AUTOMATED [redacted] TEST EQUIPMENT FOR PROTECTIVE RELAYS

A DISSERTATION

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for the award of the degree of

MASTER OF ENGINEERING

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Department of Electrical Engineering

with specialization in

MEASUREMENT AND INSTRUMENTATION

By

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(ANUJA KHIRWADKAR)

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled, AUTOMATED TEST EQUIPMENT FOR PROTECTIVE RELAYS , 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, submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee (INDIA), is an authentic record of my own work carried out for a period of about seven months from September, 1988 to March, 1989, under the supervision of Dr. H.K. Verma, Professor, Department of Electrical Engineering, University of Roorkee, Roorkee, INDIA.

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

Dated: March ,1989 (ANUJA KHIRWADKAR)

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

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ABSTRACT

An AUTOMATED TEST EQUIPMENT FOR PROTECTIVE RELAYS has been designed in this dissertation work. The motivation behind choosing this topic, lies in the importance of relay testing and the possibility of performing this time consuming, complicated task with the help of a microcomputer. Accurate and thorough testing of relays is very essential to ensure that the protective gear always operates reliably on fault.

A microcomputer supported data acquisition system has been used to test basic static (electronic) relay circuits. Programs have been written in advanced BASIC to evaluate the performance of various relays under steady state and dynamic conditions.

Over voltage, differential, directional, impedance and the admittance relays have been thoroughly tested in the laboratory and their operating characteristics (static and dynamic) displayed on the C.R.T. screen. The tests are highly automated, with a minimum of manual intervention required. It is suggested that this microcomputer based test system would lead to an economic, more accurate, efficient, less time consuming and reliable testing of relays, as compared to the conventional methods used. An ARTIFICIAL TRANSMISSION LINE used for dynamic testing of relays is very expensive and complicated. As against this, dynamic testing by this automated test system would be much cheaper, easier and flexible as well.

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CHAPTER I

INTRODUCTION

An Automated Test Equipment for protective relays has been designed in this dissertation work. Efficient protective relaying is very essential for reliable and safe operation of a power system. The stringent standards set for relay testing lead to the possibility of automation in this field, making it more accurate and efficient.

1.1 IMPORTANCE OF RELAY TESTING

The purpose of an electrical power generation and transmission system is to generate and distribute electrical energy to a multiplicity of points, with minimum possible discontinuity in service. Continuity of service is very essential in hospitals, industries and at many more places. Occurrence of faults, short circuits etc. can not be avoided on long, exposed, transmission and distribution lines.

The function of protective relaying is to cause prompt removal from service of any element of a power system when it suffers a short circuit, or when it starts to operate in any abnormal manner that might cause damage or otherwise interfere with the effective operation of the rest of the system[1]. Fires due to short circuits, damage to life, property, costly equipments etc. can be prevented (with minimum discontinuity of service) only with the help of effective, selective, highly discriminative, speedy and reliable fault relaying. Thus relays should always maintain their operating characteristics and operate reliably under faulty conditions.

The stringent standards that a protective relay has to maintain throughout its life, increases the importance of accurate relay testing. The importance of reliable operation of protective relays is so great that all possible means should be employed to ensure that the protective gear always operates correctly on the occurrence of a fault. Testing and maintenance is therefore of immense importance for protective gear.

1.2 NEED FOR AUTOMATION

Thorough and vigorous testing of relays (apart from accurate design) is the only tool available, to try and ensure their reliable operation.

The testing of protective gear has always been a problem because it is solely concerned with fault conditions and therefore testing under normal operating conditions does not always give realistic results[2]. The conventional methods of relay testing using massive test benches and artificial transmission lines which are capable of simulating a mini power system in the laboratory, are explained in the next chapter. These are complicated, time consuming and expensive methods of testing. Above all, human intervention is required in these tests, leading to possible, unavoidable errors. This would impair quality of testing. An automated, computer based approach would increase the accuracy and reliability of relay testing. Human errors would be completely eliminated and testing would become simpler, less complicated, expensive and exhaustive. Tests would also become more flexible. The mass storage capabilities of a computer can be used to store results, records etc. An attempt has therefore been made to computerize the exhaustive and complicated task of relay testing.

1.3 REVIEW OF EARLIER WORK

Before venturing to prepare an automated test equipment for protective relays, some literature survey on the work done in this field was carried out.

The paper by G.W. Swift, et.al. deals about an Automated Test system for Distance Relays[3]. They have prepared a minicomputer based relay testing equipment. Programs were written in assembly language for the steady state tests and BASIC language for the dynamic tests. An experimental set up for a distance relay has been tested under both the steady as well as the dynamic conditions.

The second paper by R.G. Coish, et.al. has described a method of minicomputer based performance evaluation of protective relays.[4] The purpose was to determine the operating characteristics of commercial distance relays under simulated field conditions and display the characteristics on video screen. Amplifiers were used at the O/P of the digital to analog converters to step up the signal amplitudes.

The present A.T.E. (automated test equipment) is microcomputer supported that results in a less expensive test system as compared to the ones described in the two papers mentioned above. Experimental static relay circuits (over-voltage, differential, directional, impedance and admittance) have been tested with the help of this less complicated test system and results/characteristics displayed on the CRT screen. The data acquisition system described in Appendix A is used for this purpose. Simpler hardware, instead of the analog to digital converter is used to monitor the trip signal of the relay. Though only static relay circuits have been tested, electromechanical relays can also be tested, if amplifiers are used. The test programs have been written in advanced BASIC. There was no need to prepare complicated assembly language routines for hardware access as a special software package (described in Appendix A) with easy commands to communicate with the external hardware (Digital to analog converters, etc.) is provided with the data acquisition system. Thus the presently prepared test system is less expensive and also much less complicated.

1.4 ORGANIZATION OF THESIS

The present thesis work deals with the design of an AUTOMATED RELAY TESTING EQUIPMENT . The entire work is divided into five major topics. Importance of relay testing, with special reference to its automation and the review of previous work done in this field,is discussed in the present chapter (i.e. Chapter I).

Chapter II deals with the existing, conventional methods of testing different types of relays.

Chapter III discusses the microcomputer supported test procedures used for testing the single and double input relays. Test results/operating characteristics for over-voltage, differential and directional relays are also given in this chapter.

In view of the importance of distance relay testing, distance relays have been separately dealt in Chapter IV. Generalized test programs for distance relays have been discussed here. The test results/operating characteristics for basic, impedance and admittance relay circuits are given at the end of this chapter.

The last chapter, i.e. Chapter V gives the conclusions and stresses upon further modifications and enhancements that can be made in this test equipment.

A brief description of the Data Acquisition System used is given in Appendix A.

The listings of the test programs are given in Appendix B.

CHAPTER II

CONVENTIONAL METHODS OF TESTING RELAYS

The testing of protective relays has always been a problem, as they are solely concerned with fault conditions, and cannot therefore be readily tested under normal system operating conditions[5]. Abnormal conditions under which relays are supposed to operate, have to be first simulated in testing laboratory and then the job of testing has to be performed meticulously.

2.1 TESTING STAGES, OBJECTIVES AND FACILITIES

Protective gear testing can be divided into three stages:

(A) Factory Tests

(B) Commissioning Tests

(C) Periodic Maintenance Tests

The first two stages prove the performance of the protective equipment during its development, manufacture and in its operational environment.

The third stage, when properly planned, ensures that this performance is maintained throughout the life of the relays and that they always conform to specifications.

A brief description of the above tests follows:

2.1.1 FACTORY TESTS

These are the tests conducted by the manufacturer. It is the responsibility of the manufacturer to provide adequate, elaborate and efficient testing of all the protective gear before it is accepted and commissioned.

These tests are aimed to verify the performance of the relays as per the declared specifications and characteristics.

Since the prime function of protective relays is to operate correctly and efficiently under abnormal power conditions, such conditions are simulated in testing laboratory, and the relay performance assessed.

The factory tests performed can be divided into two main groups. The first group includes those tests in which the operating parameters of the relay are simulated. There are a multitude of relays, having different operating parameters and characteristics and therefore they require different test procedures also.

But generally speaking one groupof tests which is meant to determine operating parameters and characteristics, require the following testing equipment.

(i) Test benches to perform STATIC TESTING of different relays

(ii) Artificial Transmission line to perform DYNAMIC TESTING of relays

(iii) High current test benches etc.

The second group of tests are meant to verify the relay performance under adverse environments.

(a) Static Testing Benches

The test benches for STATIC TESTING are normally provided with caliberated current and voltage supplies, precision grade ammeters, voltmeters, and accurate timing devices. The facilities provided on the test benches vary, depending on the type of relay to be tested.

(b) Artificial Transmission Line and Dynamic Testing

The purpose of an artificial transmission line is to closely duplicate the secondary values of the electrical conditions, that would occur during a fault on a power system.

An artificial transmission line is used for performing dynamic tests on relays. Generally, an artificial transmission line provides an adjustable current or voltage or both at the relaying point, with control of circuit time constant, duration of fault, point-on-wave at which the fault is applied, magnitude controlled source impedance in each phase (mostly the angle of impedance is kept at 85^{o} and uncontrolled), C.T. ratio adjustment facility so that the line impedance value as seen by the relay can be finely changed, and many more such facilities that aid dynamic testing of relays.

(c) High Current Test Facility and Testing

In protections, based on the comparison of the currents at the two ends of the protected part or unit of the system, it is very essential to check the through/external fault stability of the relay.

The fault conditions more onerous in this respect, are those involving high fault currents, with large time constants for the transient component of the fault current.

Test benches are available to test the through fault stability of unit protections.

Facility is provided to produce high fault currents. Reactors are available to vary the X/R ratio. Resistances are present to lower X/R ratios.

The fault can be applied at any point on the voltage waveform. So different type of faults with varying durations can be simulated.

(d) Environmental Tests

In this group of factory tests, conditions like temperature, vibration, mechanical shock, electrical impulse and so on, which might affect the correct operation of the relays, are simulated.[5] The testing equipment required for these tests are as follows:

(i) Vibrator

(ii) Climatic Simulator

(iii) Impulse Test Equipment

(iv) High Frequency Interference Equipment

(v) Impact Test Equipment

2.1.2 COMMISSIONING TESTS

These are the tests to be performed during commissioning of equipment. They have to be carefully planned and records to be kept, which will be useful in further maintenance of the relays. The work starts with collection and study of complete information on the system.

The commissioning tests normally carried out are summarized below:

(i) Making a general inspection of the equipment, checking all connections, wires on relay terminals, labels on terminal boards etc.

(ii) Measuring the insulation resistance of all circuits.

(iii) Testing main current transformers for ratio and polarity, and checking points on the magnetization curve.

(iv) Testing main voltage transformers for ratio, polarity and phasing.

(v) Inspecting and testing the relays by secondary injection.

(vi) Checking the equipment by primary injection to prove stability for external faults and to determine the effective current setting for internal faults.

The secondary injection tests involve injection of current and voltage directly into the relays to prove that the relay has not been damaged in transit and that its calibration is generally correct.[6] For these tests, portable test sets are available. They are designed to work on the commercially available low-voltage, single or three phase supply. Because of the aforesaid purposes of the secondary injection tests, it is unnecessary to have precision grade measuring instruments on these test sets. To facilitate these tests, (without disturbing the wiring), the following are provided:

(a) Test blocks or sockets

(b) Test plugs

(c) Test switch and sockets

These tests are explained for different types of relays in the ensuing paragraphs.

The primary injection tests consist in injecting heavy currents into the C.T. primaries and energizing VTs where necessary. The purpose is to prove that the CTs and VTs are properly connected to the relays. Emphasis is on proving the sensitivity of relays to internal faults and stability on external faults. Some tests are feasible only on load. Primary injection test sets or alternators are used to provide the high currents required for these tests.

2.1.3 PERIODIC MAINTENANCE TESTS

Although the relays may be in sound condition when first put into service, many troubles can develop unchecked and unrevealed because of its infrequent operation. Relays may remain inoperative for long, but should be capable of operating, when faulty situations arise. Thus periodic maintenance of relays is very essential.

Secondary injection tests should be carried out to check the relay performance (primary injection tests, once performed during commissioning, need not be repeated again), and if possible the relay should be allowed to trip the circuit breakers. The results of these tests should be checked against those obtained during commissioning. Insulation tests should also be carried out to detect any deterioration in insulation resistance.

Each of the tests mentioned above, has its own importance and should be carried out meticulously, thus leading to a reliably protected power system. Efficient testing of relays, eliminates chances of protection failure on faults.

2.2 TEST PROCEDURES

Above was a general description of the tests required to be conducted and the test equipment used. Now, we come to the different test procedures adopted depending upon the type of relay being tested.

As is very well known, a relay basically performs an act of measurement of system current, voltage, impedance, phase angle, frequency etc. (depending upon the type of relay), compares the measured value with the safe value and gives a trip output if the result of comparison so dictates.

There are two types of relays, namely, electromechanical and static. In the electromechanical relays, there is an electromagnet, whose operating coil is energized by the operating quantity. A spring or another coil energized by the restraining quantity, provides mechanical restraint, and when the operating electromagnetic force produced is larger than the restraint force, the relay contacts close.

A static relay incorporates solid state components like transistors, diodes, resistors, capacitors etc. and has no physically moving parts. The act of measurement and comparison, as well as the decision making is performed by the static relay circuits. Unlike the electromechanical relays, the output response of such relays is not in the form of opening or closing of contacts, but as a low or a high voltage signal.

2.3 TESTING OF INSTANTANEOUS OVER/UNDER VOLTAGE AND CURRENT RELAYS

An INSTANTANEOUS OVER CURRENT RELAY is designed to operate when the characteristic quantity, which is current in this case, is higher than the relay's pick up value, without any intentional time delay. Similarly, the over voltage and under voltage relays operate above and below preset threshold values.

2.3.1 STATIC TESTING

Elaborate static testing to done on special test benches by the manufacturer. The relay restrains below its designed pick up value and operates above pick up. To confirm that the relay performance matches its specifications, slowly increasing currents are fed into the relay and operating current noted.

The test bench used to obtain this characteristic has the following facilities:

(i) A variable current source with coarse and fine controls and a current limiting reactor (to reduce the harmonic component of the current fed).

(ii) Precision grade ammeter to measure the operating current.

To obtain the characteristics of an over and under voltage relay, variable voltage source is used and the pick up value noted.

2.3.2 DYNAMIC TESTING

Dynamic testing is the performance evaluation of relay under actual (fault) conditions. The conditions (system parameters like voltage, current, frequency etc.) under which the relay has to operate on actual fault, are very much different from the static conditions under which the relay is tested in static tests. The current at which an over current relay is supposed to operate is not approached gradually, (from normal current onwards) as is done in static tests.

In fact, when the fault occurs, the fault current undergoes a transient with a finite d.c. offset. The instantaneous fault current is much higher than its steady state value. The amount of d.c. offset depends upon the point on voltage waveform at which the fault occurs, being maximum when the wave is passing through zero. The relays tends to over reach in such situations. How fast

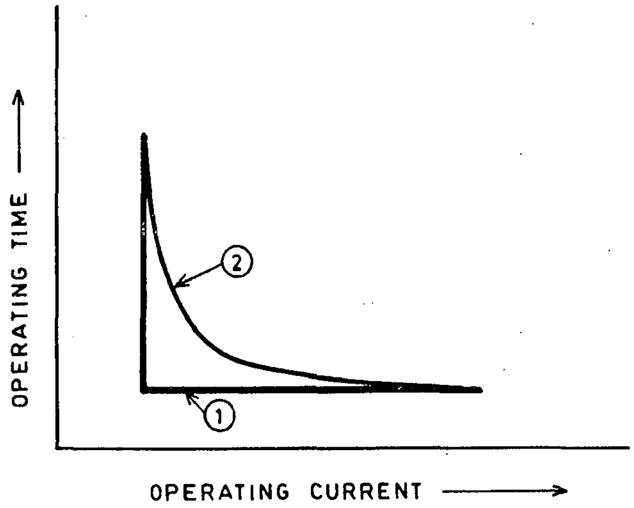

FIG. 2·1 OPERATING TIME CHARACTERISTIC FOR INSTANTANEOUS OVERCURRENT RELAY

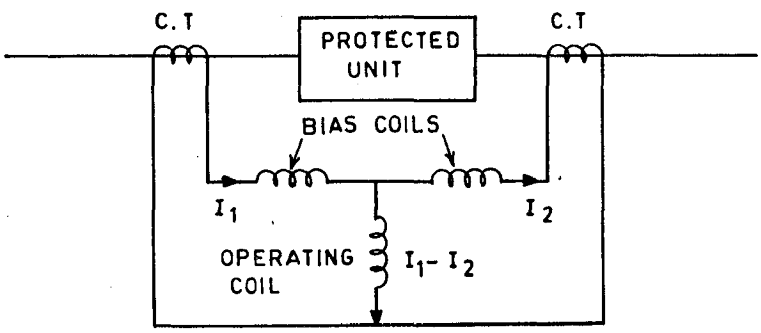

FIG. 2·3 BASIC CKT. FOR BIASED DIFFERENTIAL PROTECTION value and operates above pick up. To confirm that the relay performance matches its specifications, slowly increasing currents are fed into the relay and operating current noted.

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Relaying should be highly discriminative and therefore the operation of relay under dynamic conditions has to be essentially assessed. An artificial transmission line, described before, is capable of performing these dynamic tests. It has the facility to provide adjustable current at relay point with control of circuit time constant, duration of fault, point-on-wave at which the fault is applied and the type of fault. These facilities enable simulation of the actual circumstances under which the relay has to operate. The degree of over-reach of the relay can be determined by these tests.

The tests performed ton the voltage relays are similar to those for the over current relays.

2.3.3 SECONDARY INJECTION TESTING

As mentioned before, these are simple, less detailed relay tests performed during commissioning.

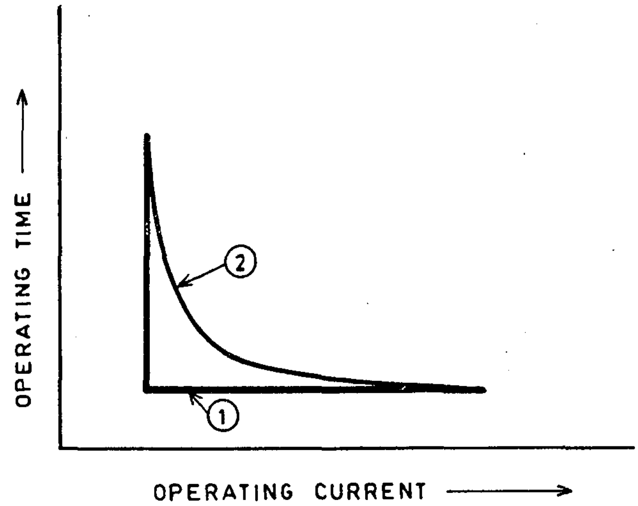
A typical set for over-current relays works on single-phase 240V supply and has the following facilities[6]:

(a) Current control by reactors.

(b) Current range selection by C.T. taps.

(c) Rugged nonprecision grade ammeter.

(d) Relay shorting switch. This switch shorts the relay coil when current is being adjusted, to avoid heating, when current has to be applied to the relay coil, the switch is unshorted.



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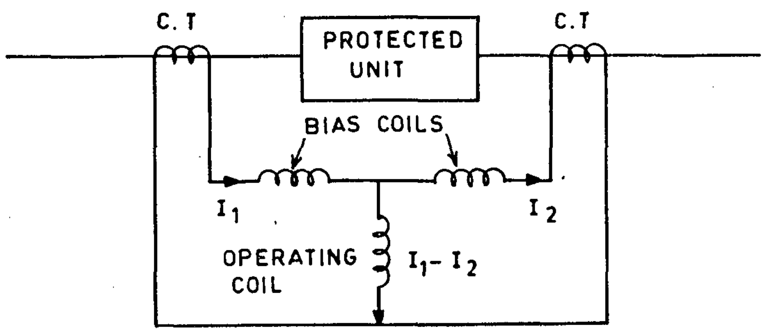


FIG. 2·3 BASIC CKT. FOR BIASED DIFFERENTIAL PROTECTION

Over-current relays should be tested for the following:

(a) Pick up current values at minimum, maximum and chosen settings.

(b) Reset current values at above settings.

Over Voltage and under voltage relays have similar tests except for the varying voltage being applied instead of current as in the over current relays.

2.4 TESTING OF TIME LAG OVER/UNDER CURRENT AND VOLTAGE RELAYS

These relays are provided with intentional time delay. The definite time delay relays have a fixed operating time, irrespective of the magnitude of fault current flowing. The operating time characteristic of a definite time delay, over current relay is as shown in Fig. 2.1.

The operating time of IDMT relays tends to become asymptotic to a definite minimum value with increase in the value of current. This is inherent in electromagnetic relays due to saturation of the magnetic circuit.

Static tests for these relays are similar to those explained for instantaneous relays, except for the necessity of measuring the operating time of the relay as well. Therefore test benches for performing static tests of these relays include timers too. Electronic timers or storage oscilloscopes may be used for this purpose.

Noting the operating time of the relay for different values of fault currents, above the pick up of the relay, helps to plot the operating characteristics.

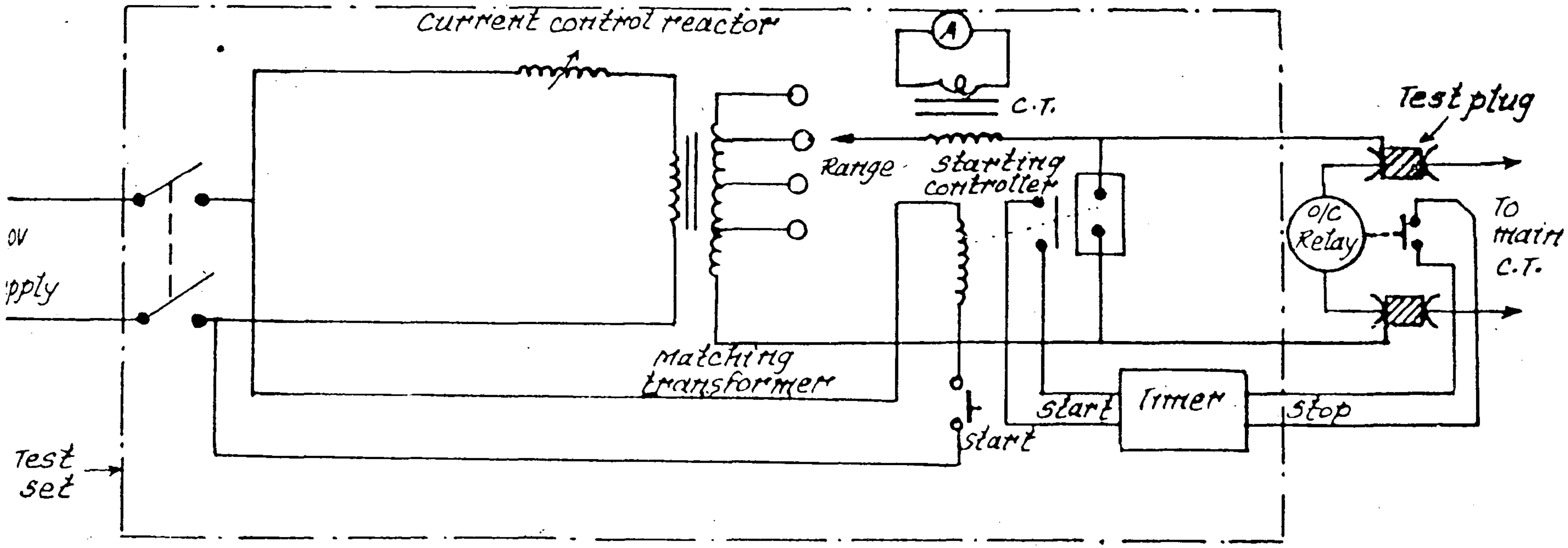


Fig 2.2. Secondary injection testing of time-lag o/c relay.

Dynamic tests are not needed as the transients are over much before the relay operates.

Time lag O/C relays have similar secondary injection tests, except for the following tests:

(i) Operating time at the an appropriate value of current is measured in case of definite time relays, and at two or three points on the time-current curve at TMS = 1 for I.D.M.T. relays.

Fig. 2.2 shows the salient details of a typical portable test set and its use for testing a time lag O/C relay.

2.5 TESTING OF BIASED DIFFERENTIAL RELAYS

A relay is defined as a differential relay, more because of the way it is connected for unit protection in the system than its actual characteristics.

The relay in its electromechanical version has $(I_1 - I_2)$ an operating coil through which flows the differential current which becomes higher than the restraint current flowing through the bias coil $(I_1 + I_2/2)$ under internal fault conditions. Refer Fig.2.3 For high external faults, the high torque produced by the restrain coil prevents the relay from operating, otherwise C.T. saturation would have resulted in faulty relay operation for a relay withous bias.

A static differential relay generally has two rectifiers supplied from the difference and through currents, respectively. Their outputs are compared by an electronic circuit or a sensitive slave relay.

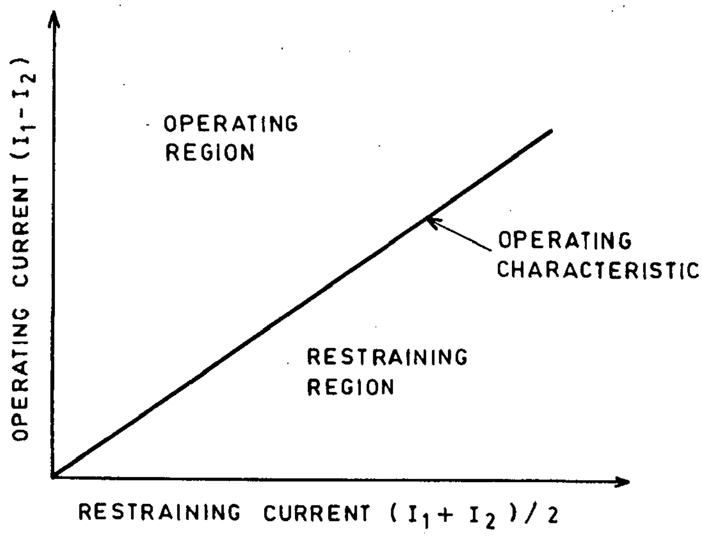


FIG. 2·4 CHARACTERISTICS FOR BIASED DIFFERENTIAL RELAY

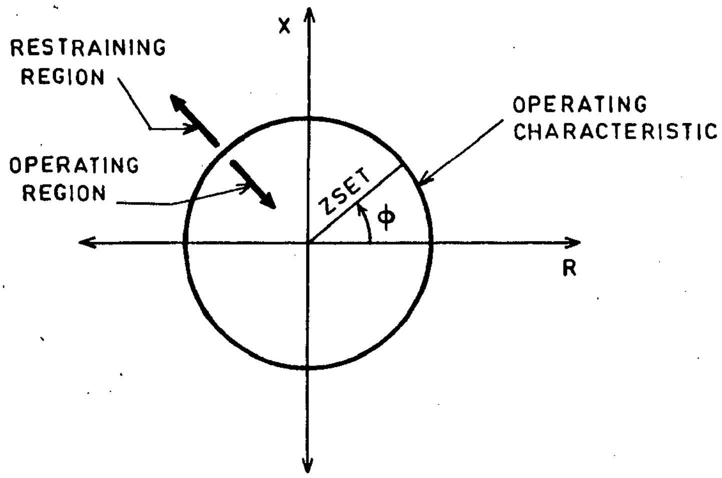


FIG. 2·8 R-X DIAGRAM FOR IMPEDANCE RELAY

The characteristic of a biased relay is as shown in the Fig. 2.4. The percentage bias and the slope of the characteristic depend upon relay design.

2.5.1 STATIC TESTING

In static testing, the relay performance has to be judged under steady state conditions and the graph between the operating and restraining current obtained. The slope of the curve gives information about the amount of percentage bias.

Testing benches are available at the manufacturer's laboratory to evaluate differential relays' performance. Two variable current sources are incorporated, a main source for high currents and an auxiliary one for low currents. Electronic timers or storage oscilloscopes are available to note the operating time of the relay. Starting contactors, precision grade ammeters and other facilities are available on such a bench.

Varying values of currents are sent through the bias coil and the operating current noted, at trip. Operating time is also measured.

2.5.2 DYANMIC TESTING

Biased differential relays should exhibit complete through fault stability, under dynamic conditions, as fault relaying should be highly discriminative. As mentioned before, the short circuit or fault current undergoes a transient, with a finite d.c. offset, before it comes to steady state. Such an asymmetrical current applied to a current transformer will induce a flux, which is

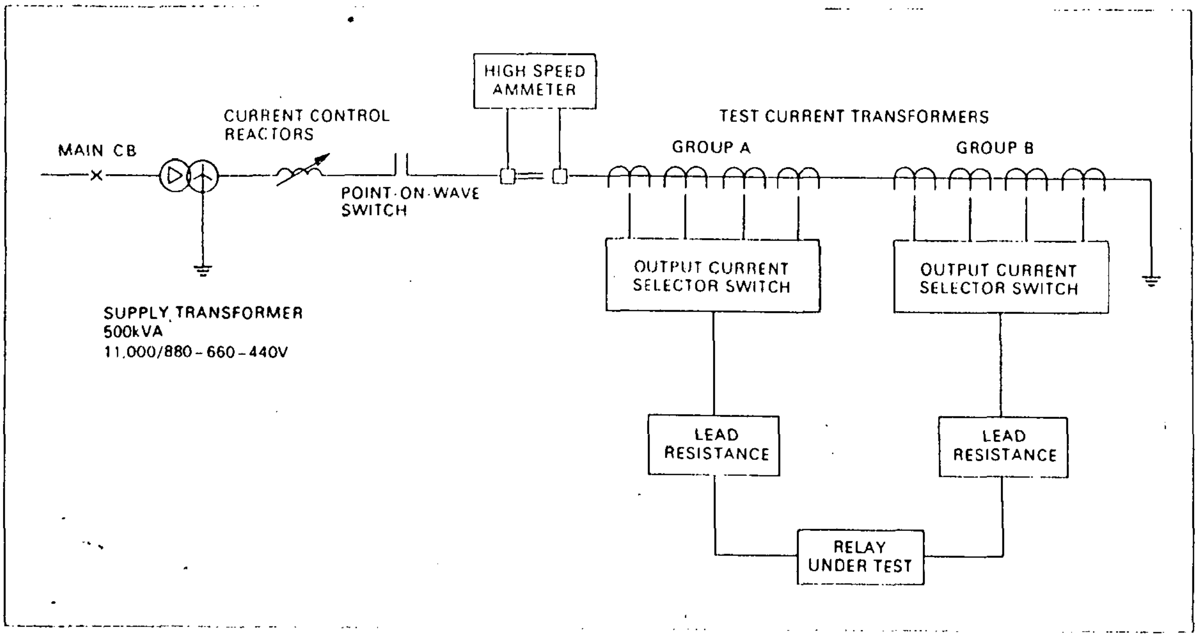


Fig 2·5 Medium current test plant

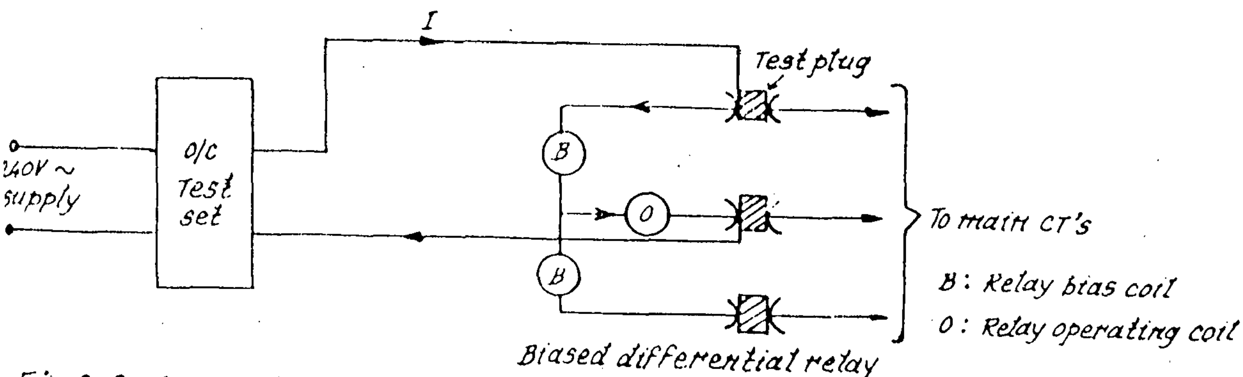


Fig. 2·6 . Current setting test on biased differential relay.

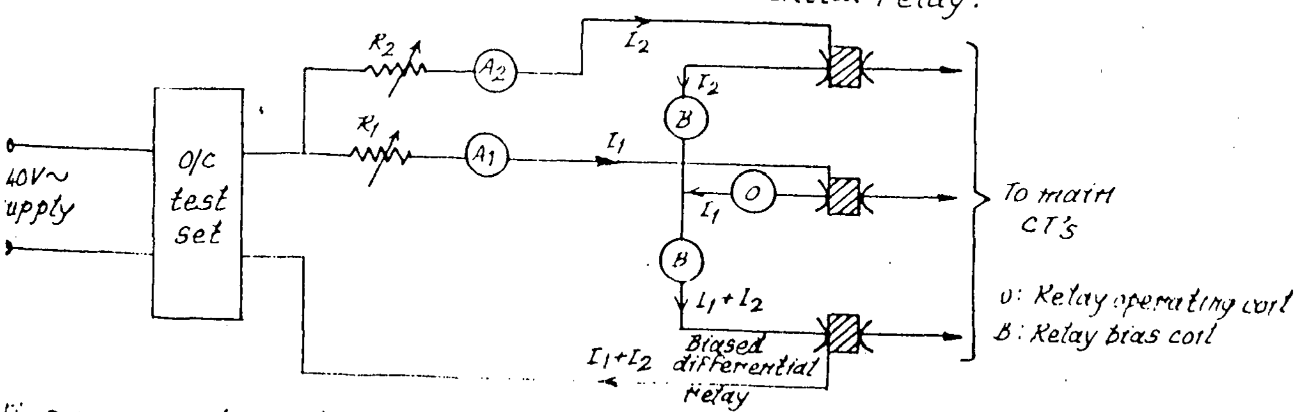


Fig. 2·7 Bias characteristic test on biased differential relay.

greater than the peak flux corresponding to the steady state alternating component of the current.[5] This may take the C.T. into saturation, reducing the dynamic exciting impedance and increasing the exciting current greatly. If now, the current transformers on either end of the protected unit differ in excitation characteristics, then the transient build up flux will differ and an excessive spill current may maloperate the relay.

To check the through fault stability of a differential relay, high current test benches are available. A typical test plant is as shown in the Fig.2.5. Reactors are available to give different fault currents and X/R ratios. Variable voltage sources, high speed measuring ammeters, resistor banks for simulation of the lead burden in secondary side of the C.Ts. and many more facilities like the one to vary the point-on-voltage at which fault occurs, are present. Fault currents with different time constant and varying degrees of d.c. offset are sent, and the ability of the relay to restrain under these conditions tested. Whether the relay operates or not on heavy internal faults is also tested. C.Ts. saturation, sometimes causes failure of operation.

2.5.3 SECONDARY INJECTION TESTING

These tests are carried out during commissioning, to prove that the relay has not been damaged in transit and that its characteristics conform to the ones specified by the manufacturer.

The current settings of the relay can be tested by an arrangement shown in the Fig.2.6.[6] It is basically an over current test set. Variable current source injects current into one bias coil and out of the operating coil. The point where relay operates is noted. In addition to this, a check can be made at one or more points on the bias characteristic, with the arrangement shown in Fig. 2.7 , wherein two ammeters and two rheostats are used to measure current and vary current, respectively.

The ratio of the operating current (measured by ammeter A_1) to restraining current (given by the reading of A_2 plus half of the reading of A_1) should tally with the corresponding point on the bias curve supplied by the manufacturer.

2.6 TESTING OF DISTANCE RELAYS

Distance relays are high performance, high speed, non unit type of relays. Impedance of a transmission line being directly proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a given point.[5] Such a distance relay's setting is equal to the impedance of the line to be protected and operates only for faults occuring between the relay location and the selected point.

The basic principle of measurement involves the comparison of the fault current seen by the relay, with the voltage at the relaying point. If V/I is less than the set value, then the relay trips otherwise restrains.

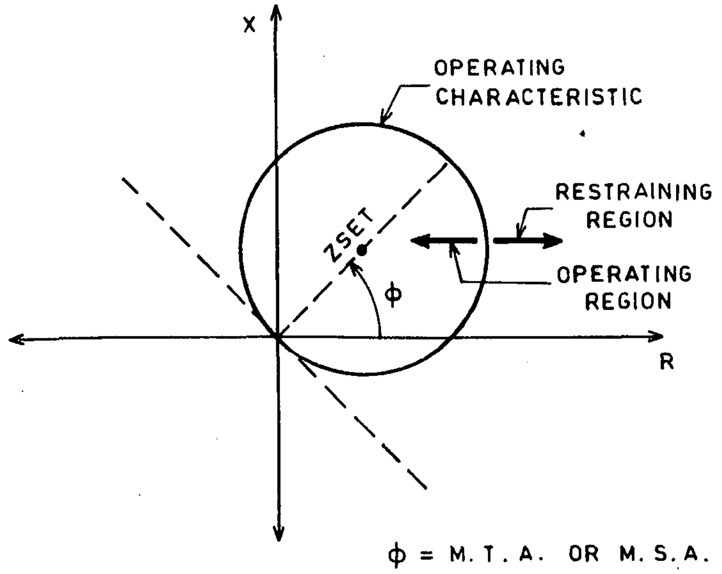


FIG. 2·9 R-X DIAGRAM FOR ADMITTANCE RELAY

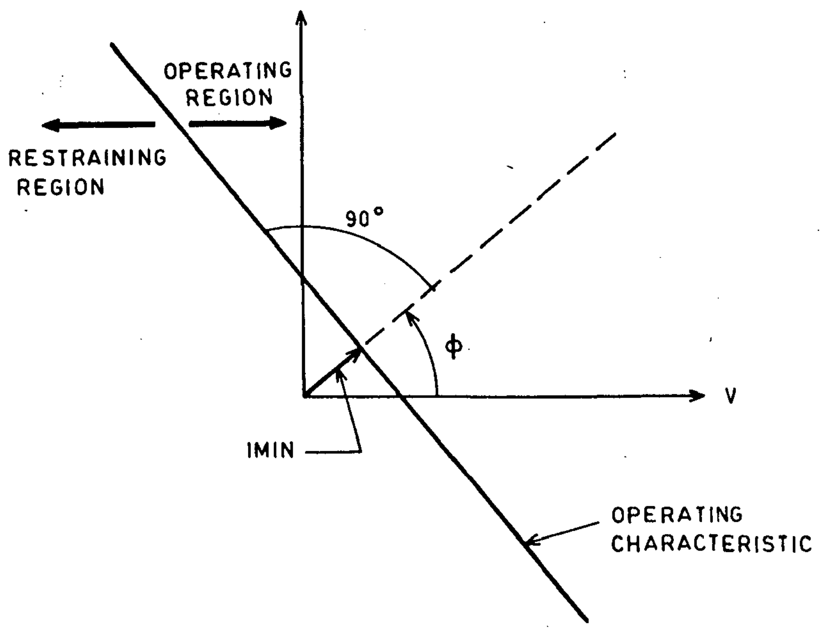


FIG. 2·10 OPERATING CHARACTERISTIC OF DIRECTIONAL RELAY ON POLAR PLANE

The R/X diagram of an impedance relay is shown in Fig.2.8 and that of an admittance relay in Fig.2.9.

2.6.1 STATIC TESTING

Through these static tests, the polar characteristics of the distance relays are obtained. They give information of the relay reach (This is equal to the radius of the circular characteristic of an impedance relay. For an admittance relay, the reach is different for different values of line angle) and the maximum torque angle (in case of electromagnetic relays) or maximum sensitivity angle (in case of static relays). The angle between the voltage vector and the current vector, for which maximum operating torque (or operating tendency) is produced is known as the M.T.A. (or M.S.A.).

In these tests, the voltage applied to the relay restraining coil is maintained constant. At different values of line angle then the operating current is gradually increased, till the relay operates. The characteristic can then easily be plotted on the R-X diagram.

Test sets are available with the following facilities:

(i) Variable voltage and current sources

(ii) Controlled phase angle of the voltage supply w.r.t. the current supply. A phase shifting transformer is incorporated in the voltage circuit for this purpose.

(iii) A timer (electronic timer) or a storage oscilloscope is present to measure the operating time of the relay.

(iv) Precision grade ammeter, voltmeter and phase meter are available for measurement.

(v) As usual, a starting contactor is present to apply the fault current.

2.6.2 DYNAMIC TESTING

The operating conditions simulated during the static tests, are not the actual, practical conditions under which the relay has to function.

Fault when occurs, occurs suddenly, thus resulting in an abrupt shoot up of fault current. The short circuit current undergoes a transient, with exponentially decaying d.c. offset (value depending upon the point-on-voltage waveform when the fault has occurred), resulting in possible over reach of the relay.

Z_S/Z_L ratio (Z_S = source impedance, Z_L = impedance of the line being protected) effects the performance of the relay. The voltage at the relaying point does not remain constant (as is assumed in static tests) but drops down, depending upon the Z_S/Z_L ratio. Below a certain value of voltage, the relay is not able to operate.

Thus it is obvious, that test procedures, more complex than the static tests, should be adopted to study and test the relay performance, with varying Z_S/Z_L ratios, different degrees of d.c. offset, different decaying time constants of the line and at different fault positions. Then and then only, can the relay be guaranteed to operate satisfactorily, when connected in a power system.

An artificial transmission line, with its before mentioned facilities, is capable of simulating these dynamic fault conditions.

2.7 TESTING OF DIRECTIONAL RELAYS

These are double input relays whose characteristic quantity is phase angle. Over current, over voltage, impedance relays do not possess inherent directional feature. They operate for fault currents flowing in either direction and therefore can not simply be used on radial feeders and lines with supplies on both the ends. Here directional units are necessary.

2.7.1 STATIC TESTING

Static testing involves plotting the operating characteristic of the relay. It is obtained by plotting the current vector on a polar plane (Refer Fig.2.10). This characteristic clearly indicates the operating and restraining zones of the relay. The M.T.A. = ϕ (in case of electromagnetic relays) and maximum sensitivity angle (in case of static relays) can be obtained from this characteristic. This governs the directional feature of the relay.

Test benches with variable voltage and current sources, controlled phase angle of the voltage supply w.r.t. current supply (a phase shifting transformer is used for this), timer and precision grade ammeters, voltmeters and phase meters are incorporated to perform the static tests.

2.7.2 DYNAMIC TESTING

The directional relays are tested under dynamic conditions with the help of Artificial Transmission Line. This equipment has numerous facilities to simulate the actual fault conditions. As explained before, the actual conditions under which the relay has to function (i.e. a suddenly occurring, exponentially decaying, offsetted sinusoidal, fault current) are different from the steady state conditions and therefore relays have to be surely tested under dynamic conditions.

Refer section 2.1.1 (b) and section 2.3.2. The operating and restraining zones of the directional relay characteristic (plotted under steady state conditions) may undergo a slight change, when obtained under dynamic conditions.

CHAPTER III

AUTOMATED TESTING OF SINGLE AND DOUBLE INPUT RELAYS

The conventional methods of testing relays were explained in the previous chapter. The present chapter deals with a new approach to testing relays, i.e. the automated, computerised approach.

The advent of low burden,electronic (i.e. the static relays) relays, has lead to the possibility of generating low power test signals with the help of a microcomputer. Being able to simulate conditions that resemble the actual operating conditions under which the relay has to operate, the test results obtained by this computerised scheme of testing relays, will give more accurate test results. This provides a better performance evaluation of the relay being tested. Automation increases the speed of testing and eliminates human errors.

A PC-AT based data acquisition system, is used to help evaluate the performance of different relay types. Operating characteristics, graphs etc. are plotted on the C.R.T. screen using powerful graphics with advanced BASIC.

Both the static as well as the dynamic tests can be performed with the help of this test system. Relay manufacturers and large consumers, like the Electricity Boards, interested in maintaining their own relay testing laboratories, can easily adopt this computerised approach.

3.1 TEST REQUIREMENTS OF SINGLE INPUT RELAYS

Before proceeding to explain the test methods used for different relay types, it is necessary to first list the tests, operating parameters/characteristics, for the same.

3.1.1 INSTANTANEOUS OVER CURRENT AND OVER VOLTAGE RELAYS

These are the relays that are sensitive to the magnitude of their characteristic quantities (A quantity, the value of which characterizes the operation of the relay, e.g. current for an over-current, voltage for an over-voltage relay, phase angle for a directional relay, and so on) and operate/reset without any intentional time delay[5].

The operating parameters/characteristics to be determined to get an insight into the relay performance are as follows:

(a) Operating Value

This is the limiting value of the characteristic quantity, at which the relay actually operates. The operating value of the relay, obtained during tests, should tally with the value as specified by the manufacturer.

(b) Reset Value

This is the limiting value of the characteristic quantity at which the relay returns to its initial position.

(c) Returning Ratio

The ratio of resetting to operating value is defined as the resetting ratio. This can be easily obtained after the two values have been separately obtained.

(d) Operating Time Characteristic

With a relay de-energized and in its initial condition, the time which elapses between the application of a characteristic quantity and the instant when the relay operates, is defined as the operating time of the relay.

As mentioned before, these instantaneous relays do not have any intentional time delays, and therefore theoretically the relays have equal, finite, operating times at all the quantities, above their threshold operating, characteristic quantities. This is illustrated in curve 1, Fig. 2.1.

The practically obtained operating time characteristic is as shown in curve 2, Fig. 2.1.

(e) Transient Over-reach Characteristic

An over-current relay is said to over-reach when it operates at a current which is lower than its setting. At the time of fault occurrence, the fault current wave is not symmetrical, but undergoes a transient. The relay is set for symmetrical current but operates in the transient period of the fault current. The degree of over-reach depends upon the amount and time constant of decay of D.C. offset.

A plot between the percentage transient over-reach and percentage d.c. offset gives full information about the relay's tendency to over-reach.

Transient Over-reach = (Operating value with steady state signal - Operating value with d.c. offset)/Operating value with steady state signal.

The characteristic for this relay is plotted for different time constant parameters. If the time constant is small, the transient decays faster, coming to steady state value earlier, thus reducing the degree of over-reach.

3.2 TEST REQUIREMENTS OF DOUBLE INPUT RELAYS

Test requirements for typical single input relays were explained before. Now we come to the double input relays.

3.2.1 MAGNITUDE SENSITIVE TWO INPUT RELAYS

A biased differential relay is a typical example of this kind. Biasing is provided in these differential relay schemes to provide through or external fault stability. A differential relay provides unit protection, by comparing the currents (or voltages in case of voltage balance schemes) on either side of the protected part and operates if the difference or unbalance current is larger than the set value of the relay (this is designed to occur only on internal faults). Such a simple scheme fails, or the relay maloperates on high through fault currents because of unequal C.T. saturation on either side of the unit.

In a biased differential relay scheme, restraint is provided by the secondary through fault current i.e. $(I_1 + I_2/2)$ which is larger than the operating, spill current $(I_1 - I_2)$ under external faults. In case of internal faults, the situation is vice-versa and the relay correctly operates. Refer Fig. 2.3.

The operating parameters/characteristics required to be determined are as follows:

(a) Operating Characteristics

This is a plot between the operating (or spill = $I_1 - I_2$) differential current and the bias current $(I_1 + I_2/2)$.

As explained above, this is the most important characteristic of the relay. Refer Fig. 2.4. As is observed, the magnitude of current to cause operation is not constant, but automatically increases as the through current increases and a definite ratio exists between them (decided by design).

This characteristic gives full information regarding the through fault stability of the relay and to what extent the relay is able to discriminate between internal and external faults.

(b) Operating Time Test

This is a plot between different operating currents to restraining currents ratio and the corresponding ~~operatings~~ times of the relay. Percentage differential relays are usually high speed or instantaneous type[1]. Intentional time delay is not required for selectivity as the inherent percentage differential characteristic makes the relays virtually immune to the effects of transients when the relays are properly applied. This plot is similar to that of an instantaneous over-current relay.

3.2.2 PHASE SENSITIVE TWO INPUT RELAYS

Directional relays and admittance relays, are examples of phase sensitive relays. Distance relays have been dealt in the subsequent chapter and only the directional relay is chosen here for explaination. The operating characteristics/parameters to be determined for this relay are as follows:

(a) Operating Characteristics Under Steady State Conditions

The operating characteristic of the relay under steady state conditions is as shown in Fig.2.10 It is obtained by plotting the operating quantity on a polar plane.

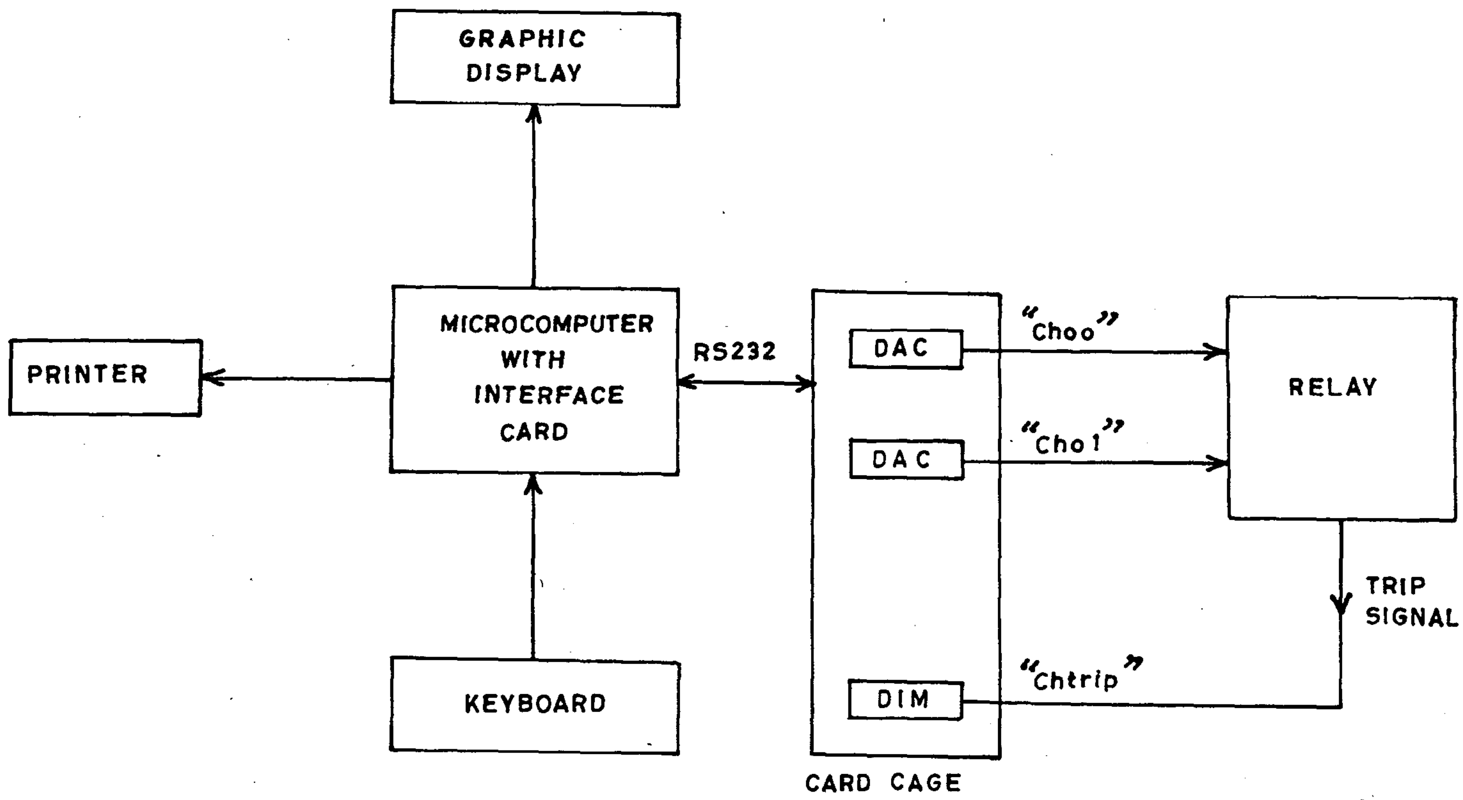
This characteristic provides information regarding the minimum current (I_{min}) required for operation and M.T.A. or M.S.A.

(b) Constant Product Characteristic

In the operating characteristics, the voltage vector is the reference quantity and is assumed constant. It is observed that for a different magnitude of the reference voltage, the operating characteristic will be another straight line, parallel to the one shown in Fig. 2.10 such that the product of V and I_{min} remains constant. Different operating characteristics for varying values of Voltage V are plotted and the constant product characteristic ($V X I_{min} = K$) is verified.

(c) Operating Characteristics Under Dynamic Conditions

This characteristic is a plot of the operating quantity on a polar plane. The test is conducted under dynamic conditions. Under actual fault conditions, the fault current is an exponentially decaying sinusoid. Therefore the relay's operating characteristic under dynamic conditions may be different from that under static conditions.



"Choo" & "Cho1" - DAC CHANNELS

"Chtrip" - DIM CHANNEL

FIG.3·1 AUTOMATED TEST EQUIPMENT

3.3 A.T.E. (AUTOMATED TEST EQUIPMENT) HARDWARE

The equipment/hardware required to conduct performance tests on various relays is listed below. Refer Fig. 3.1.

(a) Personal computer (PC - AT) having a graphics card (Enhanced Graphics Adapter i.e. E.G.A. card) and a graphics monitor.

(b) A fast, efficient PC supported data acquisition system. The Digital to Analog converter (DAC) and the Digital Input Module (DIM) cards are used to communicate signals between the PC and the relay being tested.

A PC-AT based, fast and efficient data acquisition system, manufactured by the [7] Keithley Instruments, U.S.A. has been used in the present work. An interface card placed inside the PC interfaces the computer with the outside world.

At least two channels of analog output are required to conduct the tests. Two, 16 bit resolution, fast, bipolar digital to analog converters (DACs), capable of outputting $\pm$ 10 volts signals, are available on the DAC card, thus providing the required two channels of analog output.

Static relays are basically analog to binary converters. Their output is either a high, or a low voltage signal (for e.g. T.T.L. high is above 3V and T.T.L. low is below 0.8 volts), depending on whether the relay has tripped or restrained. A DIM, capable of reading the status of its input channel (a high or a low), is used to check the status of the relay output.

The two cards, i.e. the DAC and the DIM, have been successfully used to communicate signals between the computer and the relay.

Above mentioned hardware is sufficient to conduct tests on static, low power requirement relays only. This does not mean that the scope of this A.T.E. is restricted only to static relays. As a matter of fact, it is quite feasible to test relays requiring high power levels using this same approach if high power, high quality amplifiers are interposed between the DAC outputs and the relays inputs.

3.4 TEST SOFTWARE

Soft 500, which is the powerful package provided along with the hardware (DAC card, DIM etc.), is used to write programs for data acquisition. There is easy access to the hardware, with the help of the simple SOFT 500 commands. More about this system is dealt in the Appendix A.

Programs are written in advanced BASIC, from where the assembly language routines for data input/output can easily be called. Mainly the task comprises of writing software:

(a) to compute the various samples (current and voltage) of the test signals. These signals are perfect sinusoids in case of steady state tests, and exponentially decaying sinusoids in case of dynamic tests.

(b) to output the samples on to the DAC channels, at proper intervals of time, so as to generate the required test signals. These signals can then be applied to the relay under test.

(c) to continuously monitor the relay output and check for trip.

(d) to display the operating values, characteristics (graphically) and other results of the tests on the C.R.T. screen.

3.4.1 WAVEFORM GENERATION FOR STEADY STATE TESTS

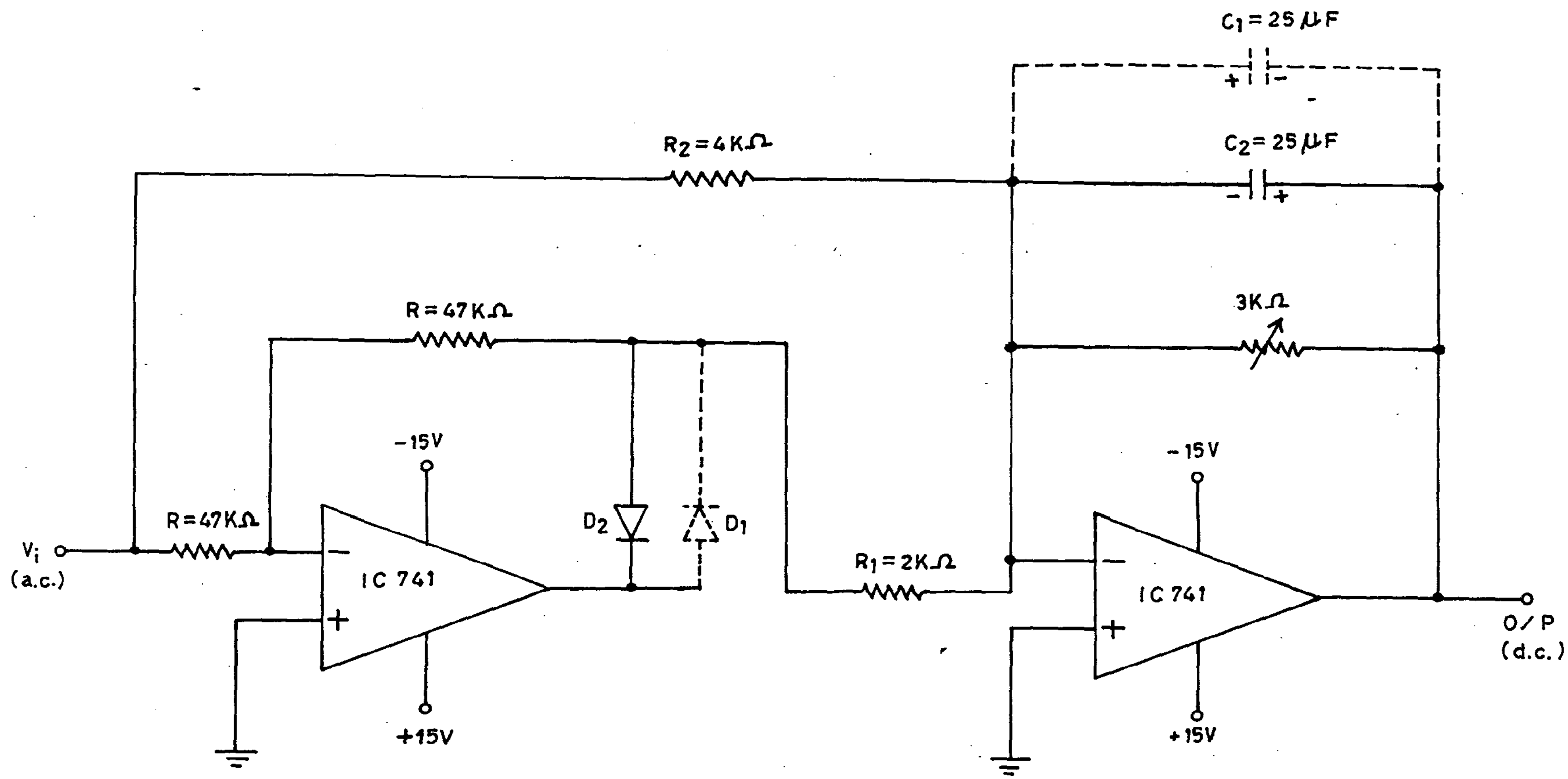
Testing of relays will be accurate, only if the test signals are accurate. Therefore, proper waveform generation, holds primary importance in relay testing.

Signals are synthesized by dividing the 50 Hz sinusoidal waveform, into twenty, equal intervals. Sinewaves are approximated, by outputting (to a DAC) the twenty samples one after the other, at an interval of 1 millisecond. Of course, there is loss in signal information during the 1 millisecond sampling interval, when the O/P of DAC is maintained constant at the previous sample value, but this loss can be reduced and the reconstructed waveform made to (almost) resemble a sinusoid, by choosing the sampling interval as small as possible (as per the Sampling Theorem).

Program in advanced BASIC is written to compute the magnitudes of twenty signal samples and store them in a BASIC array. An assembly language subroutine is then used to output these stored values onto the DAC O/P channel at a programmable interval of time (chosen as 1 millisecond in this case). Any number of cycles can be outputted as desired.

3.4.2 WAVEFORM GENERATION FOR DYNAMIC TESTS

In static tests, the test signals are pure sinusoids whereas



D_1 & C_1 FOR -ve O/P

D_2 & C_2 FOR +ve O/P

FIG. 3·2 PRECISION RECTIFIER AND FILTER CIRCUIT

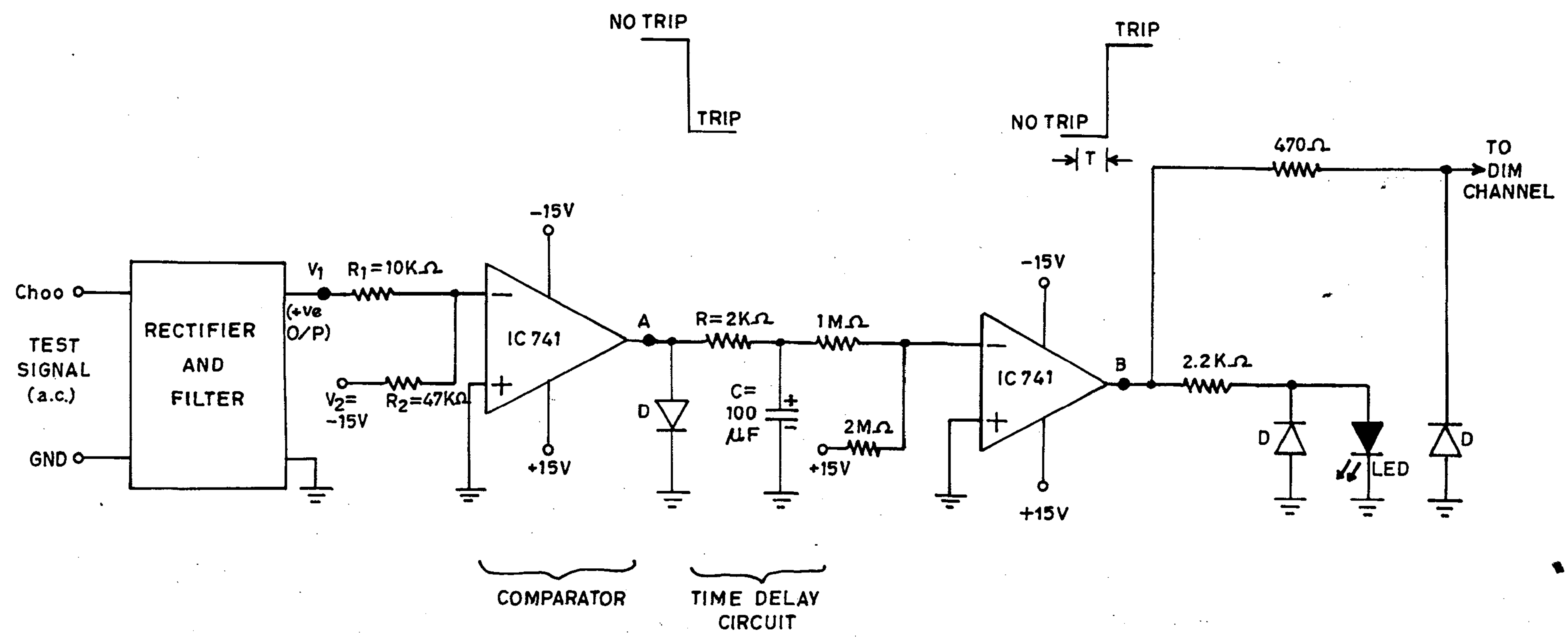


FIG.3.3 OVERVOLTAGE RELAY CIRCUIT (WITH FIXED TIME LAG)

in case of dynamic tests, the current and voltage signals applied to the relay, should conform to the actual signals to which the relay is subjected under practical, operating conditions. These tests, judge the performance of the relay under conditions, closer to the actual fault conditions. These are therefore, more important than the static tests. Under transient conditions, the fault current undergoes a transient, with a finite D.C. offset (value depending on the switching angle). An exponentially decaying sinusoid with any time constant, can easily be generated by software. Program is written to compute 2000 samples, which amounts to 100 cycles, (with sampling interval of one millisecond) and stored in a BASIC array. These stored samples are then outputted onto the DAC channel at a fixed constant interval of time (samping interval).

Any signal waveform can be generated by first computing the various voltage samples, storing them and then outputting them onto the DAC channel, at a fixed sampling interval.

3.4.3 TEST PROGRAMS FOR SINGLE INPUT RELAYS

An over voltage relay is chosen as a typical example of this type. Refer Fig. 3.2 for rectifier circuit. 8

The tests are performed on basic electronic circuits for over and under voltage relays. Refer Fig. 3.3 . The relay circuit basically comprises of a precision rectifier, level detector and

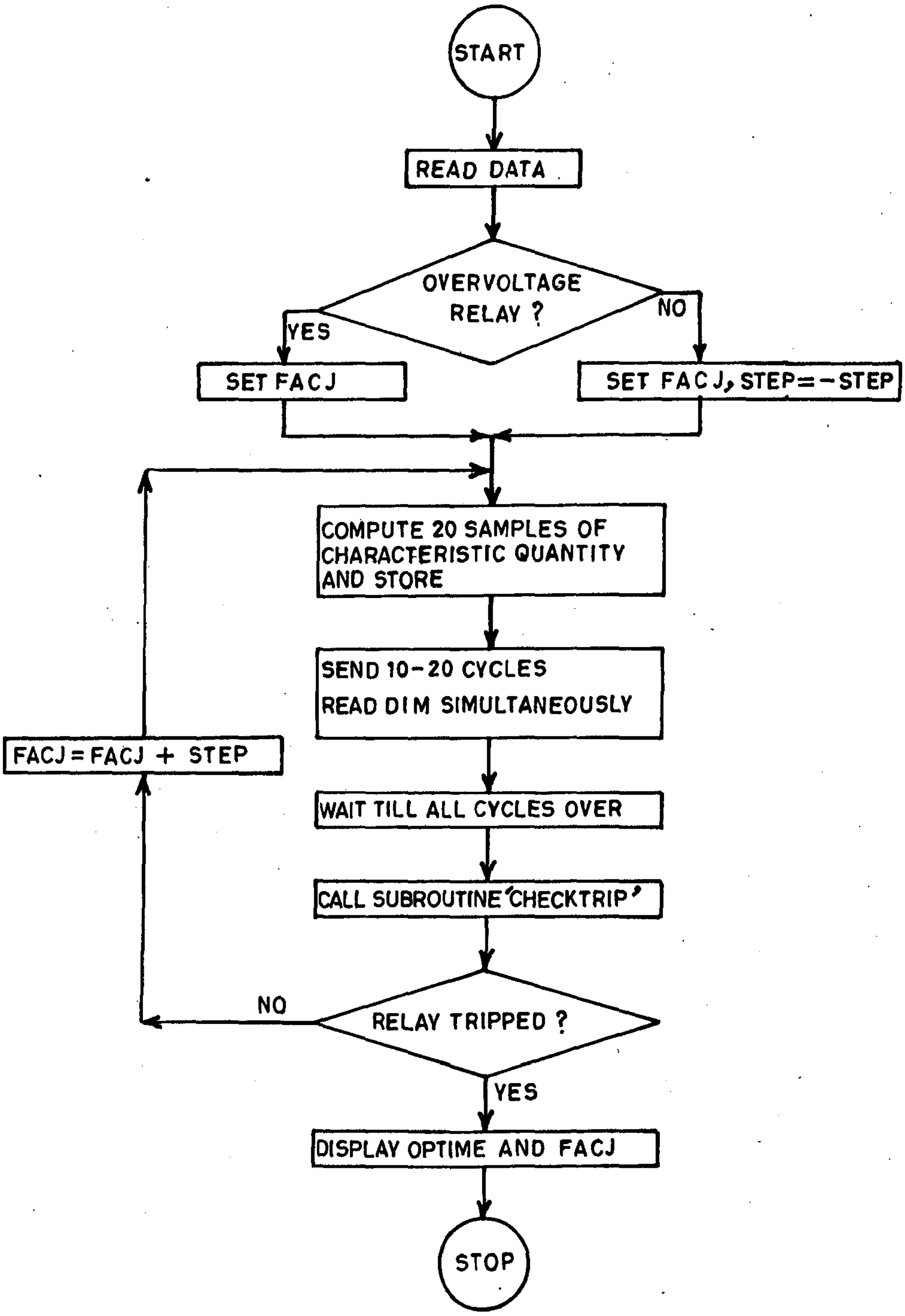
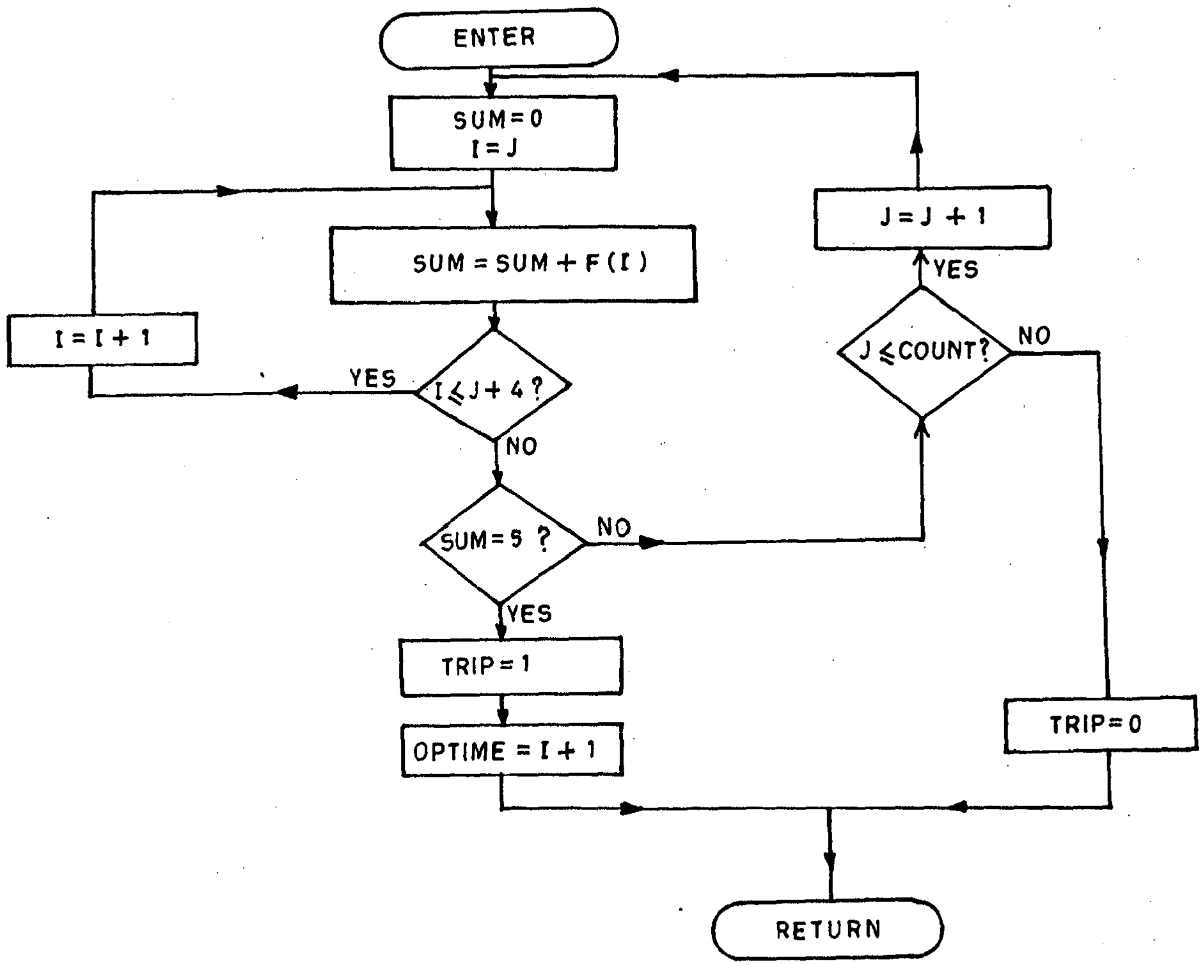


FIG. 3·4 PROGRAM FOR OPERATING CHARACTERISTIC OF OVER / UNDER VOLTAGE RELAY



COUNT = (DEPTH OF ARRAY) − 4

FIG. 3·5 SUBROUTINE 'CHECKTRIP'

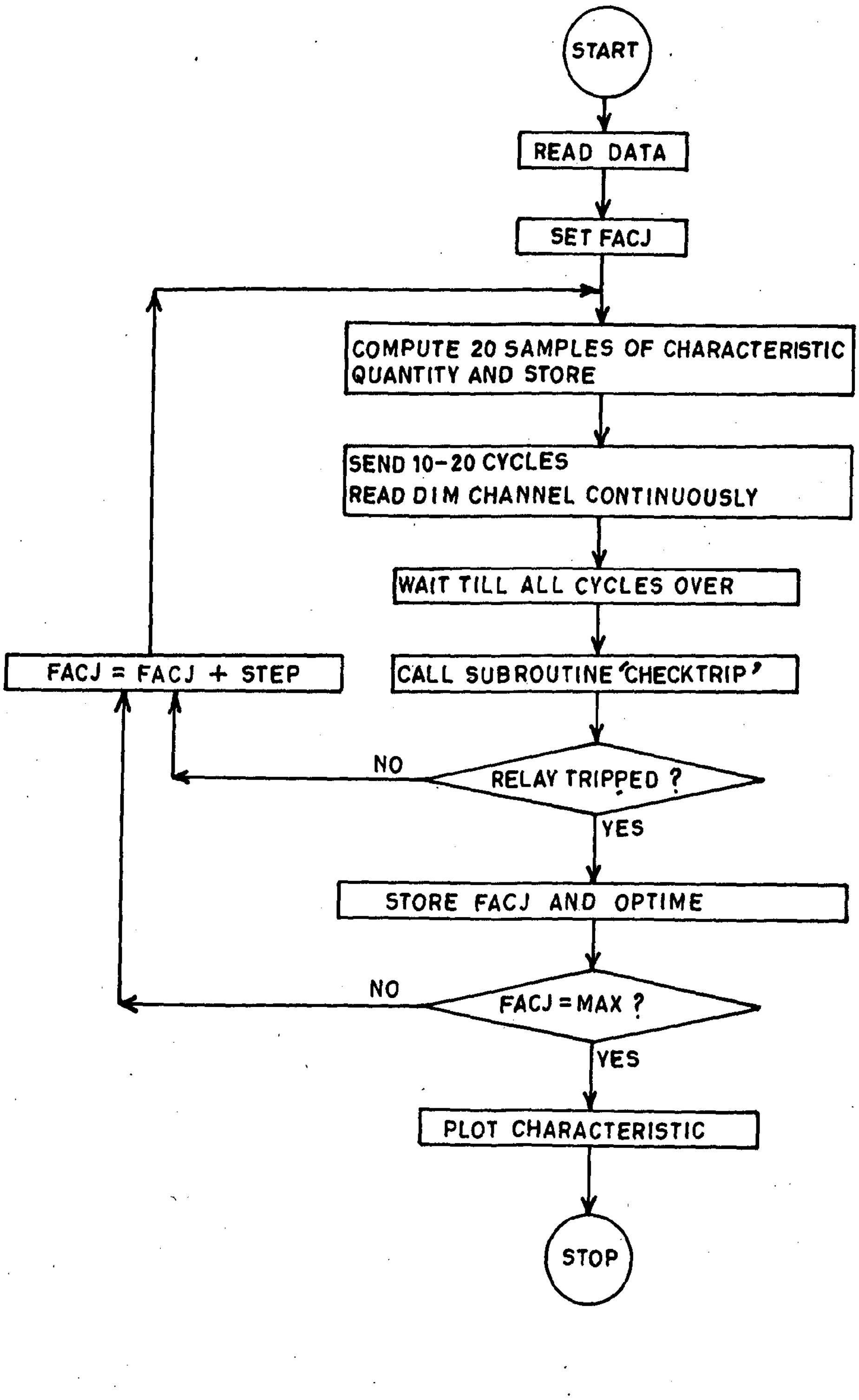


FIG. 3.6 PROGRAM FOR OPERATING TIME CHARACTERISTIC OF OVERVOLTAGE RELAY

a time delay circuit. The relay operates when $\frac{V1}{R_1} > \frac{V2}{R_2}$. The operating value of the circuit is decided by the circuit parameters and the reference voltage.

(a) Operating Value and Time Detection

Refer Fig. 3.4. For an over voltage relay, the operating value is obtained by gradually increasing the amplitude of the test signal applied to the relay, till the relay operates. The amplitude of the sinusoid is made a real variable (i.e. FACJ), which can be increased in small steps (i.e. STEP). Ten - twenty cycles (depending on the operating time of the relay) are sent at the relay I/P. Also Refer Fig. 3.5.

The relay O/P has to be continuously monitored for a trip. One channel of the DIM is tied to the relay O/P. The I/P channel of the DIM, is read every millisecond and the statuses stored in an array (i.e. F). The product of the depth of this real time created array, at which a first valid high (i.e. a 1 after trip) is registered and the sampling interval (i.e. 1 millisecond), gives the operating time of the relay (i.e. OPTIME). A valid trip is considered only if the relay O/P remains high for upto 5 milliseconds. A check is therefore made for five continuous ones in the array F.

(b) Time Current Characteristic

Refer Fig. 3.6. Once the operating value of relay is determined this characteristic can be obtained, by subjecting the relay, to signals of increasing magnitudes and noting the operating time for each. (Refer Fig. 3.5).

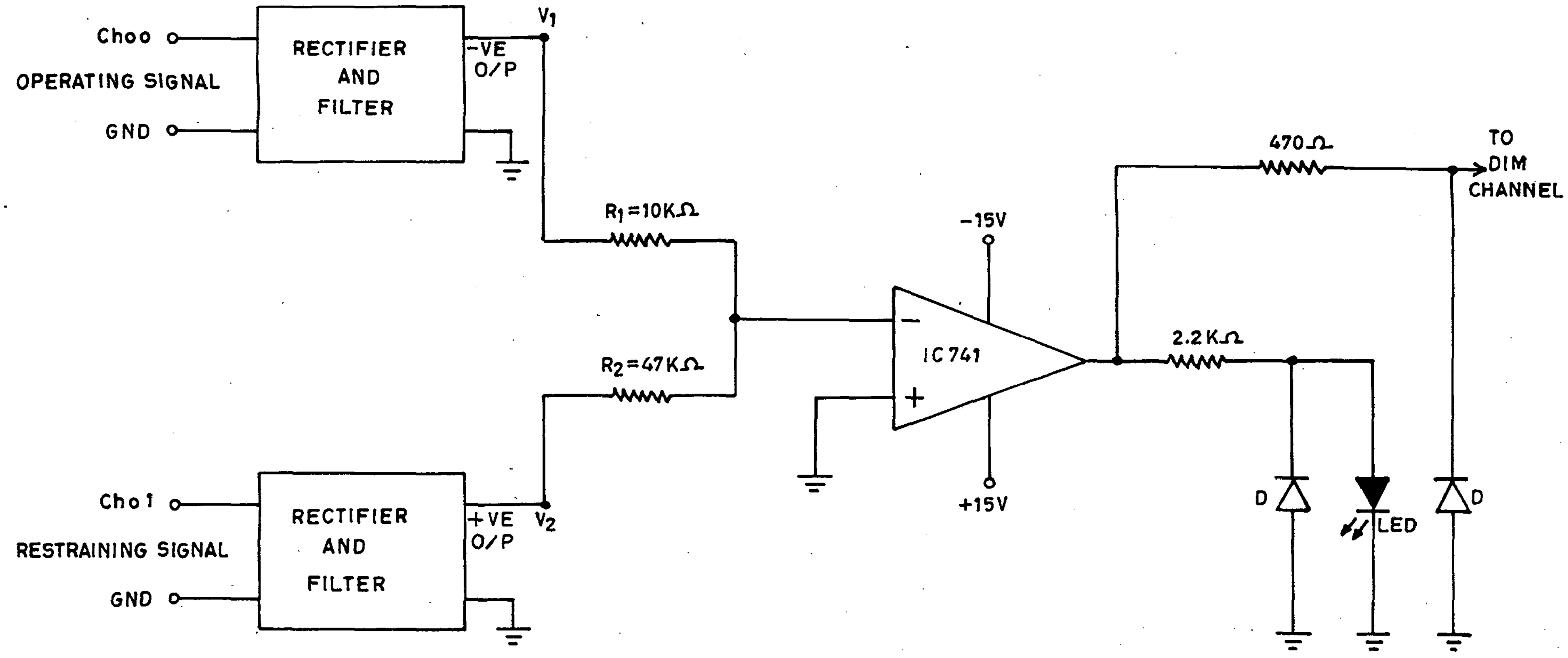


FIG. 3.7. DIFFERENTIAL RELAY CIRCUIT

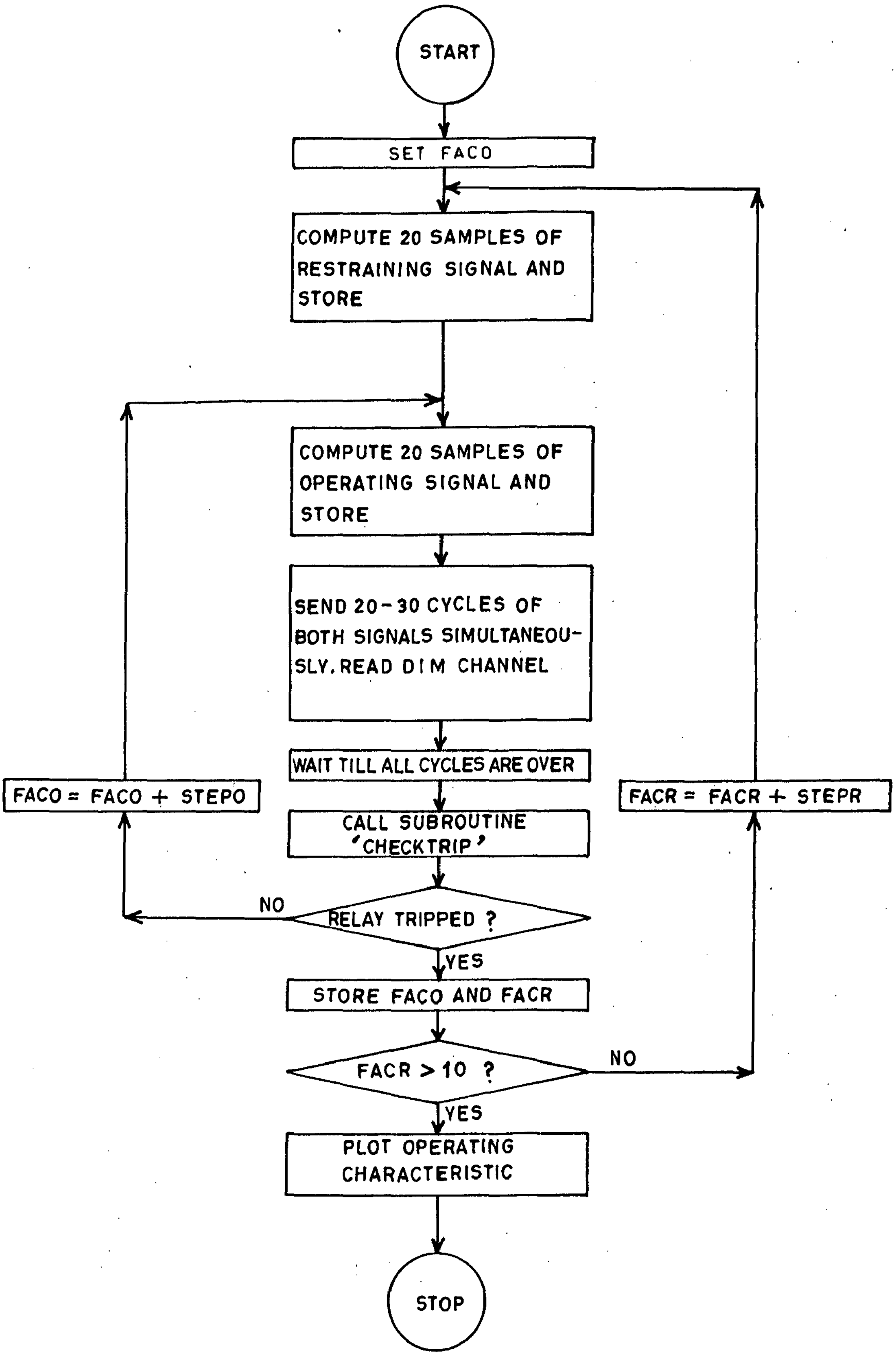


FIG. 3·8 TEST PROGRAM FOR OPERATING CHARACTERISTIC OF DIFFERENTIAL RELAY

FACJ = Amplitude of Current, MAX = 10 Volts, OPTIME = Operating Time, STEP = Increment in FACJ. Using graphics in BASIC a plot between the operating time and the characteristic quantity can be obtained.

For an undervoltage relay, there is not much difference in the testing method, except that one starts sending a high amplitude voltage and then gradually decreasing it, till a trip is registered. In fact, a single program can be written for both the relays, with facility to test any of two.

3.4.4 TEST PROGRAMS FOR BIASED DIFFERENTIAL RELAYS

(a) Operating Characteristic

As mentioned before, this characteristic (Fig. 2.4) is the most important characteristic for this relay, clearly exhibiting the relay's highly selective, discriminative nature with its through fault stability.

The basic electronic circuit for a biased differential relay is shown in Fig. 3.7. The level detector gives a high O/P when $\frac{V_1}{R_1} > \frac{V_2}{R_2}$. As the restraining signal amplitude is increased, the operating value also increases. The percentage bias or the slope of the operating characteristic is decided by the R_1/R_2 ratio.

Refer Fig. 3.8. FACO and FACR = Amplitudes of operating and restraining quantities, respectively, STEPO and STEPR = Increments in FACO and FACR respectively. Program is written to compute and store samples of two sinewaves in BASIC arrays. Their amplitudes are kept variable and therefore different amplitude sinewaves

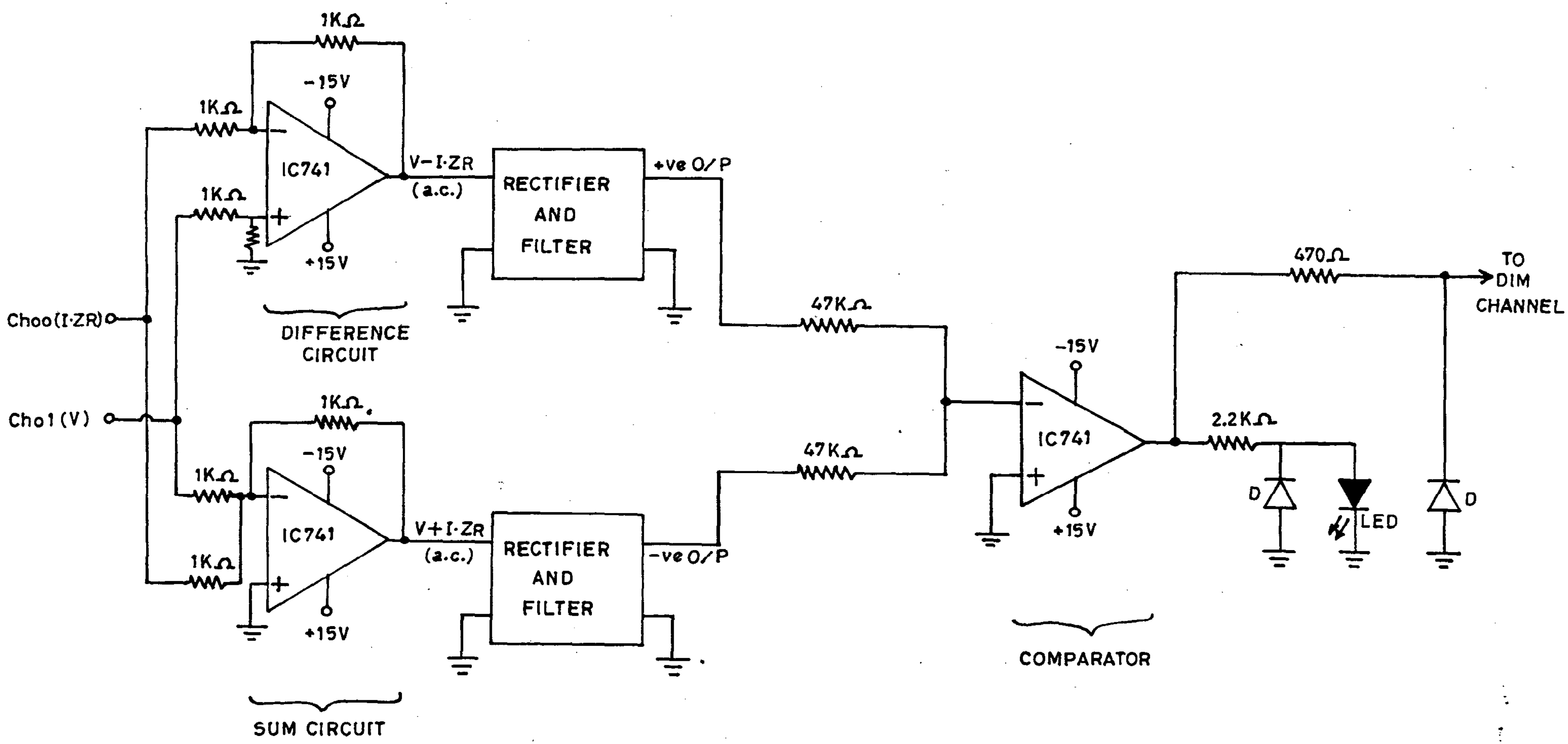


FIG. 3·9 DIRECTIONAL RELAY CIRCUIT.

can be generated. For a fixed value of the restraining signal, the operating quantity is slowly increased and the operating value noted. Relay output is monitored continuously and a valid trip indicated only if O/P remains high for a minimum of 5 milli-seconds (procedure same as explained for over voltage relays). This is repeated for many more values of the restraining quantity, so that sufficient points on the characteristic can be obtained.

Finally the characteristic is plotted from which the percentage bias can easily be obtained.

(b) Time-Current Characteristic

Procedure to obtain the time-current characteristic for this relay is same as that for the over voltage relay (described before). The restraining quantity is kept fixed. The operating quantity is increased beyond the operating value and the operating times noted down for each value. Sufficient readings are taken, so as to obtain the plot between operating/restraining value ratio and the operating time.

3.4.5 TEST PROGRAMS FOR DIRECTIONAL RELAYS

(a) Static Operating Characteristic

This characteristic of a directional relay gives information regarding its directional feature. The minimum current required for operation is also obtained.

Tests are conducted on the directional relay circuit shown in Fig. 3.9. As per the table in Fig. 3.10,

(a) Operating quantity = $V + I.Z_R$

(b) Restraining quantity = $V - I.Z_R$

Refer Fig. 3.11. THETA = Line angle, STEP = Increment in FACJ , FACJ = Amplitude of operating quantity. Program is written to generate two sinewaves, one with a fixed (i.e. for voltage) and the other with a variable amplitude.

The test starts with THETA = 0 degrees, where THETA is the angle between the system voltage and current. The current amplitude is increased in small steps. Both the voltage and the current signals are sent simultaneously on the 2 DAC channels. Relay O/P is monitored continuously (till the signals are being sent) for a trip signal (procedure is same as explained before for over-voltage relays) and the operating current noted.

The same procedure is repeated for different line angles and the corresponding operating current values stored in an array. THETA is increased in steps of 10 degrees.

Once the test run for line angles from 0 degrees to 360 degrees is over, powerful graphics in BASIC is used to display the polar plot on the CRT screen.

The co-ordinates of the various points on the characteristic are calculated as below:

x co-ordinate = I X COS (THETA)

y co-ordinate = I X SIN (THETA)

A straight line characteristic is obtained. The operating and restraining zones depend upon M.S.A. (in case of static relays) and M.T.A. (in case of electromechanical relays). once the

S.NO.	CHARACTERISTIC	AMPLITUDE COMPARATOR		PHASE COMPARATOR	
		OPERATE	RESTRAIN	OPERATE	RESTRAIN
1	DIRECTIONAL	$I.Z_R+V$	$V-I.Z_R$	$I.Z_R$	V
2	IMPEDANCE	$I.Z_R$	V	$I.Z_R-V$	$I.Z_R+V$
3	ADMITTANCE	$I.Z_R$	$K.V-I.Z_R$	$I.Z_R-V$	V

VOLTAGE INPUTS FOR VARIOUS CHARACTERISTICS

Fig. 3.10

restraint zone of the relay is approximately ascertained, the operating characteristic can be speedily obtained by skipping the points at which relay restrains. (Programme in the appendix is written for relay with M.S.A. = 0). Note: Parameters STEPF and Z in all the test programmes listed in Appendix B hold the same significance as STEP and Z1 respectively (written in the flow-charts and the test results).

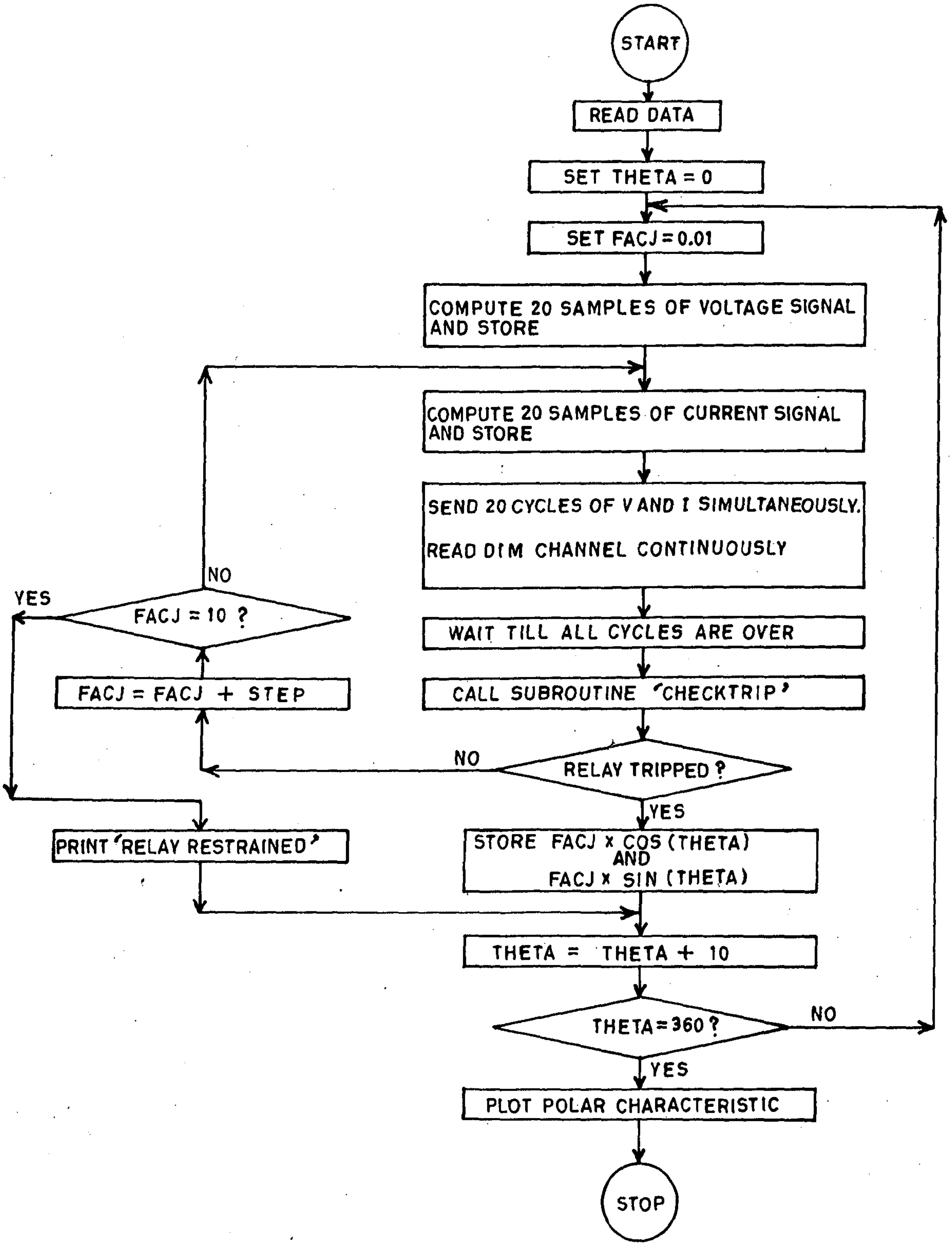


FIG. 3·11 PROGRAM FOR OPERATING CHARACTERISTIC OF DIRECTIONAL RELAY

3.5 TEST RESULTS

The tests were conducted on over voltage, biased differential and directional relays and their operating characteristics/parameters obtained.

3.5.1 OVERVOLTAGE RELAYS

(i) Operating Value Test

The operating value of the relay was found out to be 5.3 volts (peak value of the a.c. signal applied). Average d.c. value for this comes out to be equal to 3.37 volts which agrees with the operating value for which the relay circuit in Fig. 3.3 is designed.

(ii) Operating Time Characteristic

This is obtained as shown in Fig. 3.12.

3.5.2 DIFFERENTIAL RELAYS

(i) Operating Characteristic

The characteristic is obtained as shown in Fig. 3.13. The points lie on a straight line whose slope is 19.9 percent. This was the percentage bias slope for which the basic differential relay circuit was designed (Refer Fig. 3.7).

(ii) Operating Time Characteristic

The characteristic obtained is shown in Fig. 3.14. The relay is an instantaneous type and its operating time is found out to be equal to 7 milliseconds for all values of operating quantity (beyond the operating value = 0.999 volts corresponding to restraining quantity = 5 Volts). When the relay just enters the operating region, the operating time is found out to be larger i.e. equal to 12 milliseconds.

3.5.3 DIRECTIONAL RELAYS

(i) Static Operating Characteristic

The plot obtained for a directional relay circuit with M.S.A. = zero degree, is shown in Fig. 3.15. The minimum current for operation is found out to be 0.1680002 amperes. The maximum sensitivity angle (i.e. M.S.A.) for which the relay has been designed is same as obtained from the test.

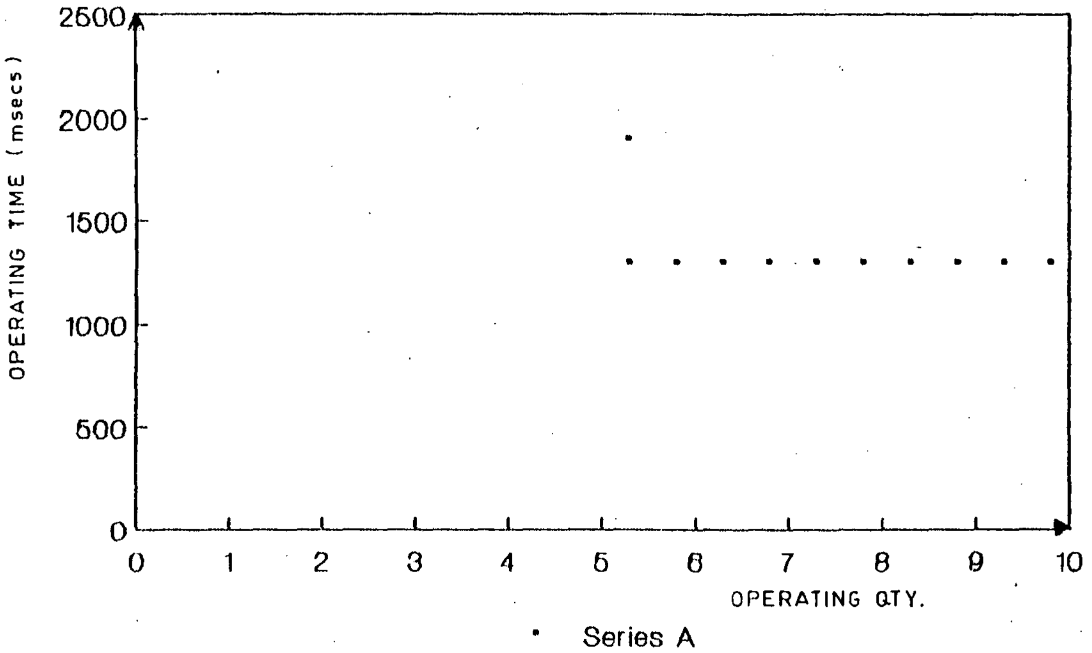


Fig.3.12 OPERATING TIME CHARACTERISTIC
OF ~~INSTANTANEOUS~~ OVERVOLTAGE RELAY.
FACJ-4, STEP-0.

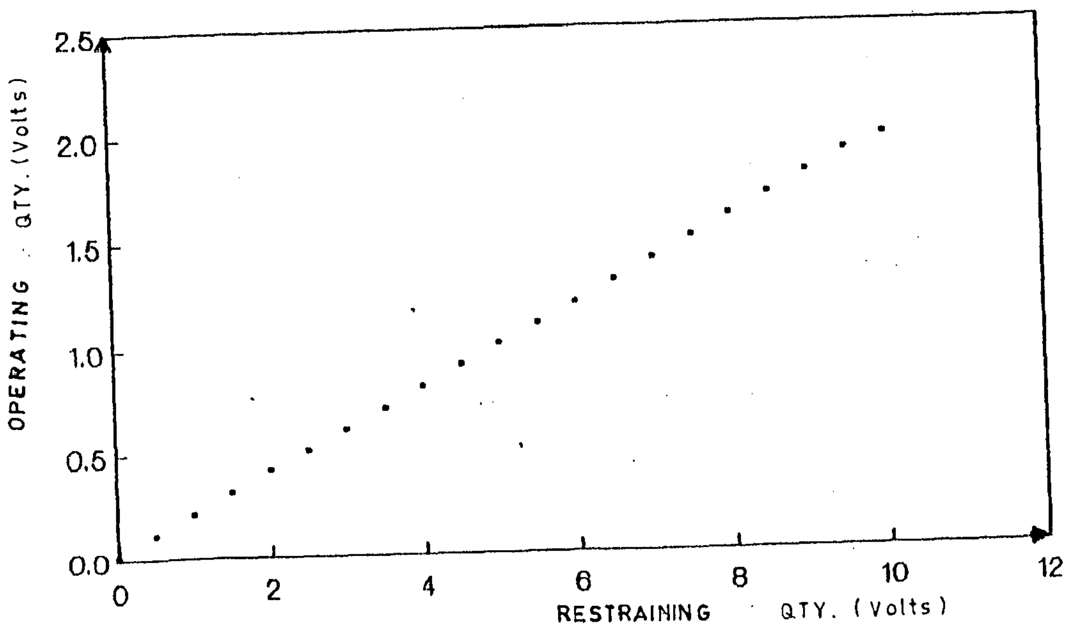


Fig.3.13:OPERATING CHARACTERISTIC
OF DIFFERENTIAL RELAY.
FACO-0.01, STEPO-0.01, STEPER-0.5

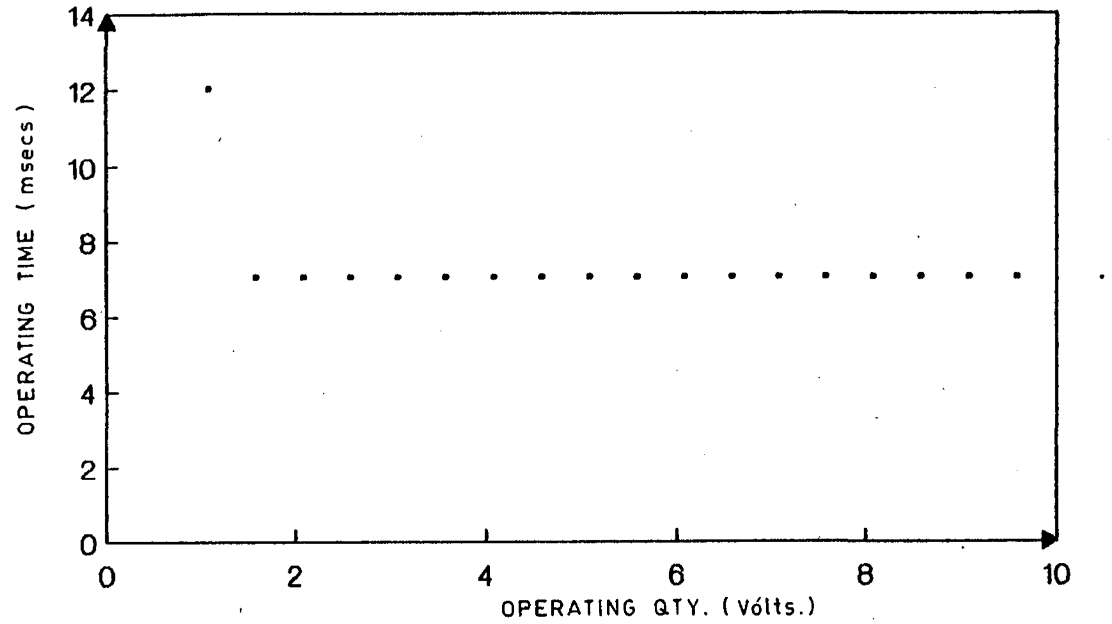


Fig.3.14 : OPERATING TIME CHARACTERISTIC OF DIFFERENTIAL RELAY. FACR=5, FACO=0.9 STEP=0.5.

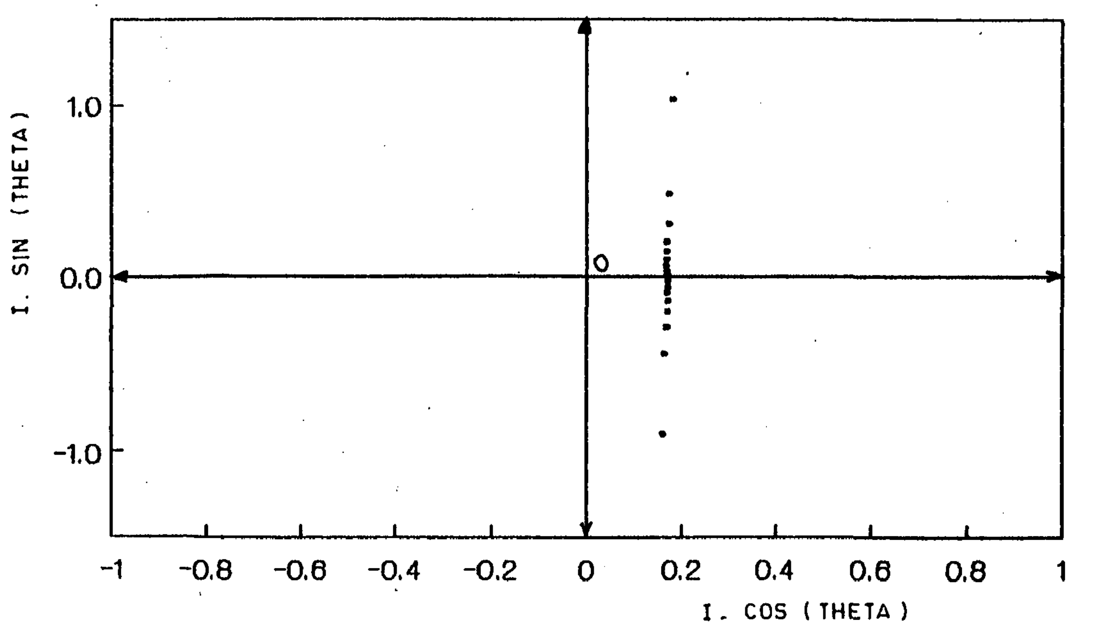


Fig.3.15: OPERATING CHARACTERISTIC OF DIRECTIONAL RELAY WITH M.S.A=0 DEGREE. FACV=4, FACJ=0.01, STEP=0.001.

CHAPTER IV

AUTOMATED TESTING OF DISTANCE RELAYS

Distance relays, being the high-speed high performance types are mostly used on transmission lines, where they have to exhibit high reliability, sensitivity and selectivity in operation. Their operating characteristics have to be therefore very accurate and the relay should behave very reliably under faulty conditions on transmission lines. Otherwise failure of operation may lead to great damage to life and property. Reliable testing of these relays, would lead to a safer, better, reliably protected transmission line. Owing to the importance of distance relays, the efficient and accurate computer based testing methods are fully justified for them.

The test methods described below, may advantageously be put to use by relay manufacturers and large consumers (like electricity boards). Secondary injection tests performed by this equipment, are much more accurate than the conventional tests involving test modules, plugs etc. Before going into the explanation of the automated, test procedures used, it is necessary to over view the test requirements of these relays. Admittance and impedance relays are chosen as typical examples of distance relays for the purpose of conducting tests.

4.1 TEST REQUIREMENTS OF DISTANCE RELAYS

Before testing any equipment, which in effect is a comparison between the expected or specified characteristics and the actual operating behaviour, it is necessary to first have a clear understanding of the equipment. A relay in general is best understood and its merits/demerits judged, by its operating characteristics. The operational behaviour of a relay, especially a distance relay, (used where uncleared faults may lead to heavy damage) should always conform to the characteristics for which it has been designed.

In the following paragraphs, are mentioned the operating characteristics of distance relays.

4.1.1 R-X DIAGRAM UNDER STEADY STATE CONDITIONS

The locus of points where the operating and restraining quantities are equal is described as the boundary characteristic of the relay and since ideally it is dependent on the ratio of voltage and current, may be plotted on a R/X diagram. 5 The radius of the circle is equal to the setting of the relay (i.e. ZSET). This corresponds to the impedance of the line to be protected by the relay. If the impedance seen by impedance relay is less than ZSET, then only the relay operates otherwise restrains. In case of admittance relays, Z for operation is line angle dependent. Thus operation occurs only when the fault occurs in the region between the relay location and the selected point. Polar characteristic speaks of the reach of a distance relay. The locus of power system impedances such as those of faults, power swings and loads may be plotted on the same diagram and in this manner the performance of the relay in the presence of system disturbances may be studied.

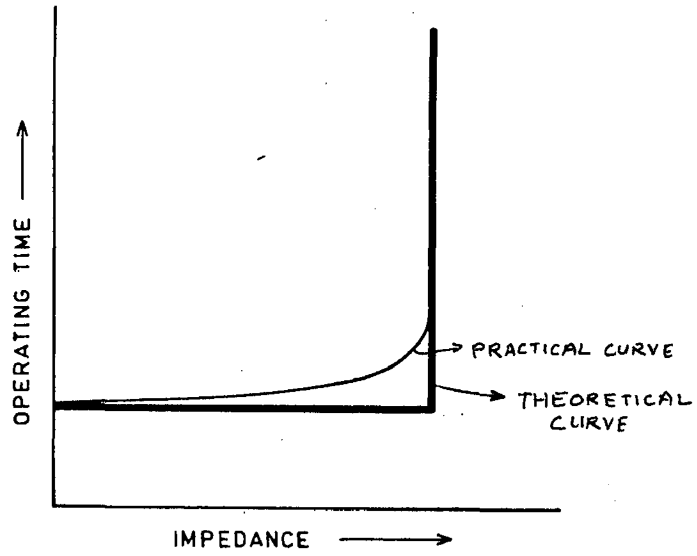


FIG. 4·1 OPERATING TIME CHARACTERISTIC FOR DISTANCE RELAYS

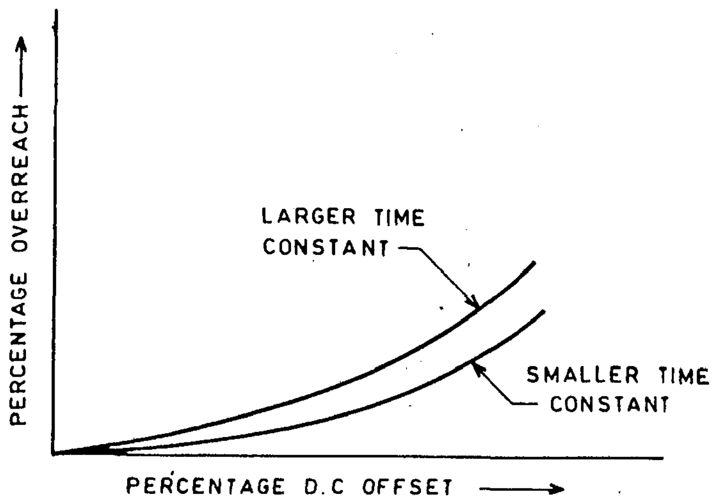


FIG. 4·2 TRANSIENT OVERREACH CHARACTERISTIC FOR DISTANCE RELAYS

4.1.2 OPERATING TIME CHARACTERISTIC

The operating time characteristic for distance relay is plotted between the distance to fault and the operating time. The theoretical and the practical curves are as shown in Fig.4.1. They are plotted for a particular value of current magnitude.

With the increasing magnitudes of the short circuit MVA in modern power systems, fault clearing times are assuming more and more importance. Damage shall be avoided, only if the faults are cleared fast, and they shall be cleared fast, only if the relay operates fast (as per its design). Thus operating time of a relay is an important parameter.

Over-reach of a relay under transient conditions, is dependent upon many factors, operating time being one of them. If operating time of the relay is larger, its tendency to over-reach is lesser. Precision relays like the zone 1 relays, should have an accuracy of ± 5 percent or better, high selectivity and low degree of over-reach.[10] Their operating times have to be therefore judiciously chosen and the relay designed accordingly. In many cases, it is safer to avoid over-reach by delaying tripping. In short this characteristic is quite important and needs careful plotting.

4.1.3 TRANSIENT OVER-REACH CHARACTERISTIC

The tendency of a distance relay to operate at impedances larger than its setting value is known as over reach.[2] Under actual fault conditions, the fault current is an exponentially decaying sinusoid, with its momentary, instantaneous value being quite offseted and larger than its steady state value. Under dynamic conditions, therefore, the relays '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, what is known as over-reach of the relay. This impairs the accuracy and selectivity of the relay which is undesirable.

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. The transient over-reach characteristic is the graphical/pictorial representation of relay dynamic behaviour. The degree of over-reach is decided by many factors (operating time, design, system parameters etc.), amount of d.c. offset in the transient fault current being the predominant.

A plot is made between the percentage d.c. offset and the percentage transient over-reach. Percentage transient over-reach = $\frac{Z_{os} - Z_{sy}}{Z_{sy}} \times 100$.

Where Z_{sy} = the maximum impedance for which the relay will operate for symmetrical currents. Z_{os} = the maximum impedance for which the relay will operate with an offset current wave. Tendency to over-reach increases with increasing percentages of D.C. offset. A typical characteristic is shown in Fig. 4.2.

4.1.4 R-X DIAGRAM UNDER DYNAMIC CONDITIONS

This is a plot of the maximum impedance seen by the relay under dynamic conditions for different values of line angles. The plots can be made for various values of percentage d.c. offsets. The impedance seen by the relay under dynamic conditions (with fault on adjacent line) may be smaller than the steady state impedance it should see once the transients have died down. The relay is always set for symmetrical values and therefore the relay tends to over-reach under the actual fault conditions.

A comparison of the impedance diagrams under steady state and dynamic conditions, help evaluating the dynamic performance of the relay. Dynamic performance of the relay at different line angles can also be observed. Larger X/R ratios result in slow decay of the transient currents. This would lead to higher transient over-reach at large X/R ratios.

4.2 AUTOMATED TEST EQUIPMENT (HARDWARE)

Equipment required for testing distance relays is same as that required for the relays mentioned in the last chapter. Refer section 3.3 and Fig. 3.1.

4.3 TEST SOFTWARE

As mentioned before, a PC based data acquisition system is used to carry out the tests. Software is written to work the hardware of the test equipment. Soft 500[7], a readymade package provided along with the data acquisition system, gives an easy and fast access to the DAC channels, DIM channels and other associated hardware. Software is written for the following purposes:

(a) To compute and store the test signals' samples in BASIC arrays.

(b) To send the stored samples of the test signals to the appropriate DAC I/P at equal intervals of time, which would then convert the I/P digital values into their corresponding analog equivalents, thus reconstructing the desired analog signal. These PC generated, accurate signals can then be applied to relay under test.

(c) Program is written to continuously monitor the relay O/P (which is hardware connected to one of the DIM channels) and store the current status in a BASIC array for further analysis.

(d) Using Graphics in BASIC[11], program is written to plot the various relay characteristics.

4.4 WAVEFORM GENERATION

Relay testing is achieved by applying PC-generated signals at their inputs. Performance evaluation of the relay will be correct only if proper test signals are used for testing. Waveform generation is thus an important part of testing and is explained in the forthcoming paragraphs.

4.4.1 STEADY STATE CONDITIONS

When a relay is being tested under steady state conditions, the signals to be applied are pure sinusoids and their amplitudes are to be gradually increased. Waveform generation under steady state and dynamic conditions was dealt in the previous chapter also.

The signal to be generated is a system frequency (50 Hz) signal. Each wave is divided into 20 equal parts. The values of the samples are first calculated and then stored in an array.

These digitized samples are then sent to the DAC I/P at a constant interval of time (1 millisecond), analog O/P remaining constant at the previous value over this sampling interval. The DAC O/P obtained is not a smooth sinewave, but can be improved by using low pass filters.

4.4.2 DYNAMIC CONDITIONS

As explained before, the actual conditions or operating parameters under which a relay has to function are far from the steady state conditions. The actual instantaneous fault current is never a pure sinusoid, but offseted and is consequently an exponentially decaying sinusoid, with a time constant decided by the systems parameters (X/R ratio). The sudden occurrence of fault and the offset current have to be simulated to conduct the dynamic tests. The relay is first kept under normal conditions. Sinusoidal, system frequency signals can be generated as done under the steady state conditions.

The samples for an exponentially decaying sinusoid can be calculated for different times (at an interval of one millisecond), using the following equation. Library functions are available in BASIC to compute the exponential and the sine of the parameters specified.

$$i(t) = Ipeak \times \sin(\omega t + THETA) + Dcoff \times Ipeak \times e^{-t/TAU}$$

where

$i(t)$ = instantaneous value of current

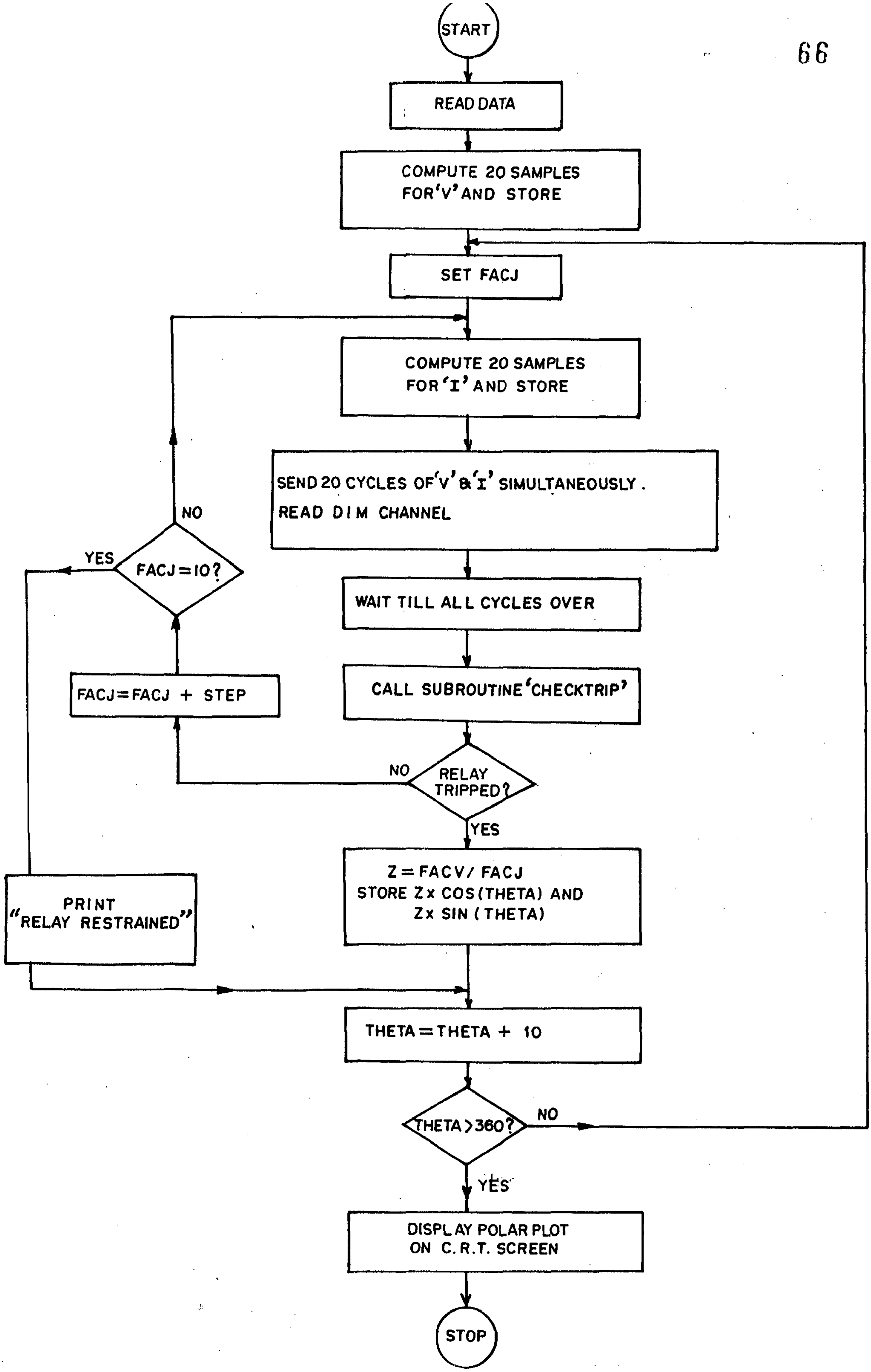


FIG. 4.3 TEST PROGRAMME FOR STEADY STATE POLAR CHARACTERISTIC OF DISTANCE RELAYS

I_{peak} = peak value of the steady state fault current

ω = angular frequency

THETA = line angle

D_{coff} = d.c. offset

TAU = time constant of the decaying transient

Two thousand samples are calculated at t = 1 millisecond, t = 2 milliseconds and so on. These two thousand values, if sent to the DAC I/P at an interval of 1 millisecond, will produce the required waveform at the DAC O/P.

4.5 TEST PROGRAMS FOR DISTANCE RELAYS

The various characteristics to be obtained for distance relays were explained before. Now the test procedures to obtain the operating characteristics will be explained one by one. A comparison can then be made between the results and the relay specifications (operating characteristics etc.).

4.5.1 R-X DIAGRAM UNDER STEADY STATE CONDITIONS

This is an important characteristic.for a distance relay. It is a plot of the maximum impedance at which the relay just operates for different line angles. Refer Fig. 4.3 . FACJ = Amplitude of current, Z = Impedance of line, THETA = Line angle, STEP = Increment in FACJ, V = Voltage across relay, I = Current. Program is written to generate two sinewaves, one of variable (i.e. current) and the other with fixed (i.e. voltage) amplitude. The test starts at THETA = 0 degree. A fixed value of voltage signal is generated at one channel (CH01) of DAC, connected to the restraining I/P to the relay. The operating current magnitude is

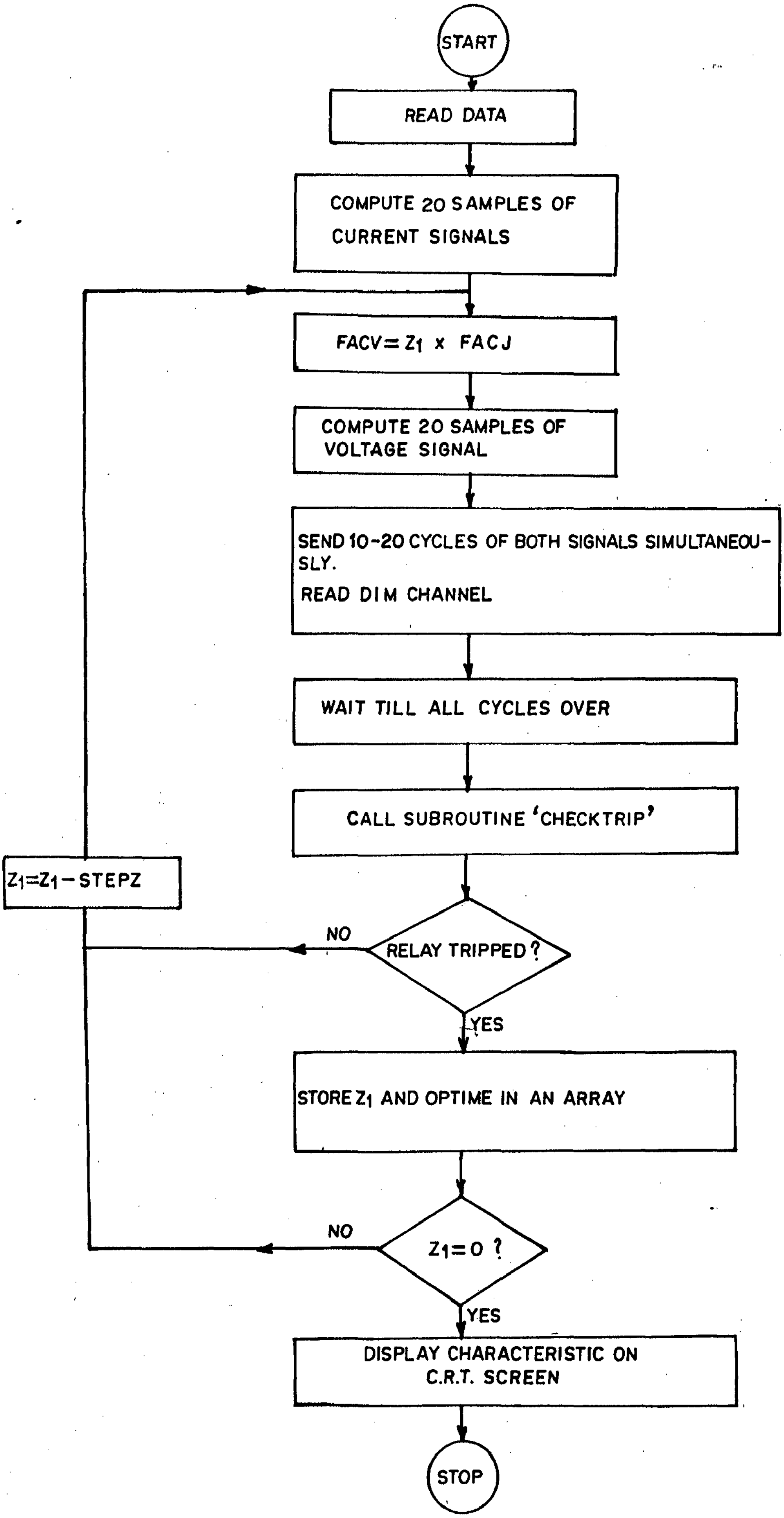


FIG.44. PROGRAMME FOR OPERATING TIME CHARACTERISTIC OF DISTANCE RELAYS

increased in small steps and the operating value of current determined. The V/I x Cos (THETA) and V/I Sin (THETA) are computed and stored in an array. Also Refer Fig. 3.5.

The same procedure is repeated for different line angles and Z x Cos (THETA), Z x Sin (THETA) stored for each run. The polar characteristic can then be displayed on the C.R.T. screen with the help of powerful graphics in BASIC.

4.5.2 OPERATING TIME CHARACTERISTICS

This is a plot between impedance and the operating time of the relay.

Refer Fig. 4.4 FACV = amplitude of voltage signal, Z1 = starting value of impedance (slightly higher than the set value of impedance), STEPZ = decrement in Z1, OPTIME = operating time of relay. Samples are calculated for a fixed value of current amplitude and stored in an array. The starting impedance (Z1) is chosen slightly larger than the relay setting. Line angle, THETA is fixed around the actual angle of the line. Samples for voltage signal (Z1 x FACJ = FACV) are calculated and stored. Twenty to thirty cycles of the test signals (number of cycles decided by the OPTIME of relay) are generated at the DAC outputs and applied to the operating and restraining I/Ps of the relay. The relay O/P is continuously monitored. A valid trip is registered only if the O/P remains high for a minimum period of 5 milliseconds. (Refer Fig. 3.5). If the relay does not operate, Z1 is reduced by a small step = STEPZ, and the whole process is repeated. On operation, the operating time is

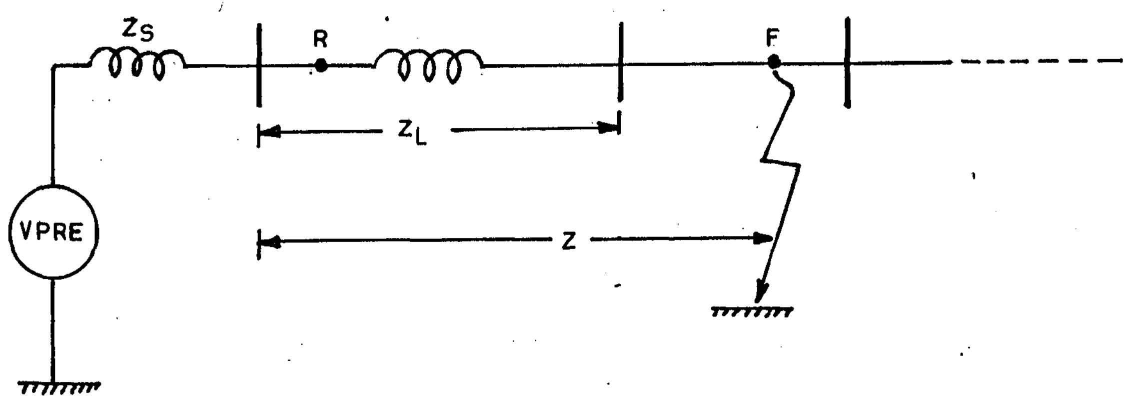


FIG.4.5. SINGLE LINE DIAGRAM FOR TRANSMISSION LINE ON FAULT

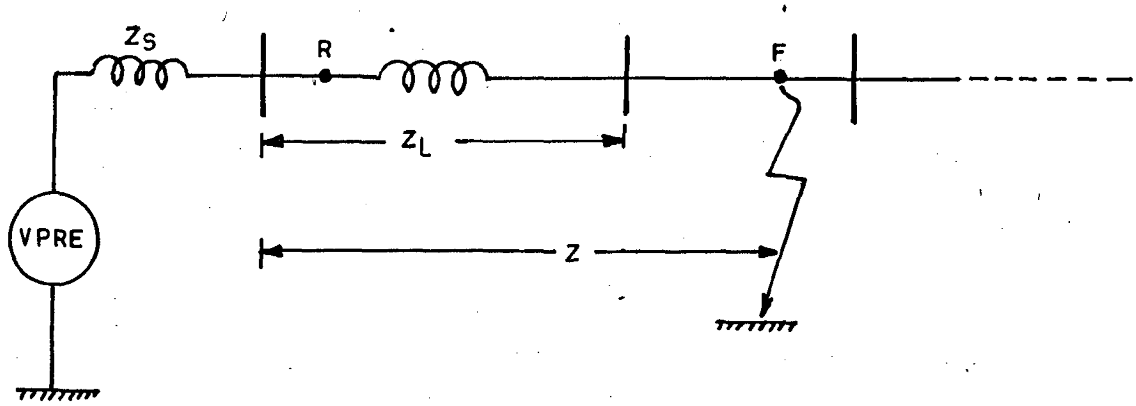


FIG.4.5. SINGLE LINE DIAGRAM FOR TRANSMISSION LINE ON FAULT

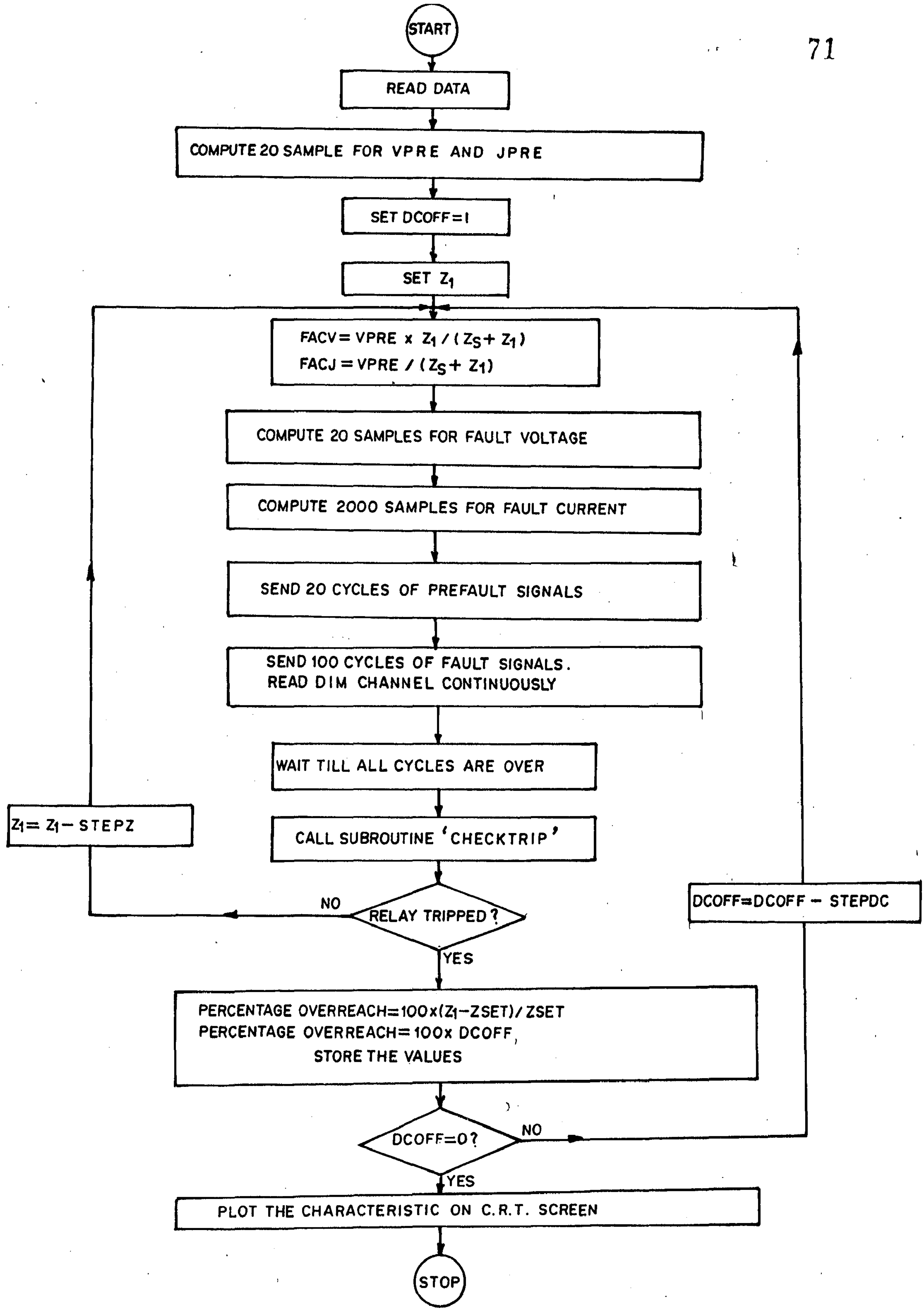


FIG. 4.6. TEST PROGRAMME FOR TRANSIENT OVERREACH CHARACTERISTIC OF DISTANCE RELAYS

calculated by finding the depth of array (array F) at which a first valid high (or a 1 after trip) is registered. This depth gives the operating time in milliseconds. Same procedure is repeated for different values of Z_1, so as to obtain sufficient points on the operating time characteristic (plotted between Z_1 and OPTIME).

4.5.3 TRANSIENT OVER-REACH CHARACTERISTIC

Refer Fig. 4.5 pt. R = relay location, pt. F = fault position, Z = impedance seen for fault on adjacent line section, Z_L = impedance of line to be protected, VPRE = prefault voltage across the relay. At the instant of fault occurrence the voltage across the relay and the fault current are as follows:

(i) $v(t) = \text{VPRE} \times Z/(Z_S + Z) \times \text{Sin}\ \omega t$

(ii) $i(t) = (\text{VPRE}/Z_S + Z) \times \text{Sin}(\omega t + \text{THETA}) + \text{DCOFF} \times \text{VPRE}/(Z_S + Z) \times e^{(-t/\text{TIMC})}$

Where TIMC = time constant of transient decay, THETA = line angle and the rest of the parameters hold the same meaning as mentioned before. The relay has a tendency to over-reach under these transient conditions. The degree of over-reach is dominated by the percentage of d.c. offset in the fault current wave. The transient over-reach characteristic illustrates this fact. Refer Fig. 4.6.

The relay is initially subjected to steady state prefault signals. Current applied to the relay is very low, s.t. the relay sees a very high impedance and remains in operative. DCOFF = amount of d.c. offset in fault current, Z_1 = starting value of line impedance, FACV = amplitude of voltage across the relay during fault, FACJ = fault current, Z_S = source impedance of line, ZSET = relay setting, STEPDC = increment in DCOFF, STEPZ = decrement in Z_1. Twenty samples of prefault voltage and current signals are stored in basic arrays. Typical values of TIMC, Z_S, and THETA are chosen. THETA is chosen equal to the actual angle of the line. Two thousand samples of fault current and twenty samples of fault voltage are calculated and stored. After the computations are over, the prefault signals (voltage and current) are applied for a sufficiently long time (20 - 30 cycles). The fault conditions are simulated by suddenly applying the fault current and voltage signals (i.e. as soon as the prefault cycles are over). The relay O/P is continuously monitored for a valid trip (as explained in sec. 4.5.2). If the relay does not operate, the Z_1 parameter is reduced by a small factor. This is a simulation of a fault occurring on the adjacent line comparitively closer to the relay location, than before. The process is repeated, till the maximum value of Z_1 at which relay just operates, is obtained.

The following quantities are computed and stored in an array:

(a) Percentage over-reach = $(Z_1 - ZSET)/ZSET \times 100$

(b) Percentage D.C. offset = DCOFF x 100

The test run is repeated for more values of DCOFF and quantities in (a) and (b) calculated for each value of DCOFF. Finally, using GRAPHICS in BASIC, a graph is plotted between percentage D.C. offset (on X - axis) and percentage over-reach (on Y-axis).

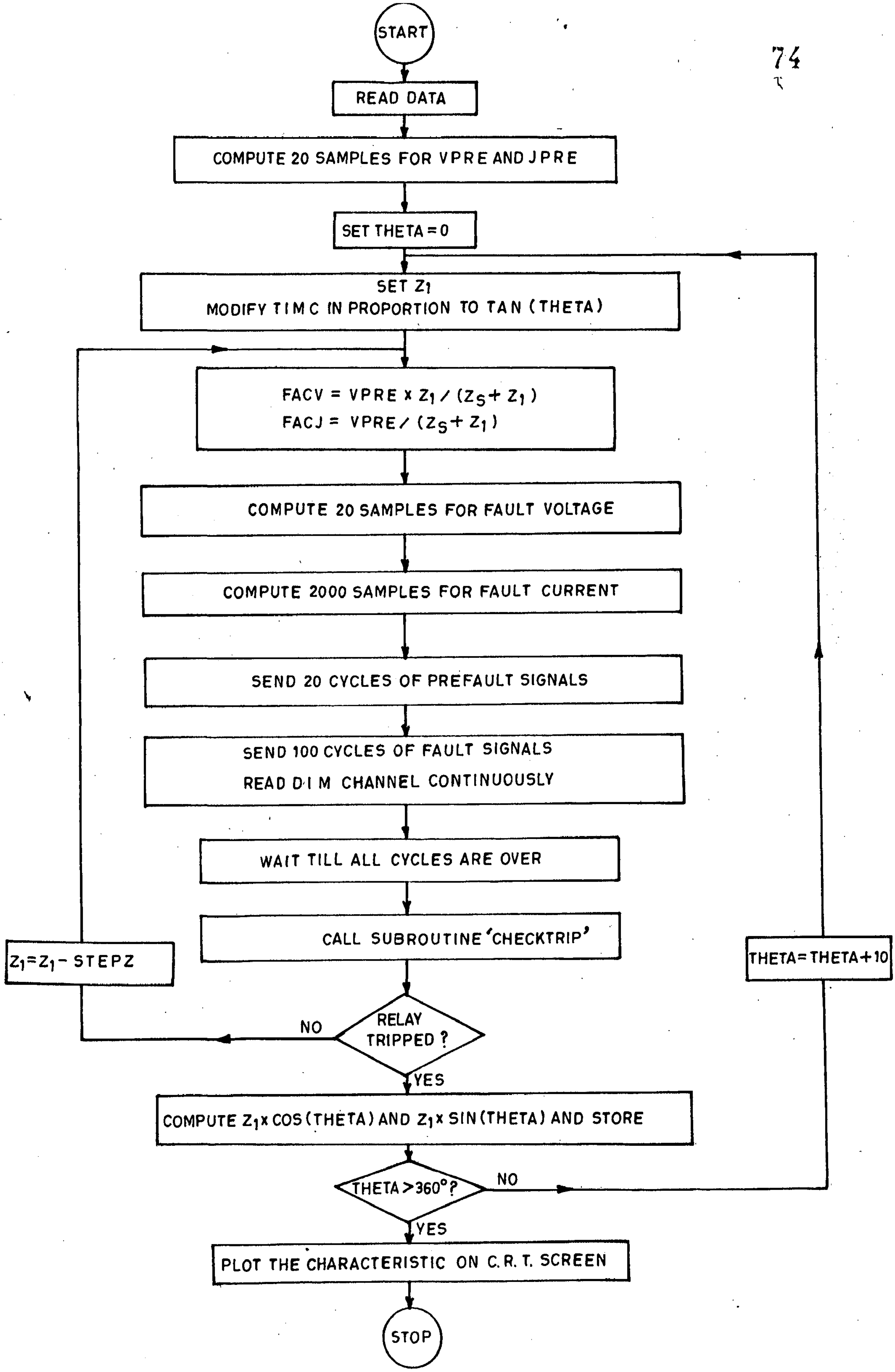


FIG. 4.7. TEST PROGRAMME FOR DYNAMIC POLAR CHARACTERISTIC OF DISTANCE RELAYS

.5.4 R-X DIAGRAM UNDER DYNAMIC CONDITIONS

Refer Fig. 4.7. The symbols mentioned in this flow-chart ean the same as in Fig. 4.6 (Refer Section 4.5.3). The test is onducted for a single value of DCOFF. The fault conditions are imulated just as in case of the previous test. The test starts t THETA = O. Z_1 is chosen larger than ZSET and the maximum value f impedance at which relay just operates is noted down. (The rocedure is same as explained in Section 4.5.3). Z_1 x Cos(THETA) nd Z_1 x Sin (THETA) are computed and stored in an array. THETA s increased in steps of 10 degrees. For the next test run (at n incremented value) of THETA, TIMC is modified in proportion to AN(THETA). Samples for fault signals are calculated using equaions (i) and (ii) (Section 4.5.3). Finally the boundary line haracteristic is obtained on the polar plane.

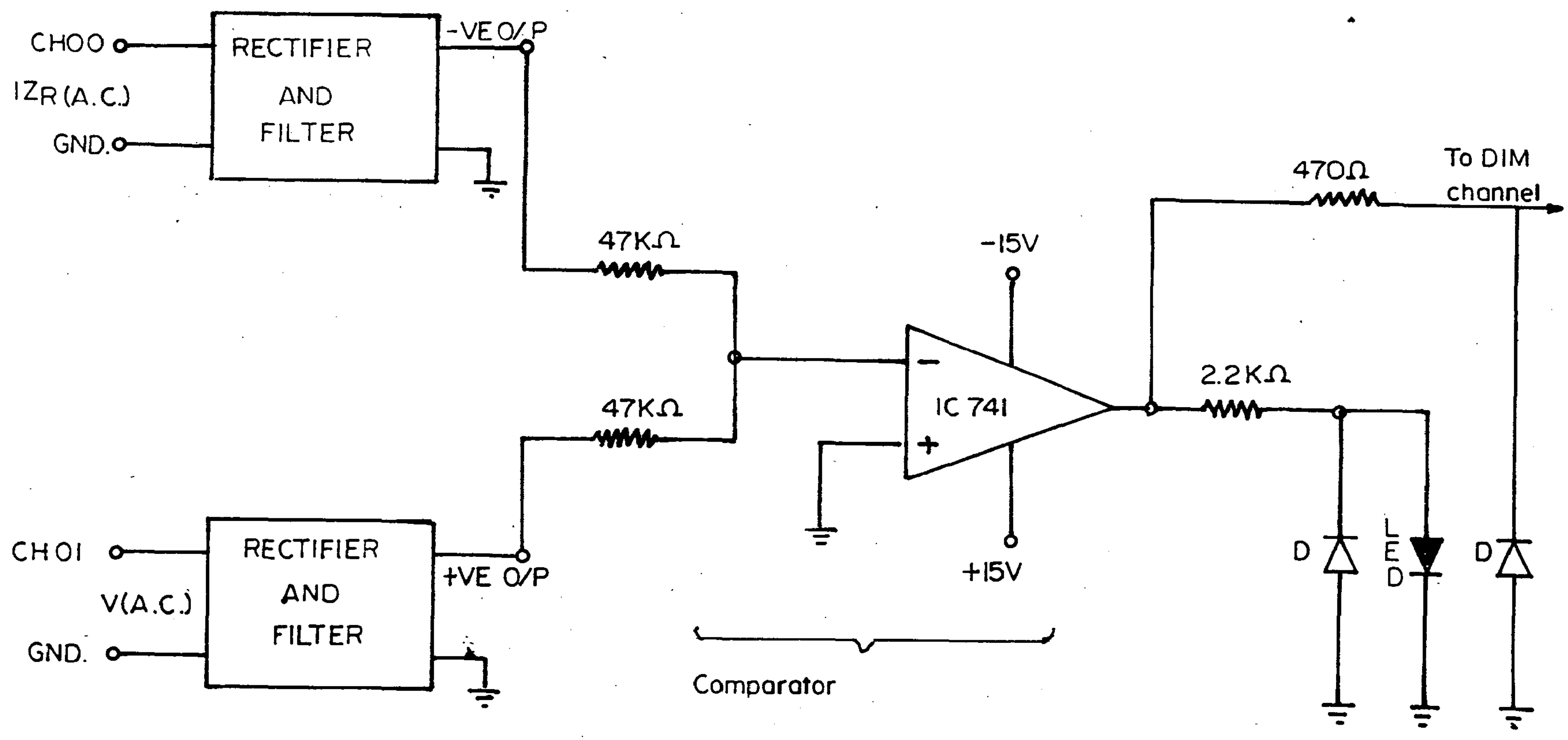


FIG.4·8 IMPEDANCE RELAY CIRCUIT

4.6 TESTING OF IMPEDANCE RELAYS

Impedance and admittance relays have been chosen as typical examples of distance relays, for testing. The generalized test programmes for distance relays have already been explained in the previous sections. A basic impedance relay circuit (electronic) has been tested under steady state and dynamic conditions.

4.6.1 IMPEDANCE RELAY CIRCUIT

The impedance relay circuit in Fig. 4.8 has been thoroughly tested. The relay circuit mainly comprises of an amplitude comparator, precision rectifiers and filters. As per the [9]table in Fig. 3.10 the voltage inputs to an amplitude comparator to obtain impedance relay characteristics are as follows:

Operating quantity = $I.Z_R$

Restraining quantity = V

These signals are generated by PC and applied to the relay I/Ps. The signals are then full wave rectified, filtered and then applied to the inverting input of the amplitude comparator. The O/P of the operational amplifier becomes high when the operating quantity exceeds the restraining quantity. The 470 ohm resistor at the O/P of the OPAMP is connected to convert the 15 volt level signal into a T.T.L. signal. The value of the resistance is chosen as per the [7]specifications of the Digital Input Module (D.I.M.). Refer Fig. 3.2 for rectifier circuit.

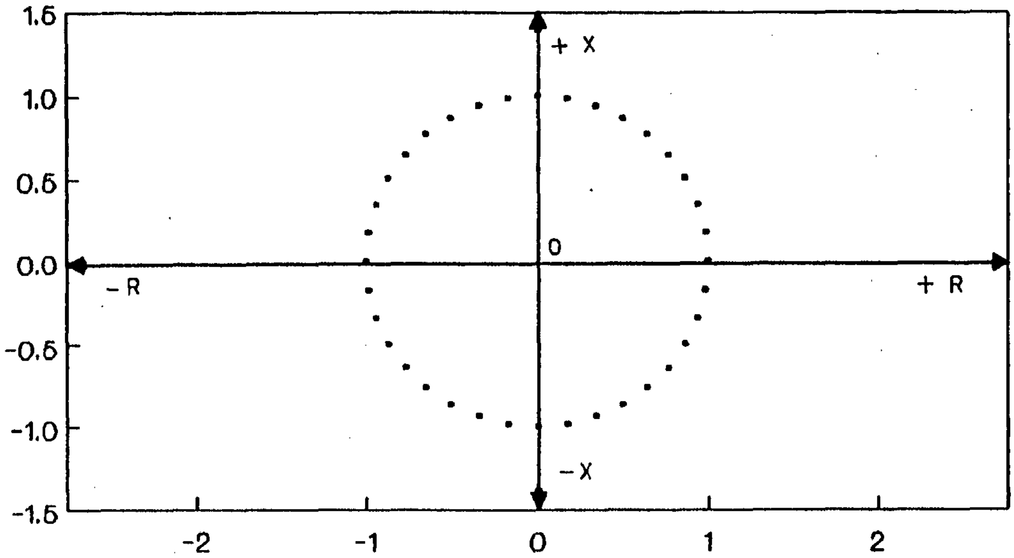


Fig.4.10:STEADY STATE POLAR CHARACTERISTIC OF IMPEDANCE RELAY. FACV=4, ZSET=1, FACJ=3, STEP=0.01

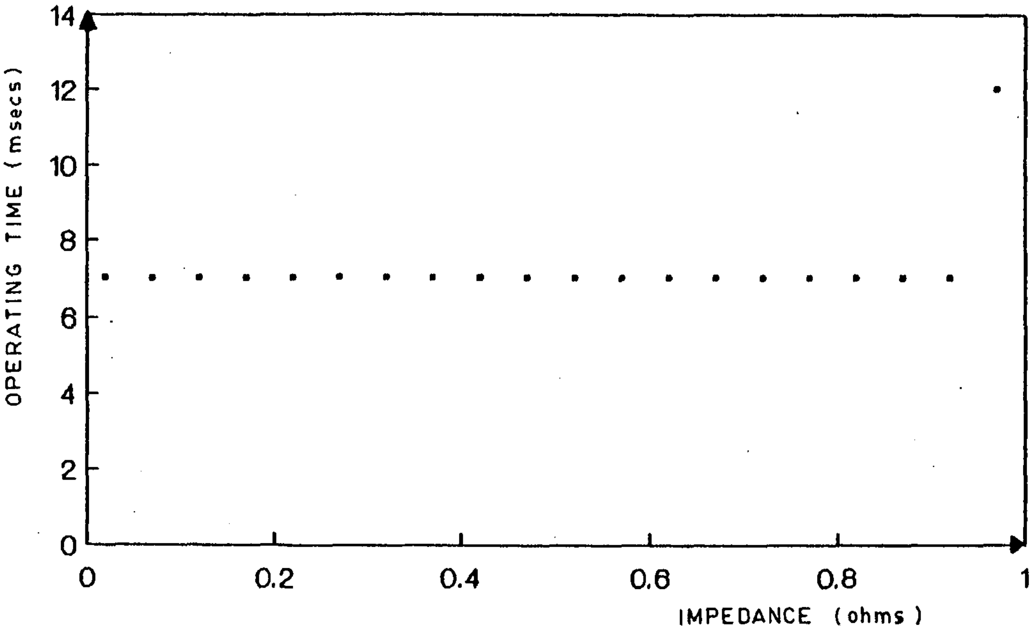


Fig.4.11 : OPERATING TIME CHARACTERISTIC OF IMPEDANCE RELAY. FACJ=4, Z1=1.1, STEPZ=0.05, ZSET=1.

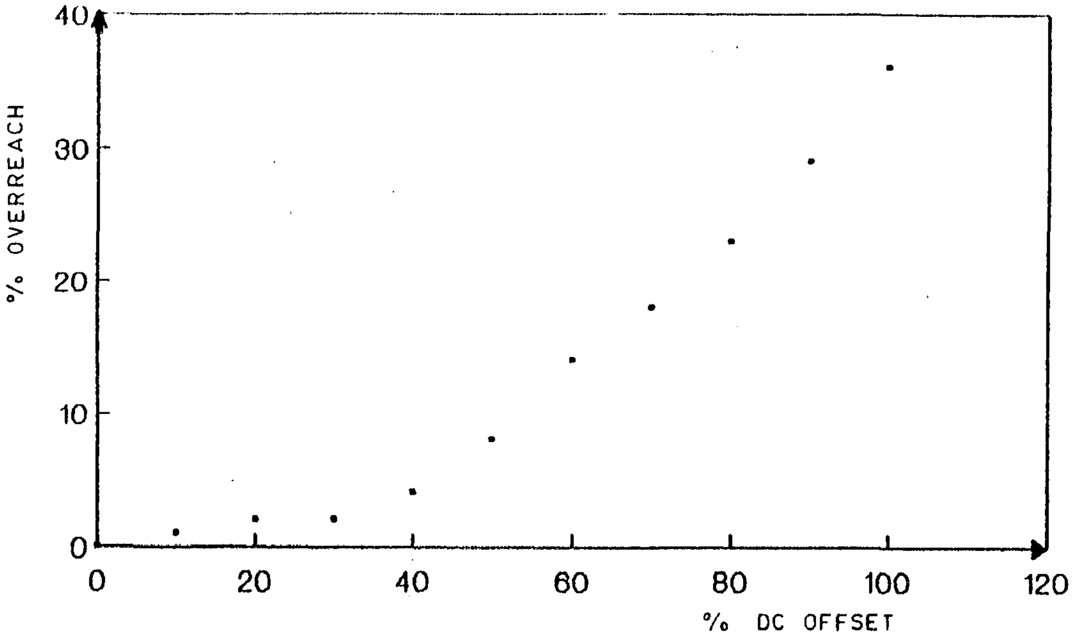


Fig.4.12:TRANSIENT OVERREACH CHARACTERISTIC OF IMPEDANCE RELAY.THETA-70, Z1-1.4 VPRE-4, JPRE-0.5, TIMC-500ms, ZSET-1.
ZS = 1, DCOFF = 1, STEPDC = 0 1, STEPZ = 0.01

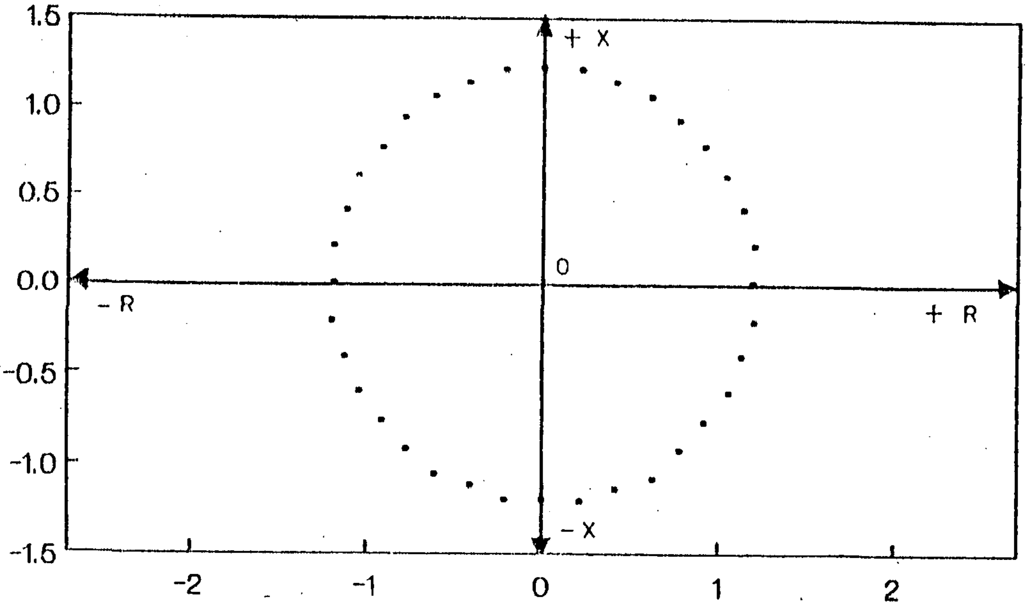


Fig.4.13:DYNAMIC POLAR CHARACTERISTIC OF IMPEDANCE RELAY. ZS-1, ZSET-1, VPRE-4 JPRE-0.5, STEPZ-0.01, Z1-1.40, DCOFF-0.0

4.6.2 TESTS CONDUCTED AND TEST RESULTS

The following tests have been conducted on the impedance relay with its setting equal to one and the characteristics obtained.

I. STATIC TESTS

(i) Steady State Polar Characteristic

The polar plot obtained is shown in Fig. 4.10. The points lie on a circle with radius equal to unity (approx.). The centre of the circle coincides with the origin.

(ii) Operating Time Characteristic

The impedance versus operating time plot obtained for this relay is shown in Fig. 4.11. The relay is of an instantaneous type and therefore the operating time of the relay (in the operating region, i.e. when $Z < 1$) is found out to be equal to 7 milliseconds. When the relay just enters it's operating region (from restraining region), its operating time is found to be higher, i.e. equal to 12 milliseconds.

II. DYNAMIC TESTS

(i) Transient Overreach Characteristic

The characteristic obtained is shown in Fig. 4.12. It is observed that the percentage overreach increases as the percentage of d.c. offset in the fault current increases, becoming a maximum of 36 percent for 100 percent d.c. offset.

(ii) Dynamic Polar Characteristic

The dynamic polar plot obtained for the impedance relay circuit is shown in Fig. 4.13. A comparison of this characteristic with that under steady state conditions, clearly shows the degree of overreach of the relay under dynamic conditions. The points lie on a circle whose radius is larger than unity. The test was conducted with 80 percent d.c. offset in the simulated fault current.

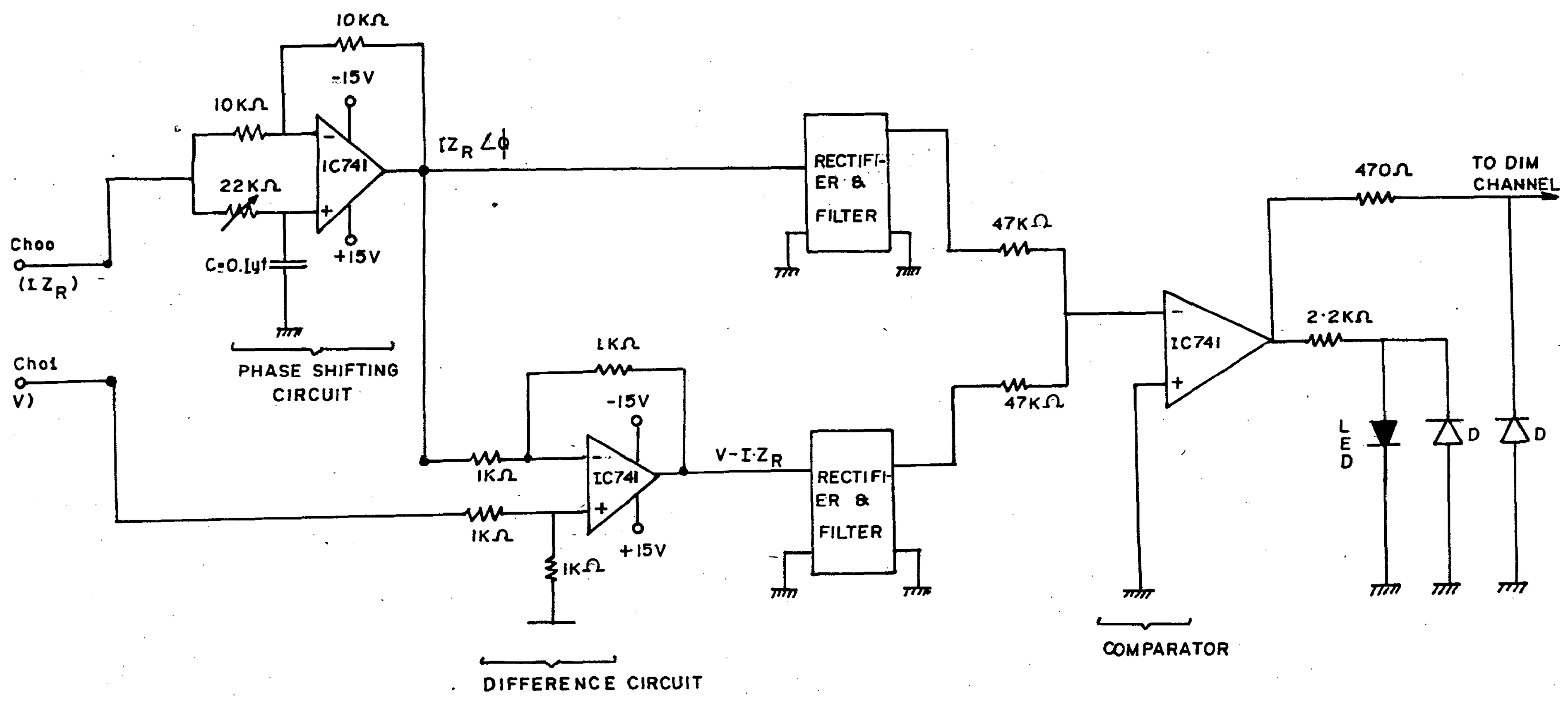


FIG. 4.9 ADMITTANCE RELAY CIRCUIT

4.7 TESTING OF ADMITTANCE RELAYS

The admittance relay circuit in Fig. 4.9 has been thoroughly tested under static and dynamic conditions. The generalized test programmes for testing have been already explained in the previous sections.

4.7.1 ADMITTANCE RELAY CIRCUIT

A static admittance relay circuit shown in Fig. 4.9 is made using an amplitude comparator with its voltage inputs as per the table in Fig. 3.10

Operating quantity $= I.Z_R$

Restraining quantity $= V - I.Z_R$

The difference signal is obtained with the help of an OPAMP (IC 741) difference circuit. The a.c. signals are full wave rectified and filtered and then applied to the amplitude comparator. Precision rectifier and filter circuit shown in Fig. 3.2 is used. The relay O/P becomes high if $|I.Z_R|$ exceeds $|V-I.Z_R|$. A phase shifting circuit is incorporated to introduce a phase shift in $I.Z_R$, thus getting a maximum sensitivity angle (M.S.A.) of $\phi/2 = \text{Tan}^{-1}(-2\pi fRC)$.

Where ϕ = M.S.A., f = frequency, R = resistance connected to the non-inverting I/P of the opamp as shown in Fig. 4.9 C = capacitor in the phase shifting circuit. Circuitry similar to that used in the impedance relay circuit is used to convert the 15 V O/P of OPAMP to a T.T.L. high signal (i.e. 5V).

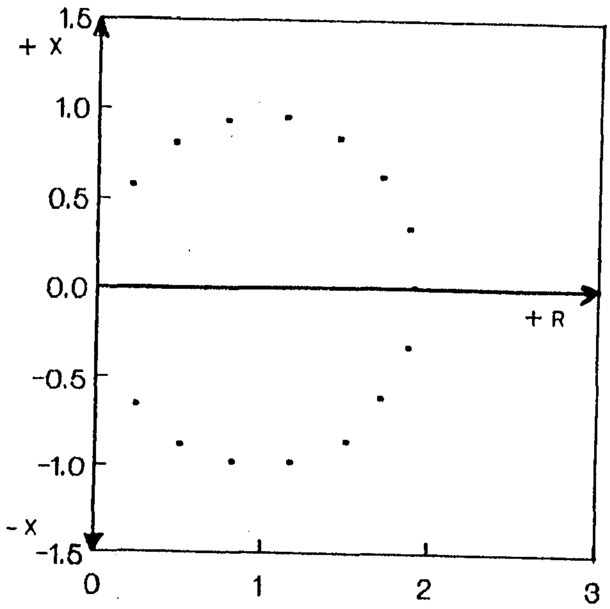


Fig.4.14: STEADY STATE POLAR CHARACTERISTIC OF MHO RELAY WITH M.S.A-0 DEGREE. FACV-4, ZSET-1, FACJ-1, STEP-0.1.

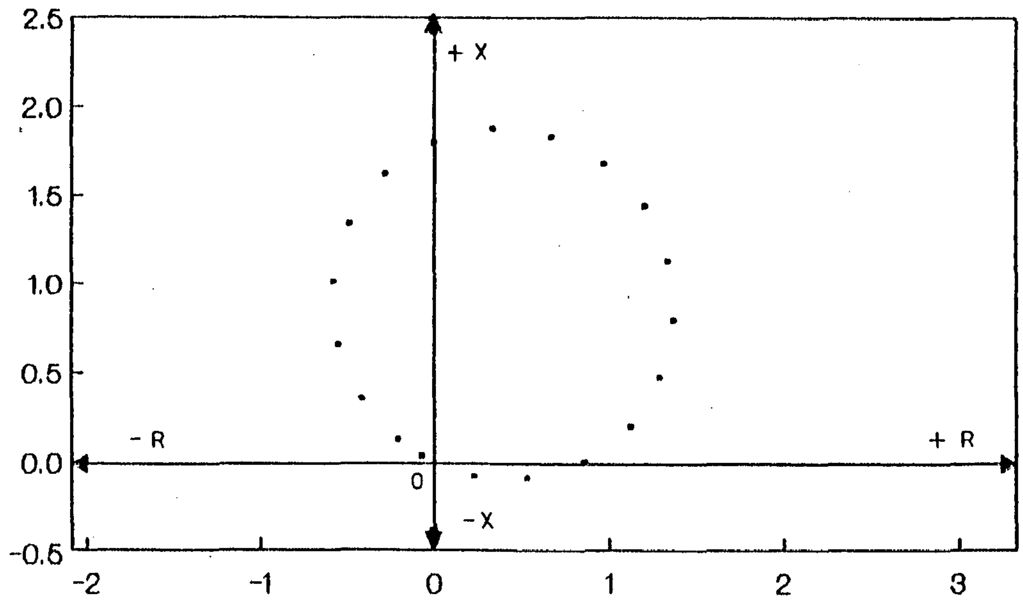


Fig.4.15 : STEADY STATE POLAR CHARACTERISTIC OF MHO RELAY WITH M.S.A-70 DEGREES. FACV-4, ZSET-1, FACJ-1, STEP-0.01.

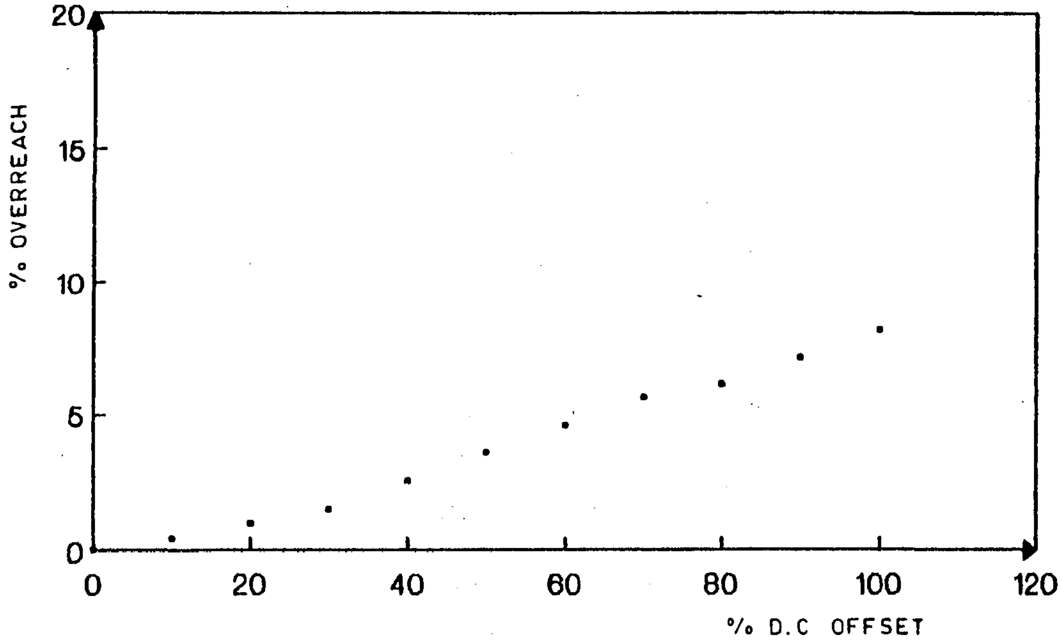


Fig.4.16 :TRANSIENT OVERREACH CHARACTER-
ISTIC OF MHO RELAY .THETA-70, Z1-2.19,
VPRE-4, JPRE-0.5, TIMC-500ms,ZSET-1.94.
ZS=1, STEPDC=0·1, STEPZ=0·01.

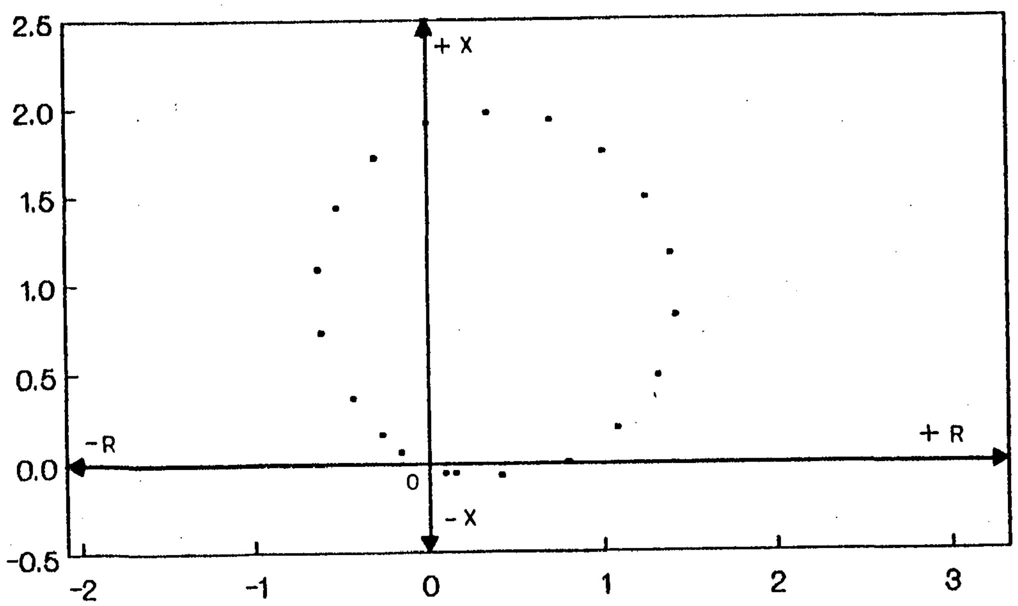


Fig.4.17: DYNAMIC POLAR CHARACTERISTIC
OF MHO RELAY WITH M.S.A-70 DEGREES.ZS-1,
ZSET-1, VPRE-4, JPRE-0.5, DCOFF-0.8.
Z1=2·2, STEPZ=0·01

4.7.2 TESTS CONDUCTED AND TEST RESULTS

The following tests have been conducted on the basic admittance relay circuit shown in Fig. 4.9.

I. STATIC TESTS

(i) Steady State Polar Characteristic of MHO relay with M.S.A. = zero degree

The polar plot for this relay is shown in Fig. 4.14. The phase shifting circuit in Fig. 4.9 is excluded to obtain MHO relay characteristics with M.S.A. = zero degree. The M.S.A. (maximum sensitivity angle) obtained from the plotted characteristic as well as the operating and the restraining regions are as expected for this relay (i.e. as per the design). The points lie on a circle which passes through the origin. ZSET = 1 approximately.

(ii) Steady State Polar Characteristic of MHO Relay with M.S.A. = 70 degrees

The circuit in Fig. 4.9 is tested under steady state conditions and the polar plot in Fig. 4.15 is obtained. The parameters (M.S.A. = 70, ZSET = 1) for which the relay has been designed are reflected in the characteristic. The operating and restraining regions also agree with the design of the relay.

II. DYNAMIC TESTS

(i) Transient Overreach Characteristic of MHO relay with M.S.A. = 70 degrees

The obtained characteristic is shown in Fig. 4.16. It is observed that the percentage overreach increases, with increase in percentage d.c. offset in the simulated fault current. It has a maximum value equal to 8.14 percent at 100 percent d.c. offset. The dynamic behaviour of MHO relay is definitely better than the impedance relay.

(ii) Dynamic Polar Characteristic of MHO relay with M.S.A. = 70 degrees

The obtained polar characteristic for this relay is shown in Fig. 4.17. The radius of the circular characteristic (on which points lie) is slightly larger than that obtained under steady state conditions, indicating the expected overreach of the relay. The test was conducted with 80 percent d.c. offset in the simulated fault current.

CHAPTER V

CONCLUSIONS AND EXTENSION OF WORK

Static and dynamic tests were conducted on various relays and their operating parameters/characteristics obtained.

After conducting the tests with this computer supported testing equipment, it was realized that this automated approach to testing is better than the conventional methods used. On account of its high accuracy, elimination of human errors, simplicity, speed and many other factors, it is fully justified to adopt this computerised approach to relay testing.

5.1 MERITS OF PREPARED AUTOMATED TEST EQUIPMENT

The merits of this computer supported test equipment are mentioned below.

(i) This test equipment is much more accurate, reliable, devoid of human errors and less expensive as compared to the conventional methods. The 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. Equipment used may deviate from its prescribed accuracy, impairing the quality of testing.

As against this, a microcomputer with its immense programmable features and a minimum of hardware (DACs, DIM and interfacing circuitry) is sufficient to conduct tests on all relay types. Different test benches are not required, a single equipment, with different software for different relays, serves the purpose of testing various relays. Most of the automated test equipment's hardware is in the form of integrated circuitry and therefore not likely to be damaged frequently. There is also less deterioration on ageing.

Test programs, once written can be used to conduct any number of tests. Manual intervention is minimum. 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 discs, floppies or other mass storage devices. Human errors in measurement, parallax removal, listing of readings are completely eliminated in case of this prepared test equipment. Regular maintenance and testing is required for the conventional, test benches, whereas such maintenance is not necessary in case of the designed test system.

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

Secondary injection tests using test plugs, sockets etc. are capable of applying sudden fault currents to the relay, but the designed, automated test equipment easily provides the near fault situations to the relay under test (by generating and applying an exponentially decaying signal to the relay), thus offering higher accuracy, with added simplicity in testing.

(iii) Plotting of relay characteristics is very simple and accurate in case of the designed test equipment. Graphics packages like LOTUS, HPG etc. can be used. As against this, the test readings have to be first taken down on paper and then the graphs/characteristics prepared manually. Human errors are very likely and also the procedure is quite tedious and time consuming.

(iv) The computer memory or the mass storage devices can be used to store the test results in case of the computer supported testing procedure. This stored information may be retrieved any time for future use. Filing the test results in the conventional approach to testing is a very tedious task.

(v) The prepared A.T.E. helps in better relay design. The relay can be tested for various fault situations that may arise in the power system. The relay design can then be modified upon unsatisfactory operation. Using the conventional methods, the procedure of obtaining the test results, plotting the characteristics and then again observing the results upon slight modification in design, would be a tedious, complicated, time consuming and a less accurate process.

Thus we conclude, that in view of the computational ability, mass storage ability, and programming flexibility of the micro-computer, the designed A.T.E. is better as compared to the conventionals methods of testing used.

5.2 EXTENSION OF WORK

It is suggested that the following changes can be incorporated in the present system so as to make it still better.

(i) The prepared test system can test only single phase relays. It may be easily extended to three phase relays. Two DAC (digital to analog converters) channels are being used in testing single phase relays. Four more DAC channels would be required for three phase relays. Present programs will have to be modified to generate four more signals.

(ii) Basic experimental, static relay circuits have been tested by this system. The test system can be extended to test electro-mechanical relays by interposing high gain, high quality amplifiers at the DAC O/Ps.

(iii) In the present test system, the analog signals are generated by outputting digitized samples at a fixed rate to the DAC O/P. There is a little loss of test signal information in the sampling interval and the reconstructed waveform is not a smooth sinusoid. These test signals can be improved and made to closely resemble a smooth sine wave by using low pass, active filters at the O/P of the DACs.

(iv) The accuracy of testing would definitely improve if the sampling rate is chosen higher than 1 millisecond. Presently, a sampling rate of 1 millisecond is chosen and this amounts to twenty samples per cycle. The test system is capable of a maximum sampling rate of 100 microseconds and this facility can be used to improve the testing accuracy. Program for waveform generation, calculation of samples, will have to be then slightly modified. Two hundred samples per cycle will have to be calculated (by program instead of twenty per cycle).

(v) In the present test system, only the D.C. transient has been incorporated in the test signal during dynamic conditions, similarly an a.c. transient can also be very easily introduced in the signals. Only some modification in the sample calculations and waveform generation will have to be done. Harmonic distortions can be incorporated in the test signals, especially for testing the differential protection for transformers.

In fact any test waveform can be generated by sending previously calculated, appropriate samples to the DAC I/P.

(vi) Frequency (over and under) have not been tested. They can very conveniently be tested with this test system. The program will have to be slightly altered. Instead of incrementing/decrementing the amplitude of the test signal, the frequency will have to kept variable and the samples calculated accordingly.

Appendix A

The Data Acquisition System, manufactured by Keithley Instruments Inc., used in this Automated test equipment is described here.

SERIES 500

The series 500, as the company names it, is a system which when interfaced to a compatible computer, forms a speedy and efficient Data Acquisition System. At the heart of the system is a rugged, aluminium-cased card cage with ten slots for the installation of I/O modules. An interface card is placed inside the computer to interface the external world with the computer. The two modules used in to prepare the test equipment are (i) AOM2 i.e. the high resolution analog O/P module (ii) DIM i.e. the Digital Input Module.

(i) AOM2

This module has 2 channels of analog O/P. Each channel has a separate D/A converter. The output characteristics of this module are given below,

Output Channels : Two

Output Ranges (switch selectable for each channel): $\pm$ 10V, 0 to + 10V.

Resolution : 16 bits

Non-linearity : $\pm$ 0.003 percent of full scale.

Output Impedance : 0.1 ohm.

Load Characteristics : 2K ohm minimum, 1000 pf maximum, short circuit protected.

Slow Rate : 20 microseconds to 0.006 percent of full scale transition.

(ii) D.I.M.

This module provides 16 channels of digital input with resistor programmable thresholds from +5 to 28V. As shipped, the module is provided for T.T.L. inputs. Each channel can be optically isolated from system circuitry and other input channels. The settling time of the isolation circuit is 5 micro-seconds, allowing sampling of high speed digital inputs. Optical isolators are the primary components of the module, providing isolated digital sensing for 16 channels. Each isolator contains an internal transmitting LED (driven by the I/P signal) and a receiving phototransistor.

The DIM's specifications are given below:

Input Channels : 16

Input Characteristics : TTL compatible

Technique : Optical

Channel to Ground : 500V peak maximum

Input Voltage : Upto 28V maximum

External supply requirements: 5 to 28 Volts at 14 mA per channel.

SOFT 500

This is a powerful software package for data acquisition written for the Keithley series 500 system. It is an extension of BASIC. The Soft 500 commands can be called directly from BASIC. These are subroutines written in assembly language. It is in short a package which allows easy access to the series 500 Data Acquisition hardware.

This is capable of background/foreground processing. Programs written can access two levels of operation: foreground and background. The foreground is the controlling BASIC program. The background is a special Soft 500 environment, such that when certain commands (Soft 500) appear in the BASIC program, tasks are set up in the background which proceed independently of the controlling program. These commands are driven by the interrupt generating circuitry on the interface card. When the Soft 500 command CALL INTON (i.e. interrupts on) is issued, the hardware's interval timers begin to generate requests for interrupts at an interval specified in the CALL INTON's parameter list.[7] Each time an interrupt occurs, the processor jumps from the foreground (i.e. the BASIC program) to the pending background tasks.

Commands like CALL ANOUT are available to select channel number, sampling rate and number of times the function has to be repeated. More details of the software used can be obtained from the manual mentioned in Reference number 7.

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APPENDIX B

```
1 REM : program for operating value detection of instantaneous
ovvervoltage relay.
2 REM : DATA : FACJ=initial amlitude of operating qty,  STEPF=
increment in FACJ.
10 DIM X(20),F(1000)
15 PI#=3.141592654# : FACJ=5 : STEPF=.01
20 T=0
30 FOR I=1 TO 20
50 X(I)=FACJ*SIN(2*PI#*50*T*.001)
60 T=T+1
70 NEXT I
80 CALL INIT
90 CALL ARMAKE'("ovrvol%",20.0,"ch00")
100 CALL ARPUT'("ovrvol%",1.0,20.0,"ch00",1,x,0)
110 CALL ANOUT'("ovrvol%","ch00",1,20,"wgo")
120 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo")
125 CALL ANOUT'("ovrvol%","ch00",1,20,"bt")
130 CALL GO'("wbt")
140 CALL INTON'(1,"mil")
150 B=2000
160 B=B-1
170 IF B<>0 THEN 160 ELSE 180
180 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
190 CALL INIT
200 FOR J=1 TO 16
210 SUM=0
220 FOR I=J TO J+4
230 SUM=SUM+F(I)
240 NEXT I
250 IF SUM=5 THEN 290 ELSE 260
260 NEXT J
270 FACJ=FACJ+STEPF
280 IF FACJ>10 THEN 310 ELSE 20
290 OPTIM=I+1
300 PRINT "relay has tripped","I=";FACJ;",";"optime=";OPTIM
310 END
```

```
1 REM : program for operating time characteristic of definite
time delay overvoltage relay.
2 REM : DATA : FACJ=initial amlitude if operating qty,  STEPF=
increment in FACJ.
10 DIM X(20),F(1000),Z(300)
15 PI#=3.141592654# : FACJ=5 : STEPF=.5
16 SUBS=-1
20 T=0
30 FOR I=1 TO 20
50 X(I)=FACJ*SIN(2*PI#*50*T*.001)
60 T=T+1
70 NEXT I
80 CALL INIT
90 CALL ARMAKE'("ovrvol%",20.0,"ch00")
100 CALL ARPUT'("ovrvol%",1.0,20.0,"ch00",1,x,0)
110 CALL ANOUT'("ovrvol%","ch00",1,100,"wgo")
120 CALL DIGIN'("chek&",2000.0,"chtrip",10,1,"wgo")
125 CALL ANOUT'("ovrvol%","ch00",1,25,"bt")
130 CALL GO'("bt")
140 CALL INTON'(1,"mil")
150 B=2000
160 B=B-1
170 IF B<>0 THEN 160 ELSE 180
180 CALL ARGET'("chek&",1.0,200.0,"chtrip",1,f)
190 CALL INIT
200 FOR J=1 TO 196
210 SUM=0
220 FOR I=J TO J+4
230 SUM=SUM+F(I)
240 NEXT I
250 IF SUM=5 THEN 290 ELSE 260
260 NEXT J
270 FACJ=FACJ+.01 : GOTO 20
290 OPTIM=(I+1)*10
300 PRINT "relay has tripped","i=";FACJ;",";"optime="
;OPTIM;"msecs"
310 SUBS=SUBS+2
320 Z(SUBS)=FACJ
330 Z(SUBS+1)=OPTIM
340 FACJ=FACJ+.5
350 IF FACJ<10 THEN 20 ELSE 390
390 SCREEN 9 : COLOR 4
400 SCREEN 0,0,0
410 SCREEN 9 : COLOR 4
420 LINE (10,190)-(10,10) : LINE (10,190)-(320,190)
430 FOR I=1 TO SUBS
440 XCOR%=10+(Z(I)*15)+10
450 YCOR%=190-(Z(I+1)*9.000001E-02)
460 PSET (XCOR%,YCOR%),15
470 NEXT I
480 PRINT"operating time characteristic of overvoltage relay
with definite time delay"
490 B$=INPUT$(1)
500 SCREEN 0,0,0
510 END
```

```
1 REM : program for operating characteristic of biased
 differential relay.
2 REM : DATA : FACO= initial value of operating qty,  STEPO=
increment in FACO,  STEPR=  increment in restraining qty.
10 DIM X(20,2),Y(50),F(100)
11 CALL INIT
20 FACR=0 : FACO=.01 : STEPO=.01 : STEPR= .5
25 SUBS=-1
30 T=0 : SUBS=SUBS+2 : C=1
40 FOR I=1 TO 20
50 X(I,2)=FACR*SIN(2*3.141592654#*50*T*.001)
60 T=T+1
70 NEXT I
90 T=0
100 FOR I=1 TO 20
110 X(I,1)=FACO *SIN(2*3.14*50*T*.001)
120 T=T+1
130 NEXT I
135 IF C=1 THEN 136 ELSE 137
136 CY%=100 : GOTO 150
137 CY%=10 : GOTO 150
150 CALL ARMAKE'("difftim%",20.0,"ch00,ch01")
160 CALL ARPUT'("difftim%",1.0,20.0,"ch01",2,x,0)
170 CALL ARPUT'("difftim%",1.0,20.0,"ch00",1,x,0)
175 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo","stat")
180 CALL ANOUT'("difftim%","ch00,ch01",1,10,"wgo")
185 CALL ANOUT'("difftim%","ch00,ch01",1,cy%,"bt")
190 CALL GO'("wbt")
195 CALL INTON'(1,"mi1")
200 B=2000
211 B=B-1
212 IF B<>0 THEN 211 ELSE 225
225 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
230 CALL INIT
240 FOR J=1 TO 16
250 SUM=0
255 FOR I=J TO J+4
260 SUM=SUM+F(I)
262 NEXT I
264 IF SUM=5 THEN 310 ELSE 265
265 NEXT J
270 FACO=FACO+STEPO : C=C+1
280 IF FACO=10 THEN 350
290 GOTO 90
310 PRINT"relay has tripped" : PRINT "I(op)=";FACO,"I(res)=";FACR
320 Y(SUBS)=FACO : Y(SUBS+1)=FACR
330 FACR=FACR+STEPR
340 IF FACR>10 THEN 350 ELSE 30
350 PRINT"press any key to continue"
360 B$=INPUT$(1)
490 SCREEN 9 : COLOR 4
500 LINE (10,150)-(310,150)
510 LINE (10,150)-(10,10)
```

```
511 FOR IX=39 TO 300 STEP 29
512 LINE (IX,150)-(IX,146)
513 NEXT IX
514 FOR IY=15 TO 105 STEP 45
515 LINE(10,IY)-(14,IY)
516 NEXT IY
520 FOR I=1 TO SUBS STEP 2
530 XCOR%=(Y(I+1)*29)+10
540 YCOR%=150-INT(Y(I)*45)
550 PSET (XCOR%,YCOR%),15
560 NEXT I
570 LOCATE 1,1 : PRINT"differential relay charecteristic"
580 END
```

```
1 REM : program for operating time characteristic of differential
relay.
2 REM : DATA : FACR= fixed value of restraining vol,
FACO= initial value of current,  STEPO= increment in FACO.
10 DIM X(20,2),Z(300),F(100),C(100)
11  CALL INIT
20 PI#=3.141592654# :FACR!=5 : STEPO=.5 : FACO=.9
30 T=0
40 FOR I=1 TO 20
50 X(I,2)= FACR!*SIN(2*PI# *50*T*.001+(THETA*(PI#/180)))
60 T=T+1
70 NEXT I
80 SUBS=-1
120 T=0
130 FOR I=1 TO 20
140 X(I,1)=FACO!*SIN(2*PI#*50*T*.001)
150 T=T+1
160 NEXT I
170 CY%=100
180  CALL ARMAKE'("im%",20.0,"ch00,ch01")
190 CALL ARPUT'("im%",1.0,20.0,"ch01",2,x,0)
200 CALL ARPUT'("im%",1.0,20.0,"ch00",1,x,0)
211 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo","stat")
212 CALL ANOUT'("im%","ch00,ch01",1,20,"wgo")
213 CALL ANOUT'("im%","ch00,ch01",1,cy%,"bt")
214 CALL GO'("wbt")
215 CALL INTON'(1,"mil")
216 B=2000
217 B=B-1
218 IF B<>0 THEN 217 ELSE 225
225 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
226 CALL INIT
229 FOR J=1 TO 16
230 SUM=0
231 FOR I=J TO J+4
232 SUM=SUM+F(I)
233 NEXT I
234 IF SUM=5 THEN 320 ELSE 235
235 NEXT J
300 FACO=FACO+.01
310 GOTO 120
320 OPTIM=I+1
321 PRINT "relay has tripped", "I(op)=";FACO;",";  "OPTIME=";OPTIM
322 SUBS=SUBS+2
340 Z(SUBS)=FACO
350 Z(SUBS+1)=OPTIM
360 FACO=FACO+STEPO
370 IF FACO>10 THEN 389 ELSE 120
389 PRINT "press any key" : B$=INPUT$(1)
390 FOR I=1 TO SUBS STEP 2
400 PRINT I,Z(I),Z(I+1)
410 NEXT I
420 PRINT "press any key to continue"
```

```
425 B$=INPUT$(1)
430 SCREEN 9 : COLOR 4
440 LINE (10,190)-(10,10) : LINE (10,190)-(320,190)
450 FOR I=1 TO SUBS STEP 2
500 XCOR%=(Z(I)*15)+10
510 YCOR%=190-(Z(I+1)*9)
520 PSET (XCOR%,YCOR%),15
530 NEXT I
540 LOCATE 1,1 : PRINT"operating time characteristic of
differential relay"
545 PRINT "press any key to end"
550 B$=INPUT$(1)
560 SCREEN 0,0,0
600 END
```

```
1 REM : program for operating characteristic of directional relays.
2 REM : DATA : FACV=amplitude of voltage,  FACJ=initial amplitude
of current,  STEPF=  increment in FACJ,  ZSET = relay setting.
10 DIM X(20,2),AMP(300),F(100)
11 CALL INIT
20 PI#=3.141592654# :FACV!=4 : ZSET=1 : STEPF=.001 : FACJ=.01
30 T=0
40 FOR I=1 TO 20
50 X(I,1)= FACV!*SIN(2*PI# *50*T*.001)
60 T=T+1
70 NEXT I
80 SUBS=-1
90 THETA=0
100 FACJ!=.01 : C=1
120 T=0
130 FOR I=1 TO 20
140 X(I,2)=ZSET*FACJ!*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))
150 T=T+1
160 NEXT I
165 IF C=1 THEN 166 ELSE 167
166 CY%=100 : GOTO 180
167 CY%=20 : GOTO 180
180 CALL ARMAKE'("im%",20.0,"ch00,ch01")
190 CALL ARPUT'("im%",1.0,20.0,"ch01",1,x,0)
200 CALL ARPUT'("im%",1.0,20.0,"ch00",2,x,0)
211 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo","stat")
212 CALL ANOUT'("im%","ch00,ch01",1,20,"wgo")
213 CALL ANOUT'("im%","ch00,ch01",1,cy%,"bt")
214 CALL GO'("wbt")
215 CALL INTON'(1,"mil")
216 B=2000
217 B=B-1
218 IF B<>0 THEN 217 ELSE 225
225 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
226 CALL INIT
229 FOR J=1 TO 16
230 SUM=0
231 FOR I=J TO J+4
232 SUM=SUM+F(I)
233 NEXT I
234 IF SUM=5 THEN 320 ELSE 235
235 NEXT J
300 FACJ!=FACJ!+STEPF : C=C+1
310 IF FACJ!>10 THEN 560 ELSE 120
320 PRINT "relay has tripped","I=";FACJ!;",";"THETA=";THETA
321 SUBS=SUBS+2
340 AMP(SUBS)=FACJ!*COS(THETA*(PI#/180))
350 AMP(SUBS+1)=FACJ!*SIN(THETA*(PI#/180))
355 IF THETA<90 THEN 360 ELSE 361
360 THETA=THETA+10 : C=1 : GOTO 120
361 IF THETA=90 THEN 370
362 THETA=THETA-10 :C=1 :  IF THETA=270 THEN 390 ELSE 120
370 THETA=360: C=1 : GOTO 100
```

```
390 FOR I=1 TO SUBS STEP 2
400 PRINT"i cos=";AMP(I),"i sin=";AMP(I+1)
410 NEXT I
420 PRINT "press any key to continue"
425 B$=INPUT$(1)
430 SCREEN 9 : COLOR 4
440 LINE (20,100)-(320,100) : LINE (160,190)-(160,10)
450 FOR I=1 TO SUBS STEP 2
500 XCOR%=(AMP(I)*750)+160
510 YCOR%=100-(AMP(I+1)*180*(200/320))
520 PSET (XCOR%,YCOR%),15
530 NEXT I
540 LOCATE 1,1 : PRINT"DIRECTIONAL RELAY CHARACTERISTIC"
544 PRINT "press any key to end"
545 B$=INPUT$(1)
546 SCREEN 0,0,0
550 END
560 PRINT "relay restrained for THETA=";THETA
570 GOTO 355
```

```
1 REM :program for steady state polar characteristic of
distance relays.
2 REM : DATA  : FACV=amplitude of voltage, FACJ=initial
amplitude of current.
3 REM : DATA  : STEPF= increment in FACJ,  ZSET= relay setting.
10 DIM X(20,2),Z(300),F(100)
11  CALL INIT
20 PI#=3.141592654# :FACV!=4 : ZSET=1 : STEPF=.01
30 T=0
40 FOR I=1 TO 20
50 X(I,1)= FACV!*SIN(2*PI# *50*T*.001)
60 T=T+1
70 NEXT I
80 SUBS=-1
90 THETA=0
100 FACJ!=1
120 T=0
130 FOR I=1 TO 20
140 X(I,2)=ZSET*FACJ!*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))
150 T=T+1
160 NEXT I
165 IF FACJ!=1 THEN 166 ELSE 167
166 CY%=100 : GOTO 180
167 CY%=20 : GOTO 180
180  CALL ARMAKE'("im%",20.0,"ch00,ch01")
190 CALL ARPUT'("im%",1.0,20.0,"ch01",1,x,0)
200 CALL ARPUT'("im%",1.0,20.0,"ch00",2,x,0)
211 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo","stat")
212 CALL ANOUT'("im%","ch00,ch01",1,20,"wgo")
213 CALL ANOUT'("im%","ch00,ch01",1,cy%,"bt")
214 CALL GO'("wbt")
215 CALL INTON'(1,"mil")
216 B=2000
217 B=B-1
218 IF B<>0 THEN 217 ELSE 224
224 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
225 CALL INIT
226 FOR J=1 TO 16
227 SUM=0
228 FOR I=J TO J+4
229 SUM=SUM+F(I)
230 NEXT I
231 IF SUM=5 THEN 320 ELSE 232
232 NEXT J
300 FACJ!=FACJ!+STEPF
310 IF FACJ!>10 THEN 560 ELSE 120
320 IMPE!=(FACV!)/(FACJ!): PRINT "relay has tripped","I=";FACJ!;
",";"THETA=";THETA;",";"Z=";IMPE!
322 SUBS=SUBS+2
340 Z(SUBS)=IMPE!*COS(THETA*(PI#/180))
350 Z(SUBS+1)=IMPE!*SIN(THETA*(PI#/180))
360 THETA=THETA+10
370 IF THETA<360 THEN 100 ELSE 390
390 FOR I=1 TO SUBS STEP 2
400 PRINT"z cos=";Z(I),"z sin=";Z(I+1)
410 NEXT I
420 PRINT "press any key to continue"
425 B$=INPUT$(1)
```

```
430 SCREEN 9 : COLOR 4
440 LINE (20,100)-(320,100) : LINE (160,190)-(160,10)
450 FOR I=1 TO SUBS STEP 2
460 XCOR%=(Z(I)*80)+160
470 YCOR%=100-(Z(I+1)*80*(200/320))
520 PSET (XCOR%,YCOR%),15
530 NEXT I
540 LOCATE 1,1 : PRINT "steady state polar characteristic
of distance relay"
550 END
560 PRINT"relay restrained for THETA=";THETA
570 GOTO 360
```

```
1 REM : program for operating time characteristic of distance relays.
2 REM : DATA : FACJ= fixed value of current amplitude,  Z=initial
value of impedance,  STEPZ= decrement in Z,  ZSET= relay setting.
10 DIM X(20,2),Z(300),F(100)
11  CALL INIT
20 PI#=3.141592654# :FACJ!=4 : ZSET=1 : THETA=70 : STEPZ=.05
30 T=0
40 FOR I=1 TO 20
50 X(I,2)= ZSET*FACJ!*SIN(2*PI# *50*T*.001+(THETA*(PI#/180)))
60 T=T+1
70 NEXT I
80 SUBS=-1
90 Z=1.1
100 FACV!=Z*FACJ!
120 T=0
130 FOR I=1 TO 20
140 X(I,1)=FACV!*SIN(2*PI#*50*T*.001)
150 T=T+1
160 NEXT I
170 CY%=100
180  CALL ARMAKE'("im%",20.0,"ch00,ch01")
190 CALL ARPUT'("im%",1.0,20.0,"ch01",1,x,0)
200 CALL ARPUT'("im%",1.0,20.0,"ch00",2,x,0)
211 CALL DIGIN'("chek&",20.0,"chtrip",1,1,"wgo","stat")
212 CALL ANOUT'("im%","ch00,ch01",1,20,"wgo")
213 CALL ANOUT'("im%","ch00,ch01",1,cy%,"bt")
214 CALL GO'("wbt")
215 CALL INTON'(1,"mil")
216 B=2000
217 B=B-1
218 IF B<>0 THEN 217 ELSE 225
225 CALL ARGET'("chek&",1.0,20.0,"chtrip",1,f)
226 CALL INIT
229 FOR J=1 TO 16
230 SUM=0
231 FOR I=J TO J+4
232 SUM=SUM+F(I)
233 NEXT I
234 IF SUM=5 THEN 320 ELSE 235
235 NEXT J
300 Z=Z-.01
310 GOTO 100
320 OPTIM=I+1
321 PRINT "relay has tripped","Z=";Z;",";"OPTIME=";OPTIM
322 SUBS=SUBS+2
340 Z(SUBS)=Z
350 Z(SUBS+1)=OPTIM
360 Z=Z-STEPZ
370 IF Z<0 THEN 389 ELSE 100
389 PRINT "press any key" : B$=INPUT$(1)
390 FOR I=1 TO SUBS STEP 2
400 PRINT I,Z(I),Z(I+1)
410 NEXT I
420 PRINT "press any key to continue"
425 B$=INPUT$(1)
430 SCREEN 9 : COLOR 4
440 LINE (10,190)-(10,10) : LINE (10,190)-(320,190)
450 FOR I=1 TO SUBS STEP 2
500 XCOR%=(Z(I)*150)+10
510 YCOR%=190-(Z(I+1)*9)
```

```
520 PSET (XCOR%,YCOR%),15
530 NEXT I
540 LOCATE 1,1 : PRINT"operating time characteristic of distance relays"
545 PRINT "press any key to end"
550 B$=INPUT$(1)
560 SCREEN 0,0,0
600 END
```

```
1 REM : program for transient overreach characteristic of distance relays.
2 REM : DATA : THETA=actual line angle,  ZS=source impedance,  TIMC= deca
time constant of postfault current,  ZSET=relay setting, VPRE=prefault vr
amplitude,  JPRE=prefault current amplitude,  Z=initial value of impedan
DCOFF=fixed dc
10 DIM X(20,2),VOLF(20),AMPF(4000),F(4000),D(100)
20 ZSET=1 : VPRE=4 : JPRE=.5 : PI#=3.141592654# : THETA=70: ZS=1 : TIMC
:ZSET=1 : STEPDC=.1 : STEPZ=.01 : Z=1.4 : DCOFF=1
30 T=0
40 FOR I=1 TO 20
50 X(I,1)=VPRE*SIN(2*PI#*50*T*.001)
60 X(I,2)=ZSET*JPRE*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))
70 T=T+1
80 NEXT I
81 SUBS=-1
110 FACV!=VPRE*(Z/(ZS+Z))
120 FACJ!=VPRE/(ZS+Z)
130 T=0
140 FOR I=1 TO 2000
150 TAU=-(T/TIMC)
160 AMPF(I)= ZSET*FACJ!*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))+
(DCOFF*FACJ!*EXP(TAU))
170 T=T+1
180 NEXT I
181 T=0
182 FOR I=1 TO 20
183 VOLF(I)=FACV!*SIN(2*PI#*50*T*.001)
184 T=T+1
185 NEXT I
190 CALL INIT
200 CALL ARMAKE'("prefltZ",20.0,"ch00,ch01")
210 CALL ARMAKE'("posfvZ",20.0,"ch01")
211 CALL ARMAKE'("posfjZ",2000.0,"ch00")
220 CALL ARPUT'("prefltZ",1.0,20.0,"ch00",2,x,0)
230 CALL ARPUT'("prefltZ",1.0,20.0,"ch01",1,x,0)
240 CALL ARPUT'("posfvZ",1.0,20.0,"ch01",1,volf,0)
250 CALL ARPUT'("posfjZ",1.0,2000.0,"ch00",1,ampf,0)
260 CALL DIGIN'("chek&",2000.0,"chtrip",1,1,"wgo","stat")
270 CALL ANOUT'("posfvZ","ch01",1,100,"wgo")
271 CALL ANOUT'("posfjZ","ch00",1,1,"wgo")
273 CALL ANOUT'("prefltZ","ch00,ch01",1,20,"bt")
275 CALL GO'("wbt")
280 CALL INTON'(1,"mil")
290 B=2000
300 B=B-1
310 IF B<>0 THEN 300 ELSE 320
320 CALL ARGET'("chek&",1.0,2000.0,"chtrip",1,f)
321 CALL INIT
330 FOR J=1 TO 1996
340 SUM=0
350 FOR I=J TO J+4
360 SUM=SUM+F(I)
370 NEXT I
380 IF SUM=5 THEN 450 ELSE 390
390 NEXT J
410 Z=Z-STEPZ
420 GOTO 110
450 SUBS=SUBS+2
```

```
460 D(SUBS)=DCOFF*100
470 D(SUBS+1)=((Z-ZSET)/ZSET)*100
480 PRINT "relay tripped","DCOFF=";D(SUBS);",";"VF=";FACV;",";"IF=";FACJ
",";"Z=";Z;",";"OVVRCH=";D(SUBS+1)
490 DCOFF=DCOFF-STEPDC
500 IF DCOFF < 0 THEN 110 ELSE 504
504 PRINT"press any key to continue"
505 B$=INPUT$(1)
506 CLS
510 SCREEN 9 : COLOR 4
520 LINE (10,190)-(10,10) : LINE (10,190)-(310,190)
530 FOR I=1 TO SUBS STEP 2
540 D(I)=10+INT(D(I)*3)
550 D(I+1)=190-INT(D(I+1)*1.8)
560 PSET (XCOR%,YCOR%),15
570 NEXT I
580 PRINT "transient overreach characteristic of distance relays"
590 B$=INPUT$(1)
595 SCREEN 0,0,0
630 END
```

```
1 REM : program for dynamic polar characteristic of distance relays
2 REM : data: ZS=source impedance,  ZSET=relay setting,
VPRE=prefault voltage,  JPRE=prefault current,  Z=initial value of impe-
dance,  STEPZ=decrement in z,  DCOFF=dc offset in post fault current.
10 DIM X(20,2),VOLF(20),AMPF(4000),F(4000),D(100)
20 ZSET=1 : VPRE=4 : JPRE=.5 : PI#=3.141592654# :
ZS=1 : DCOFF=.8 : STEPZ=.01
24 SUBS=-1
25 THETA=0
30 T=0
40 FOR I=1 TO 20
50 X(I,1)=VPRE*SIN(2*PI#*50*T*.001)
60 X(I,2)=ZSET*JPRE*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))
70 T=T+1
80 NEXT I
100 Z=1.26 : GOSUB 900
110 FACV!=VPRE*(Z/(ZS+Z))
120 FACJ!=VPRE/(ZS+Z)
130 T=0
140 FOR I=1 TO 2000
150 TAU=-(T/TIMC)
160 AMPF(I)= ZSET*FACJ!*SIN(2*PI#*50*T*.001+(THETA*(PI#/180)))+
(DCOFF*FACJ!*EXP(TAU))
170 T=T+1
180 NEXT I
181 T=0
182 FOR I=1 TO 20
183 VOLF(I)=FACV!*SIN(2*PI#*50*T*.001)
184 T=T+1
185 NEXT I
190 CALL INIT
200 CALL ARMAKE'("prefIt%",20.0,"ch00,ch01")
210 CALL ARMAKE'("posfv%",20.0,"ch01")
211 CALL ARMAKE'("posfj%",2000.0,"ch00")
220 CALL ARPUT'("prefIt%",1.0,20.0,"ch00",2,x,0)
230 CALL ARPUT'("prefIt%",1.0,20.0,"ch01",1,x,0)
240 CALL ARPUT'("posfv%",1.0,20.0,"ch01",1,volf,0)
250 CALL ARPUT'("posfj%",1.0,2000.0,"ch00",1,ampf,0)
260 CALL DIGIN'("chek&",2000.0,"chtrip",1,1,"wgo","stat")
270 CALL ANOUT'("posfv%","ch01",1,100,"wgo")
271 CALL ANOUT'("posfj%","ch00",1,1,"wgo")
273 CALL ANOUT'("prefIt%","ch00,ch01",1,20,"bt")
275 CALL GO'("wbt")
280 CALL INTON'(1,"mil")
290 B=2000
300 B=B-1
310 IF B<>0 THEN 300 ELSE 320
320 CALL ARGET'("chek&",1.0,2000.0,"chtrip",1,f)
321 CALL INIT
330 FOR J=1 TO 1996
340 SUM=0
350 FOR I=J TO J+4
360 SUM=SUM+F(I)
370 NEXT I
380 IF SUM=5 THEN 450 ELSE 390
390 NEXT J
```

```
410 Z=Z-STEPZ
420 GOTO 110
450 PRINT "relay tripped","VF=";FACV!;",";"IF=";FACJ!;",";"Z=";Z;
",";"THETA=";THETA
460 SUBS=SUBS+2
470 D(SUBS)=Z*COS(THETA*(PI#/180))
480 D(SUBS+1)=Z*SIN(THETA*(PI#/180))
490 THETA=THETA+10
500 IF THETA>360 THEN 504 ELSE 30
504 PRINT"press any key to continue"
505 B$=INPUT$(1)
506 CLS
510 SCREEN 9 : COLOR 4
520 LINE (20,100)-(320,100) : LINE (160,190)-(160,10)
530 FOR I=1 TO SUBS STEP 2
540 D(I)=160+INT(D(I)*80)
550 D(I+1)=100-INT(D(I+1)*80*(200/320))
560 PSET (XCOR%,YCOR%),15
570 NEXT I
580 PRINT "dynamic polar characteristic for distance relays"
590 B$=INPUT$(1)
595 SCREEN 0,0,0
630 END
900 IF (THETA=90) OR (THETA=270) THEN 920
910 TIMC=((TAN(THETA)/(2*PI#*50))*1000)+500 : GOTO 930
920 TIMC=525
930 RETURN
```