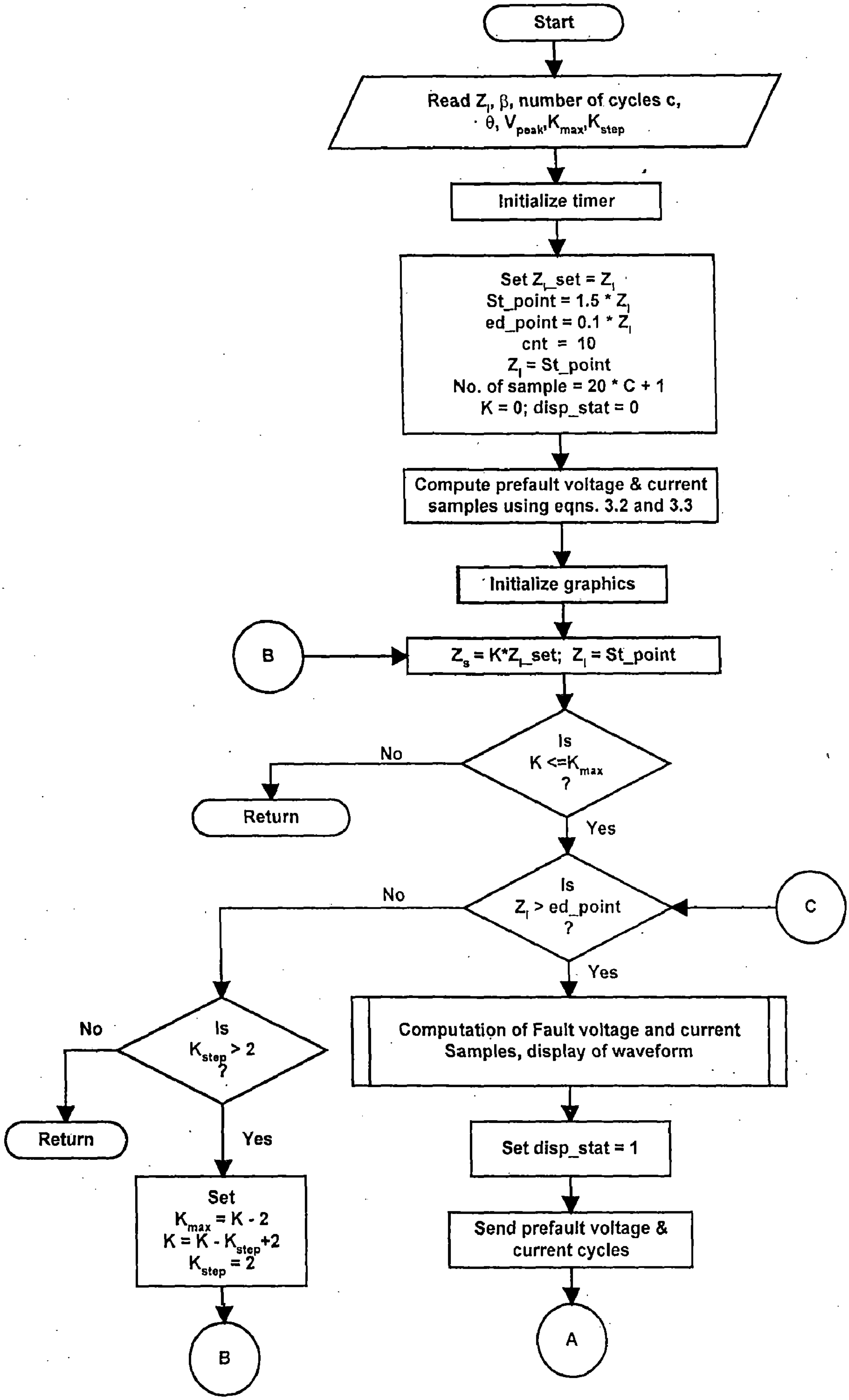


Fig. 4.7 : Flowchart for Accuracy-Range Curve (Contd.)

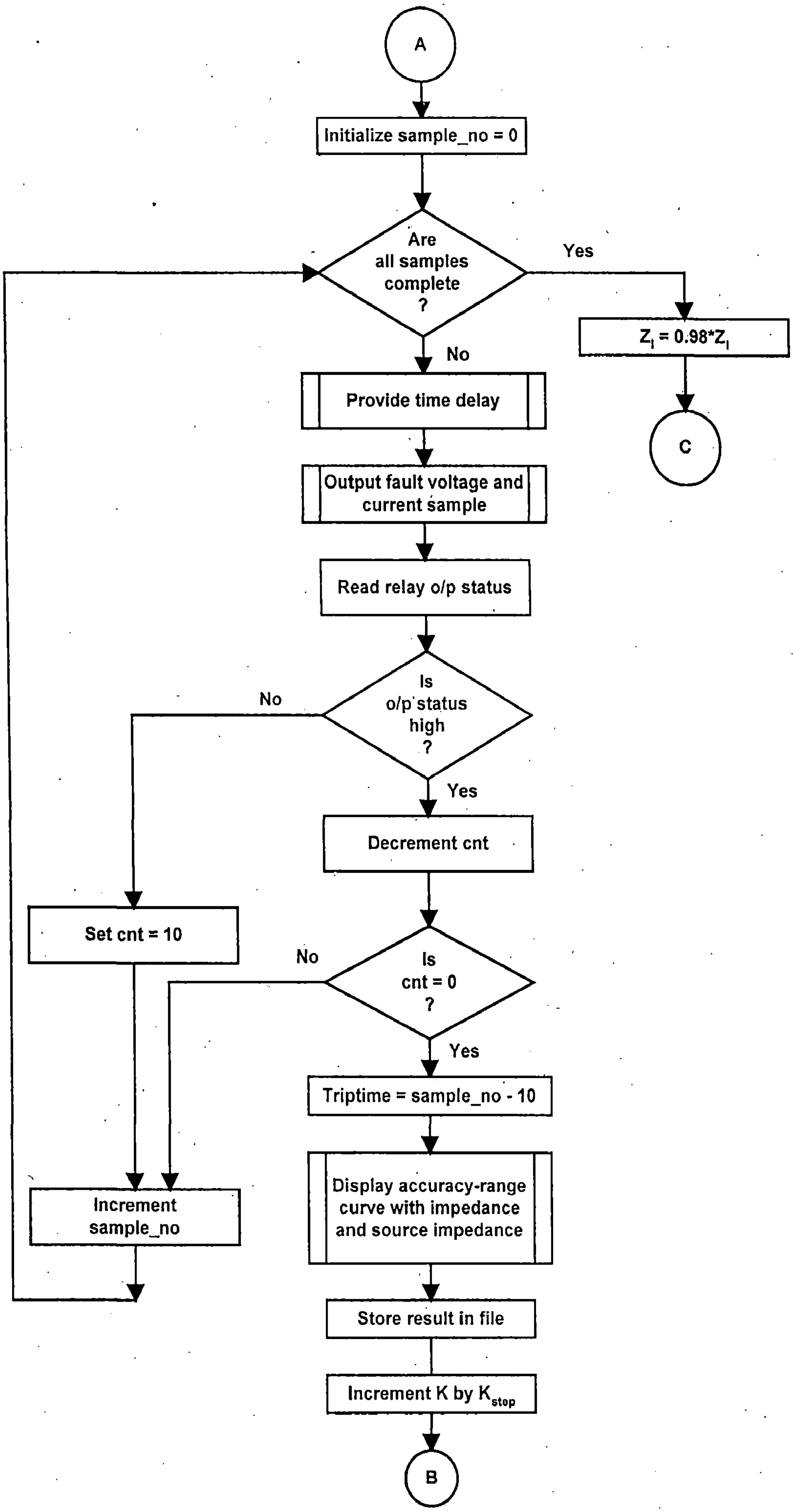


Fig. 4.7 : Flowchart for Accuracy-Range Curve

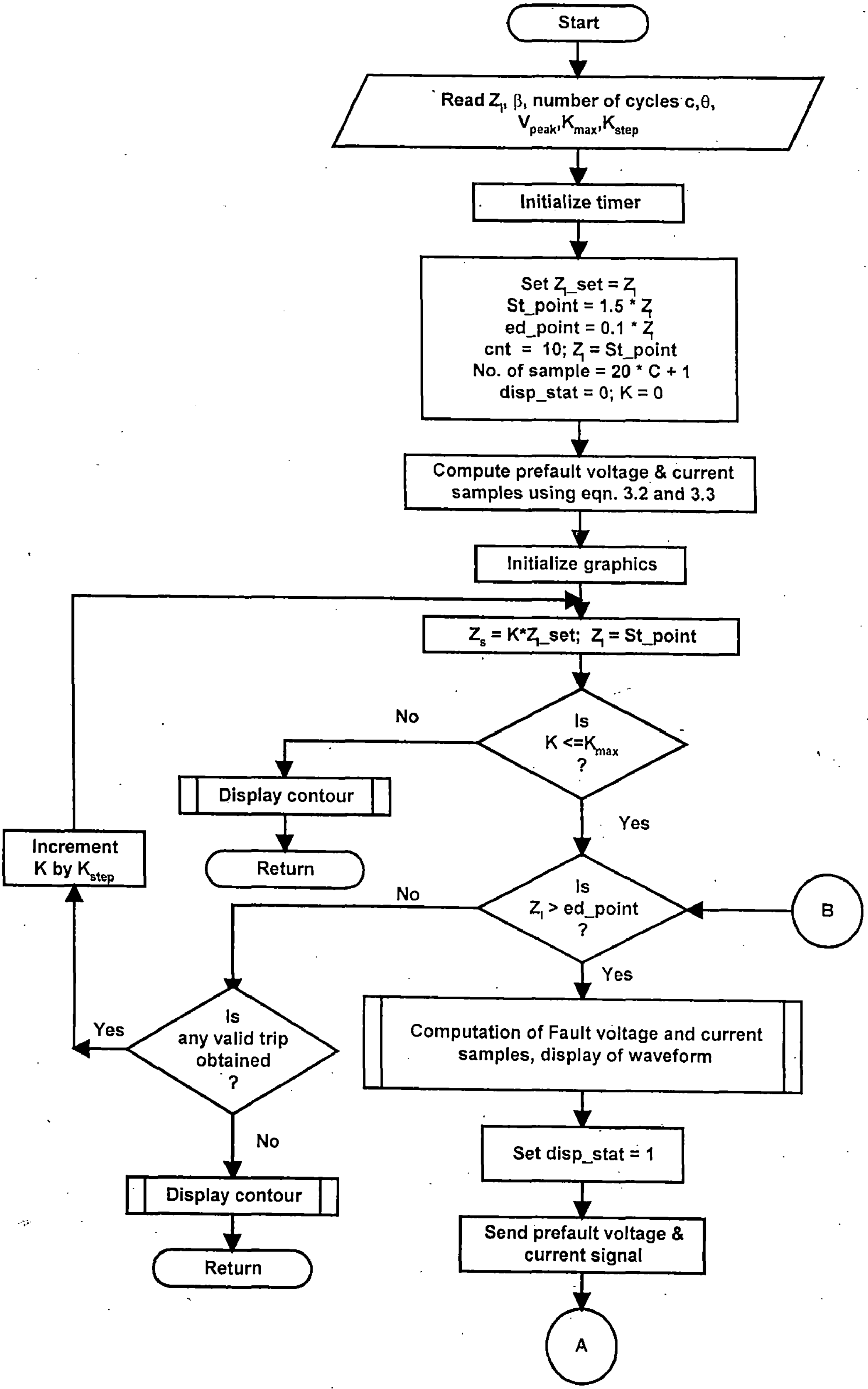


Fig. 4.8 : Flowchart for Accuracy-Range Contour (Contd.)

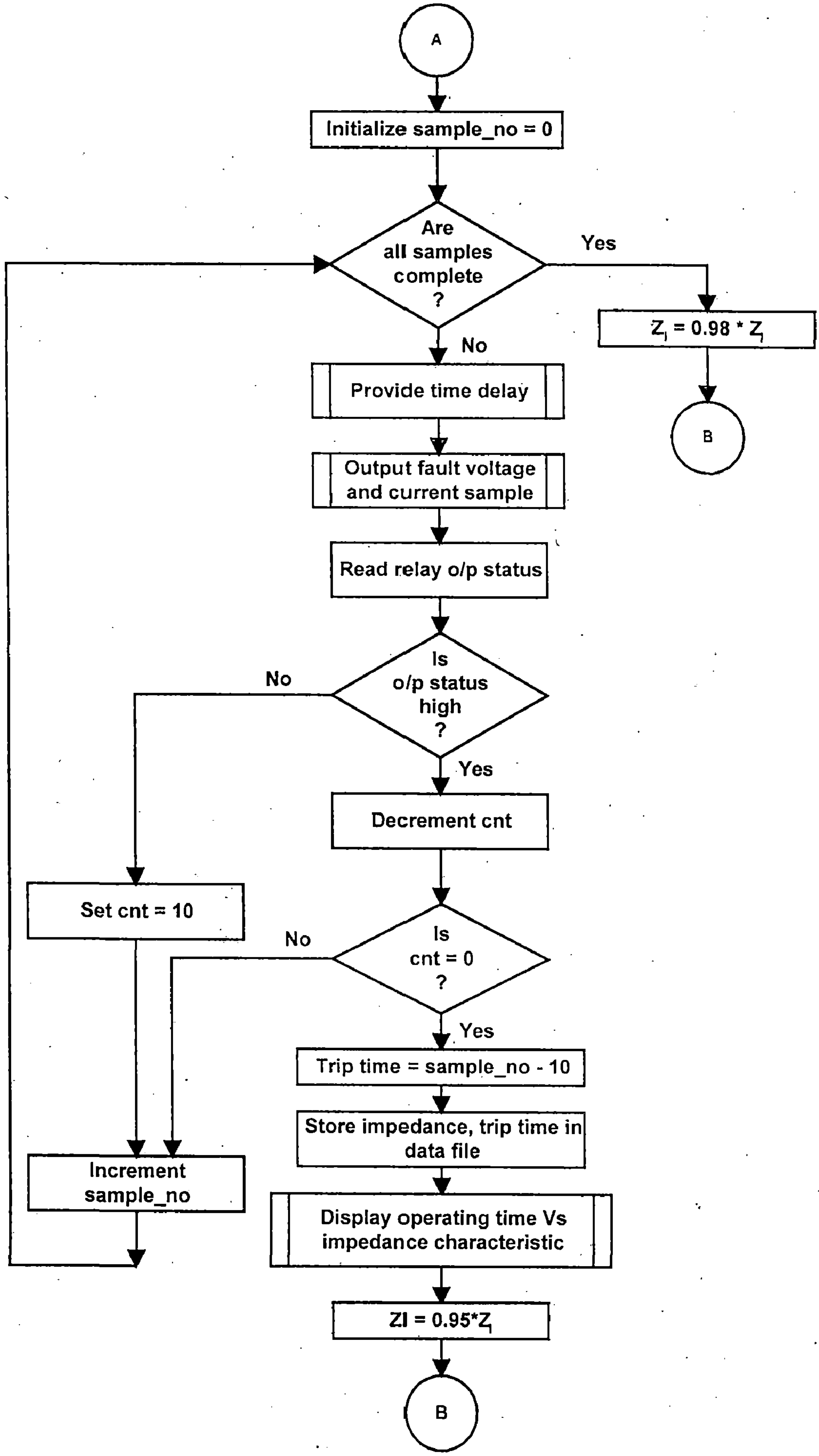


Fig. 4.8 : Flowchart for Accuracy-Range Contour

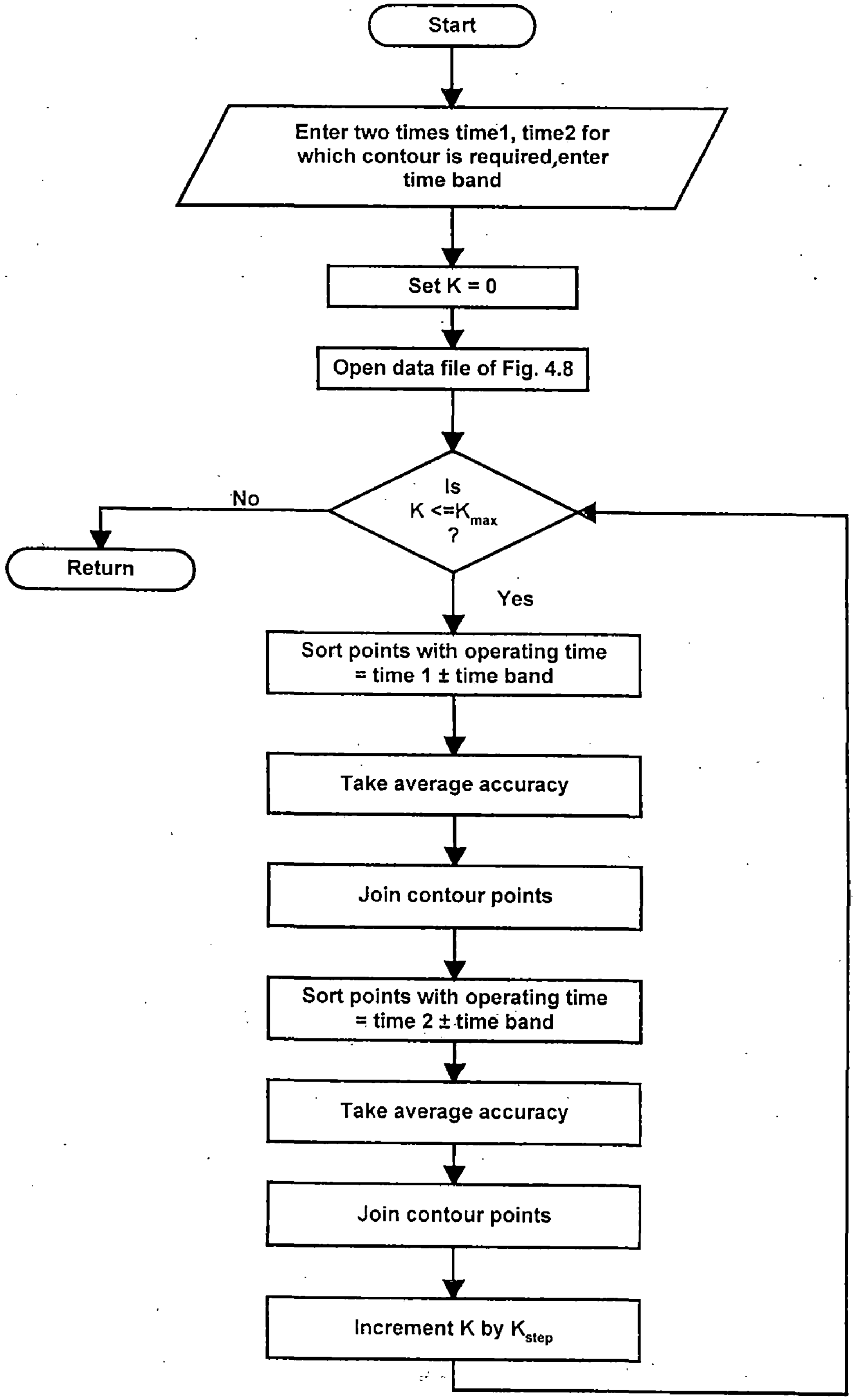


Fig. 4.9 : Flowchart for contour display subroutine

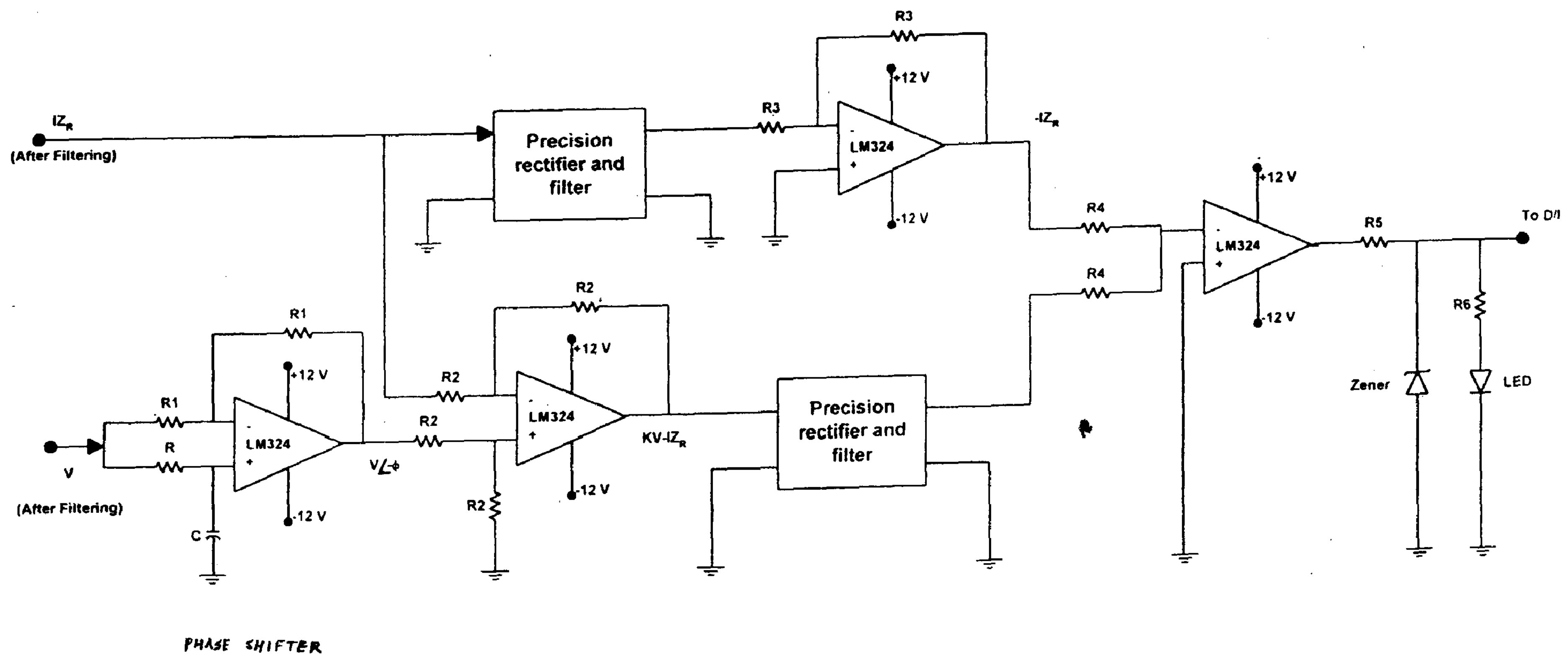


Fig. 4.10 : Single-Phase Mho Relay Circuit

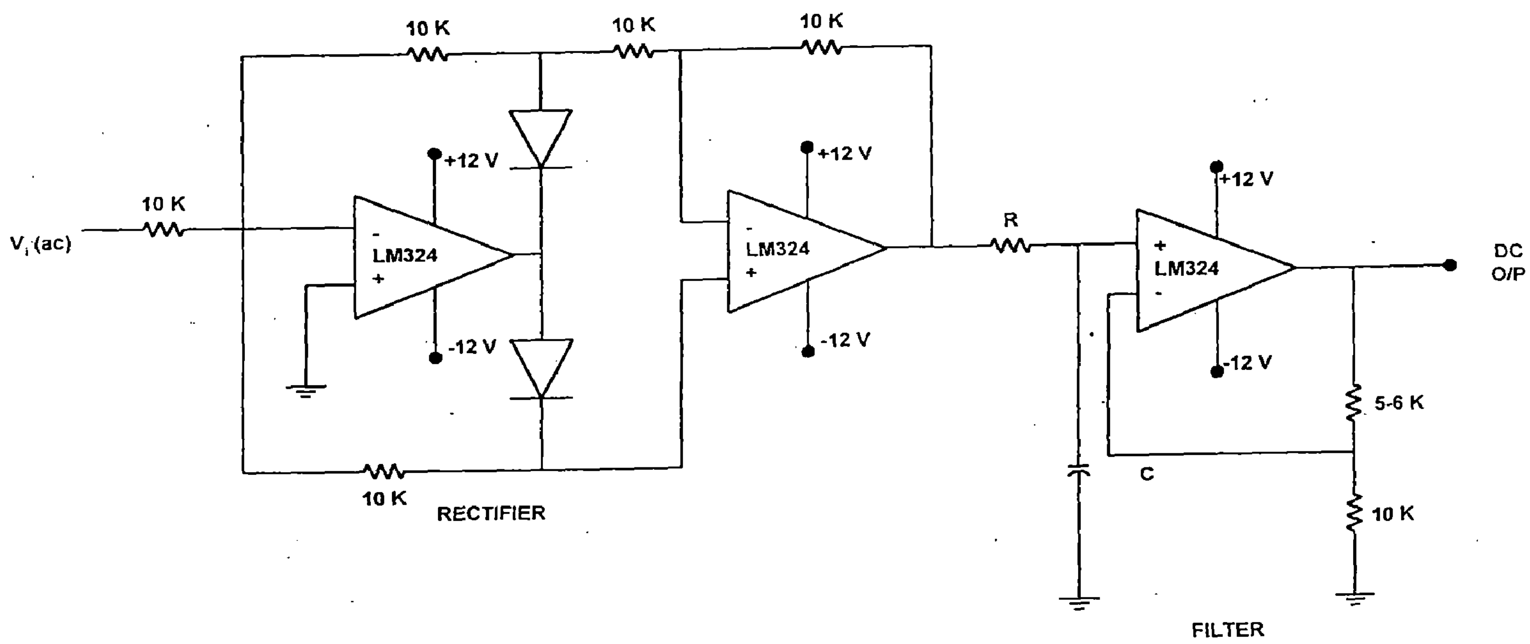


Fig. 4.11 : Precision Rectifier and Filter Unit

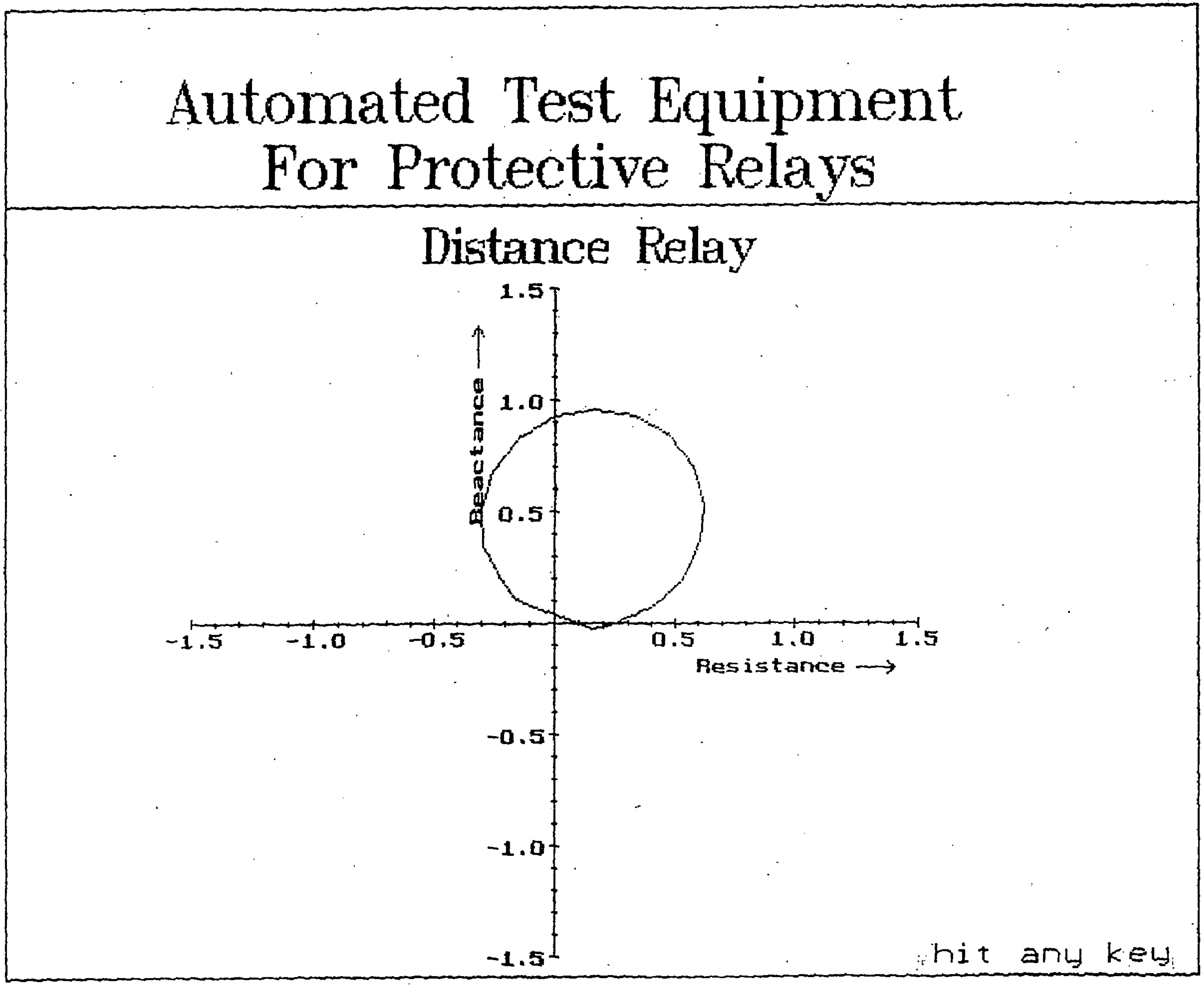


Fig. 4.12 : Steady-State Characteristic

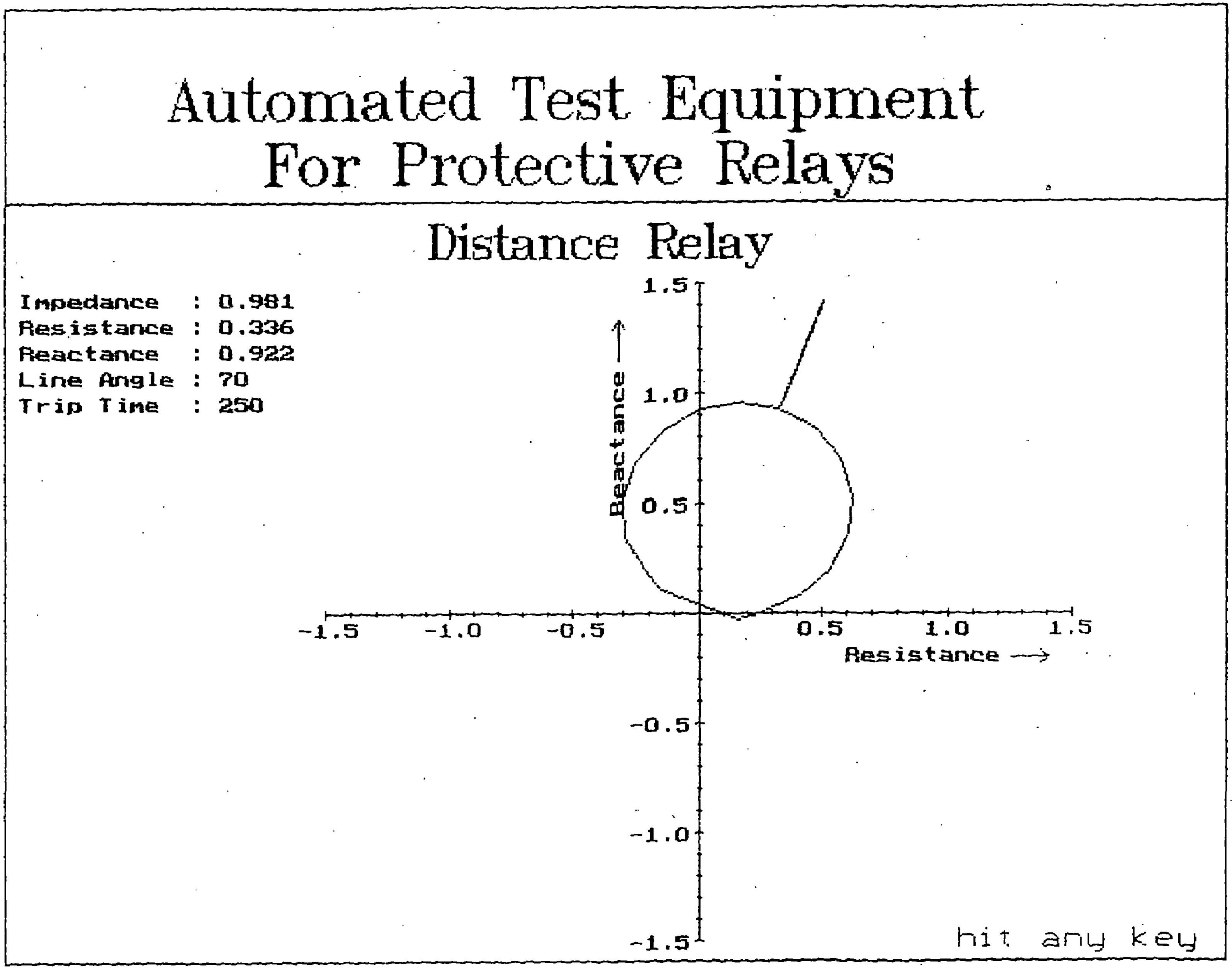


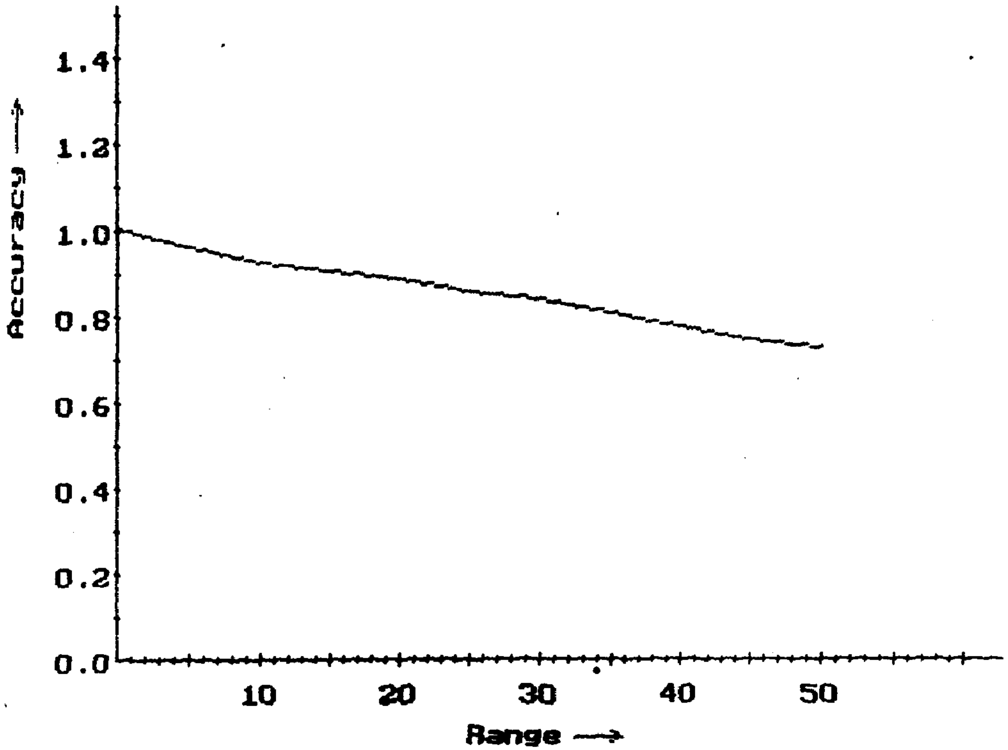
Fig. 4.13 : Single-Phase Dynamic Trip-Locater

Automated Test Equipment For Protective Relays

Distance Relay

Zs : 100
Z1 : 0.725

RANGE	ACCURACY
0	1.001
5	0.962
10	0.924
15	0.905
20	0.887
25	0.852
30	0.835
35	0.802
40	0.770
45	0.740
50	0.725



hit any key

Fig. 4.14 : Accuracy-Range Curve for Mho Relay

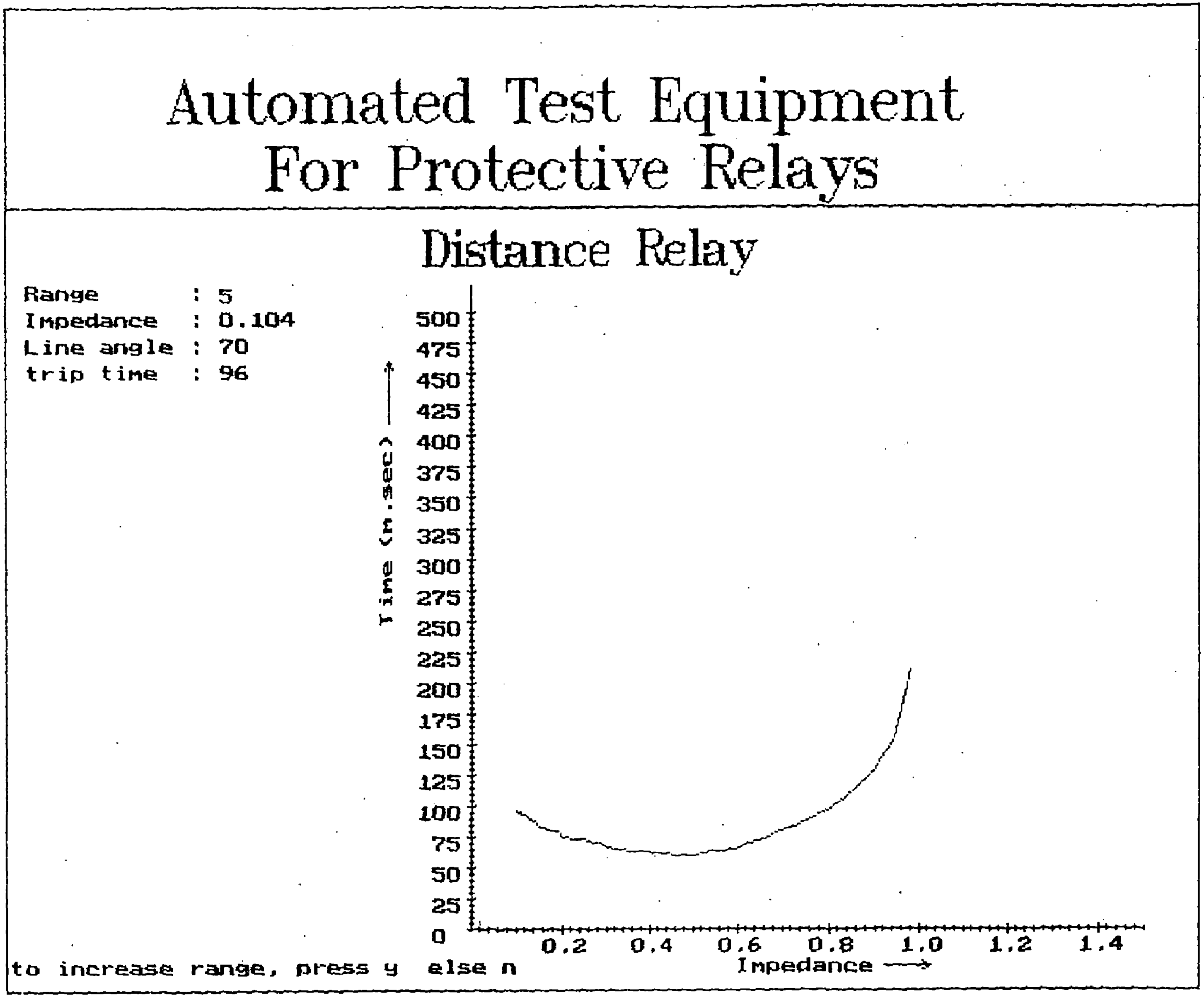


Fig. 4.15 : Operating Time Vs Impedance Characteristic

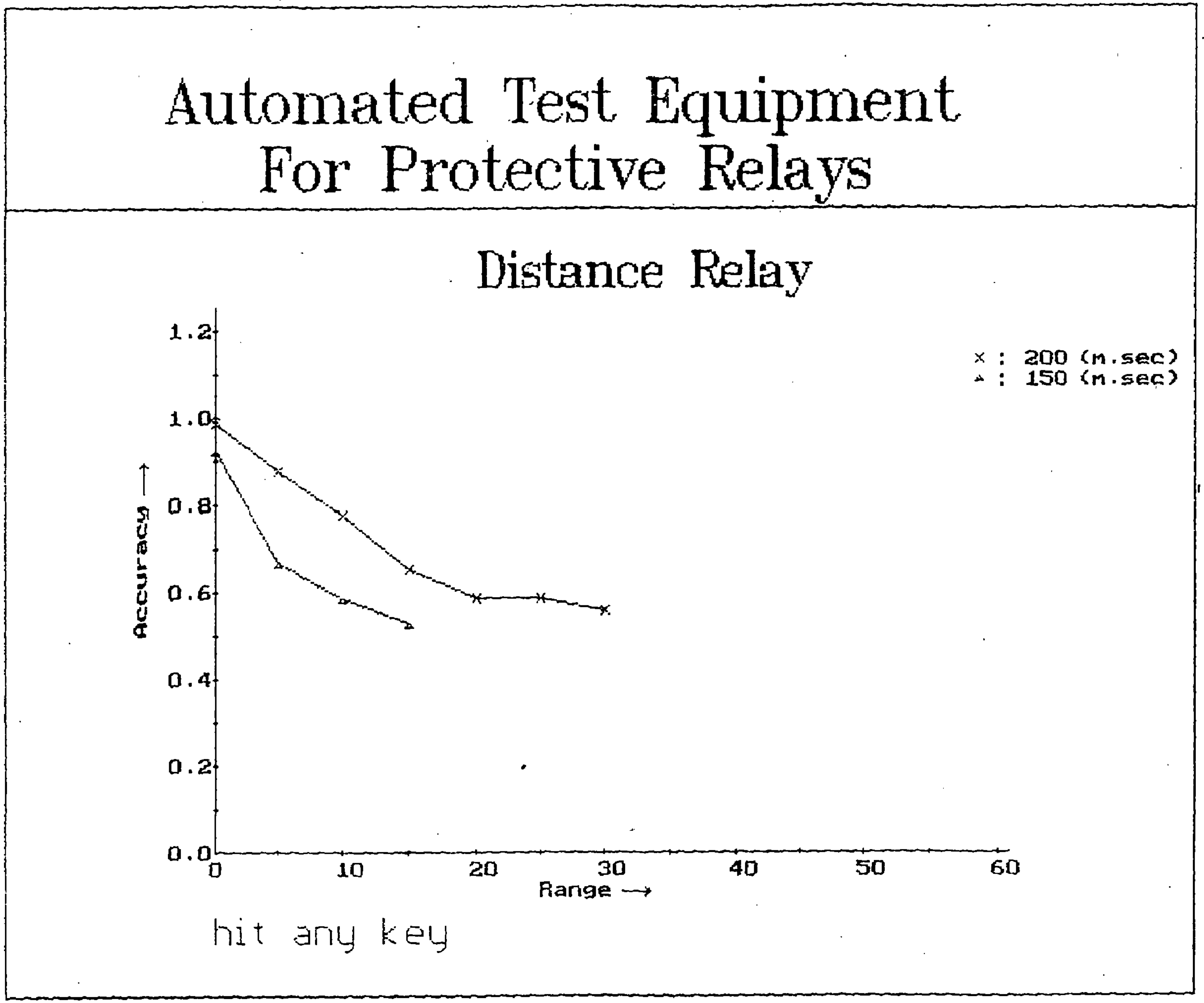


Fig. 4.16 : Accuracy-Range Contour for Mho Relay

TESTING OF THREE-PHASE DISTANCE RELAYS

Power system network in our country and all over the world are three phase networks. This requires 3 phase relay units to be incorporated in the network to protect the system from fault outages. A three phase relay may or may not require the tripping of all 3 single phase units, depending on type of fault which it is going to detect. Once again Mho relay is chosen as typical example of 3-ϕ distance relay. This chapter describes the testing procedure for 3-phase relay.

5.1 TESTING PROCEDURE FOR THREE-PHASE DISTANCE RELAYS

For testing of three phase relay, three voltage signals and three current signals are needed. These signals under dynamic conditions are generated by using eqns. 3.13 – 3.18 provided for 3-ϕ quantities, in Chapter 3. One set of voltage and current signals are applied over the R-phase relay unit and similarly other sets of voltage and current signals are applied over Y phase and phase B relay units. Trip status of individual phase unit is scanned after every 1 milli second. And according to the trip status of individual unit, impedance value and corresponding triptime for the unit are stored. Each single phase unit may or may not trip for same impedance value, and for even same impedance value trip time obtained for individual 1-ϕ unit may be different.

The flowchart for testing 3-ϕ distance relay is shown in Fig. 5.1 and algorithm discussed below :

(i) First of all, parameters such as V_{peak}, source impedance Z_s, source angle α, line impedance Z_l equal to relay settings, line angle β and no. of cycles for operation are entered.

(ii) Starting and end point impedance values are established as st_point and ed_point.

(iii) No. of samples for operation are set to 20 times of number of cycles + 1.

(iv) Three trip status trp_statR, trip_statY, trip_statB for R, Y, B phase units are initialized to zero. Indicating none of the phases R, Y, B has reached to valid trip condition.

(v) Once again individual phase voltage and current samples for R, Y, B phases are computed according to the trip_statR, trip_statY, trip_statB using eqns. 3.13 – 3.18 and generated waveform is displayed or not depending on status of disp_stat.

(vi) Three count values cntR, cntY, cntB are set to 10.

(vii) Again before applying fault voltage and fault current samples to the relay, 10 cycles of prefault voltages and currents are applied to the individual phase unit.

(viii) Fault voltage and fault current samples are sent to the relay units and individual relay unit status is recorded.

(ix) If any particular phase relay has tripped then corresponding count cntX, $X \to R, Y, B$ is decremented by one else set to 10 again.

(x) If any cntX is zero, it is assumed that corresponding phase unit is having valid trip. Corresponding impedance and trip time equal to sample no. 10 is stored. Trip_stat X is modified to 1, cntX is set to 10.

(xi) After completion of requested no. of cycles Z_l gets decremented by multiplying it with 0.98.

(xii) If Z_l is greater than ed_point then operation from step (v) repeats again, else program terminates.

5.2 CASE STUDY : TESTING OF THREE-PHASE MHO RELAY

Three identical single-phase units as shown in Fig. 4.10 are considered combinedly to form one 3-phase unit. The output of these units may be logically ORed. Here testing procedure adopted traces tripping impedance and tripping time for each single phase unit.

Dynamic trip-locater obtained is shown in Fig. 5.2 showing trip impedance and trip time for each unit.

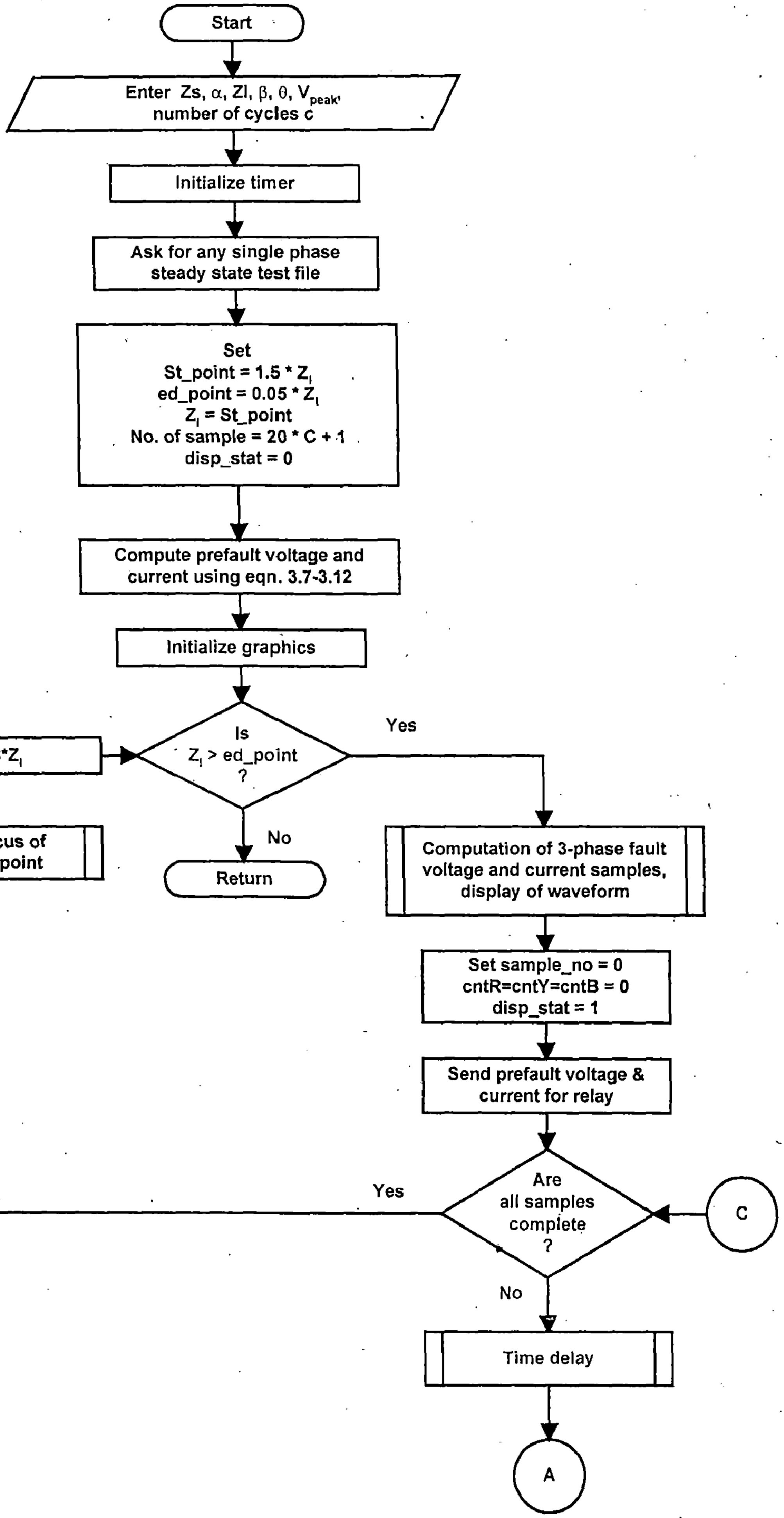


Fig. 5.1 : Flowchart for 3-Phase Dynamic trip-Locater (Contd.)

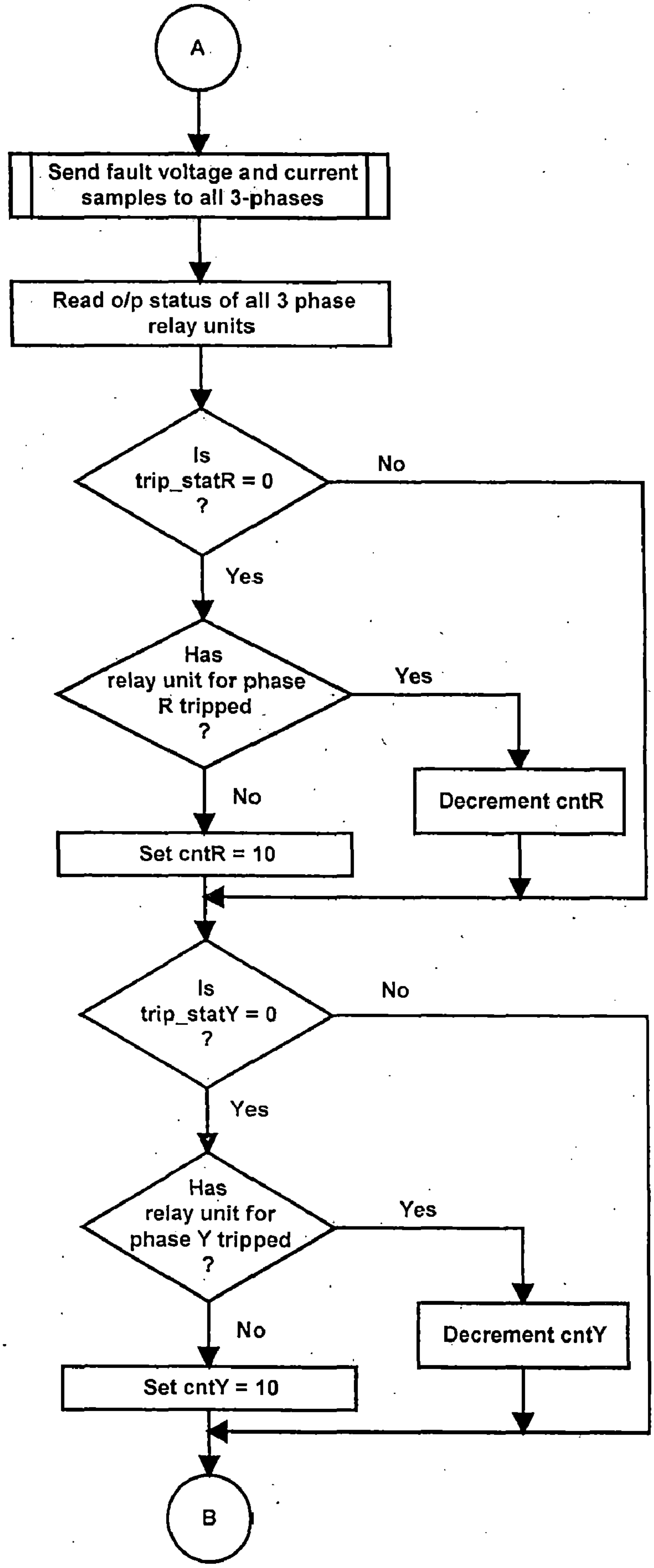


Fig. 5.1 : Flowchart for 3-Phase Dynamic trip-Locater (Contd.)

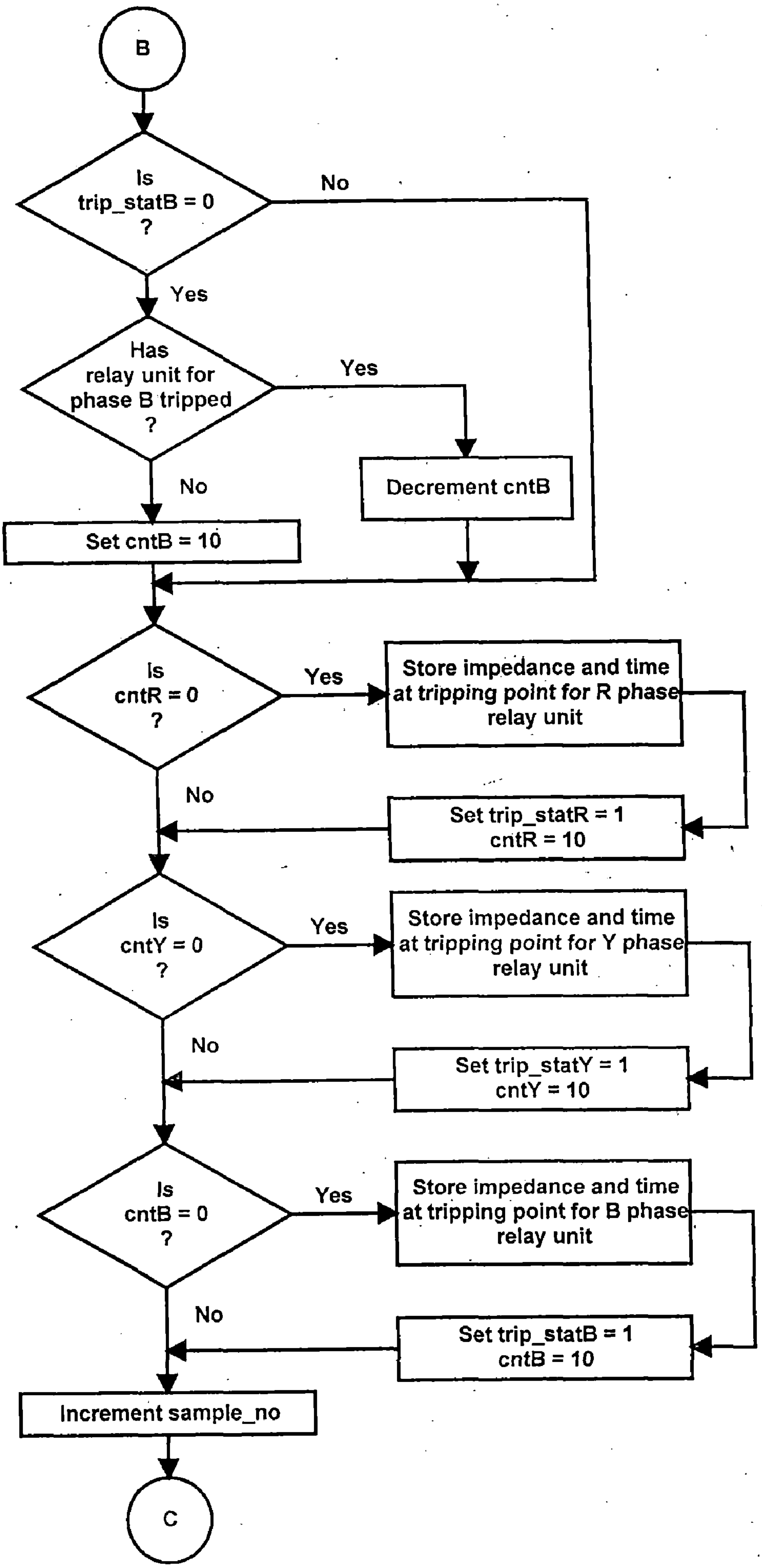
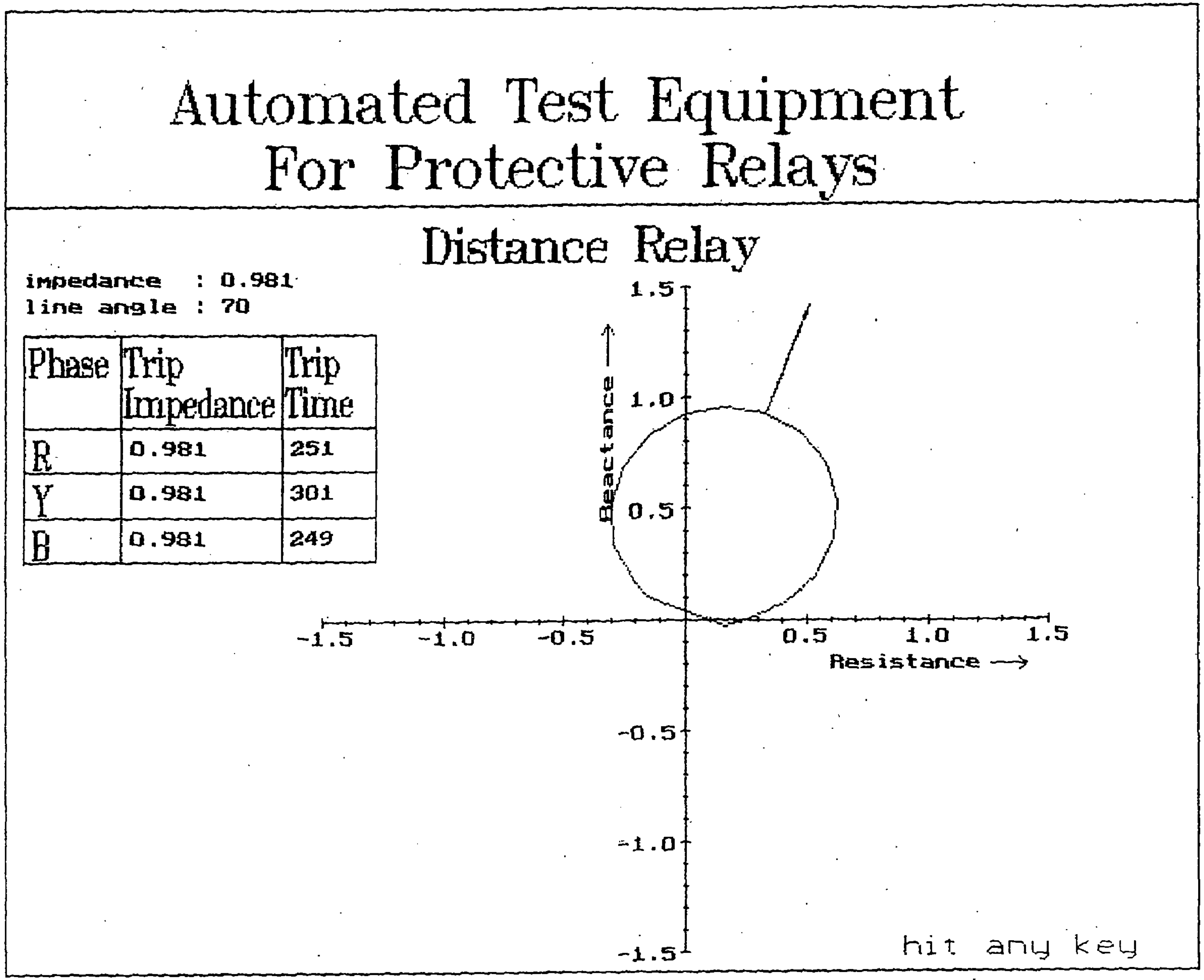


Fig. 5.1 : Flowchart for 3-Phase Dynamic trip-Locater



Phase	Trip Impedance	Trip Time
R	0.981	251
Y	0.981	301
B	0.981	249

Fig. 5.2 : Three-Phase Dynamic Trip-Locater

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

This dissertation work presents an automated test equipment developed for dynamic testing of protective relays. This computerized test equipment may offer following advantages over conventional test systems :

(i) This test equipment is much more accurate, reliable, devoid of human errors and less expensive as compared to the conventional methods. Conventional testing methods are quite complicated and time consuming. Massive test benches having variable current/voltage sources, autotransformers etc. are used for relay testing. A mini power system is simulated in the laboratory and the testing is expensive and complex.

As compared to this, a P.C. with its immense programmable features and a minimum of hardware is sufficient to conduct tests on the relays. A single equipment with different software for different relays may serve the purpose of testing. High performance data acquisition card and timer is placed in the PC. Hardware circuit developed for filtering is cheap and simple.

(ii) This automated test equipment provides great flexibility in testing. The relays can be tested for any simulated fault conditions. Practically any signal waveform can be generated on the computer. In case of conventional methods, the exponentially decaying fault current is simulated by the use of circuit components (capacitances, resistances, inductances etc.). Library functions to compute sine, cosine, exponential etc. are available in high level languages. So this automated test system offers greater flexibility and accuracy in the waveform generation and is therefore a better means to test the relay under actual fault conditions.

(iii) Testing with this automated test system requires minimum manual effort. Test sequences can be repeated for any number of times without any difficulty. Test readings need not be taken down on paper and then records made, as in case of conventional methods. The data/results/readings can be easily stored on hard disks, floppies or other mass storage devices. Human errors in measurements, parallax removal and listing of readings are completely eliminated in case of this prepared test equipment.

In conventional methods the test readings have to be first taken down on paper and then the graphs/characteristics are prepared manually. Human errors are very likely and also the procedure is quite tedious and time consuming. As against to this automated test equipment itself prepares graphs/characteristics using inbuilt library functions of graphics. These graphs are plotted on-line as the test procedure progresses. Even to plot these characteristics in later times, we don't need to perform tests again but the testing results obtained during tests and stored in data files in either computer hard disk or floppies can be used.

(iv) On-line displays of parameters and characteristics /plots make this method of relay testing a real time approach. This automated test equipment gives sufficient information regarding the progress in testing stages. Graphical user interface provided, makes this automated test equipment very convenient and easy to operate.

Comprehensive testing procedures for distance relays were developed and testing was carried out on a Mho relay, however, the testing software is so generalized that any type of distance relay can be tested. Most of the testing aspects for distance relays have been covered and every possible information is provided over screen on-line.

6.2 FUTURE SCOPE

Some of the future aspects which may be obtained in automated relay testing are :

(i) In present test equipment, only the dc transient has been incorporated. Similarly, a.c. transients can also be easily introduced in the test signals. Only some modification in the sample calculation program is needed. In fact test signals can be generated using data obtained by Electro-Magnetic Transient Programs (EMTP).

(ii) In present work, primarily the distance relay testing has been dealt with. The distance relay testing is more elaborate and difficult to implement than any other relay testing, since it requires two inputs (for single phase relays) and six inputs (for 3-phase relays). Other types of relay testing requiring lesser number of inputs can easily be implemented with some modifications in the software.

(iii) The present test equipment is capable of testing low power static relays only. Relays requiring high power level can be tested by this approach by employing high power, high quality amplifiers between the DAC outputs and the relay.

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PCL 726 : AN INTRODUCTION

PCL 726 introduced by Dynalog Micro Systems is an add on card which can be plugged into any IBM/PC/XT/AT compatibles. It provides a high performance Digital to Analog Conversion (DAC). Its application area include simulation of analog signals, Industrial control and data transmission, motor control and robotics.

MAIN FEATURES :

- 6 independent D/A output channels.
- 12 bit resolution, double buffered D/A converters.
- 16 digital input and 16 digital output channels. They are all TTL compatible.
- Multiple Voltage Range :
  Unipolar : 0 to 10 V, 0 to 5 V
  Bipolar : +/ -10 V, +/ - 5 V

D/A Application

The PCL 726 provides D/A channels which use double buffered 12 bit multiplying D/A converters. The D/A registers are write registers which use addresses BASE 10 to BASE 11.

While programming D/A channels, the most significant byte (high byte data) is sent first. It is then temporarily held by a register and is not released to the D/A converter. After the least significant byte (low byte data) is written, the low byte data and high byte are added and passed to the D/A converter at the same time. This double buffering process protects the D/A data integrity through a single step update.

Connectors CN3 and CN4 support all D/A signal connections. The connector CN3 was used in this project. The pin assignment for CN3 is as follows :

Courtesy Technical Manual of PCL 726 card by Dynalog India Ltd.

CONNECTOR 3 (CN3) - D/A OUTPUT (CH#1 TO CH#3)

SIGNAL NAME	PIN NO.	PIN. NO.	SIGNAL NAME
-5 V REF OUT	1	2	-10 V REF OUT
-5 V REF OUT	3	4	-10 V REF OUT
D/A#1 V OUT	5	6	D/A#1 I OUT
D/A#1 REF OUT	7	8	A. GND
D/A#2 V OUT	9	10	D/A#2 I OUT
D/A#2 REF IN	11	12	A.GND
D/A#3 V OUT	13	14	D/A#3 I OUT
D/A#3 REF IN	15	16	A.GND
A.GND	17	18	A.GND
NC	19	20	NC

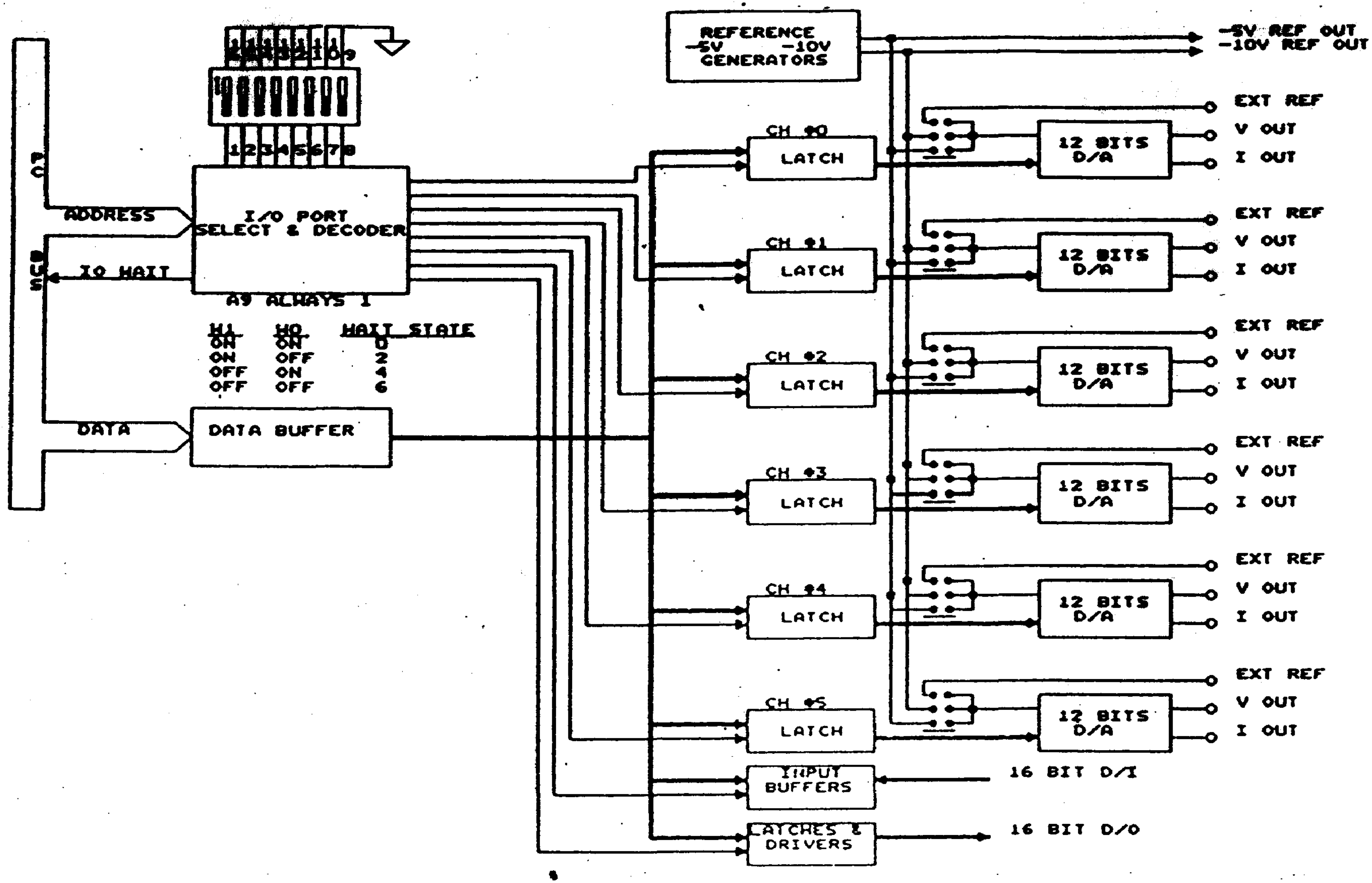
Digital Input & Ouput

The PCL 726 provides 16 digital input and 16 digital output channels. It is fairly straight forward to program the digital input and output channels.

Connectors CN2 was used for digital input. Its pin assignment is as follows :

CONNECTOR 2 (CN2) - DIGITAL INPUT

SIGNAL NAME	PIN NO.	PIN. NO.	SIGNAL NAME
D/I 0	1	2	D/I 1
D/I 2	3	4	D/I 3
D/I 4	5	6	D/I 5
D/I 6	7	8	D/I 7
D/I 8	9	10	D/I 9
D/I 10	11	12	D/I 11
D/I 12	13	14	D/I 13
D/I 14	15	16	D/I 15
D.GND	17	18	D.GND
+5 V	19	20	+12 V



BLOCK DIAGRAM