DESIGN AND DEVELOPMENT OF MICROPROCESSOR BASED MULTI FUNCTIONAL RELAY

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With Specialization in Power System Engineering)

By

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JUNE, 2008

Dedicated to my parents,

R.K.Manohar, R.Rabitha

and

my sister, R.Devika

I.D. No.-M.T.429.../2008-13/BG

Candidate's Declaration

As partial fulfillment of the requirements for the Master of Technology (Electrical) Degree (Honors), I hereby submit for your considerations this dissertation entitled: **"Design and development of microprocessor based multi functional relay"**. *I declare that the work submitted in this dissertation is to the best of my knowledge and ability and is an authentic record of my own work carried out during the period from July 2007 to June 2008 under the supervision of* **Sri. Bharat Gupta, Assistant Professor, Electrical Engineering Department, Indian Institute of Technology Roorkee.**

This work has not been previously submitted for a degree at the Indian Institute of Technology Roorkee or any other institutes.

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Date 27-06-2008

Certificate

This is to certify that the above statements made by the student are correct to the best of my knowledge.

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Abstract

The author in this report presents the design and development of processor based multifunctional relay. The functions implemented are over current relay, Earth fault relay, Under/Over voltage relay, Under/Over frequency relay. The user can select different combination of relays, the options are as follows

Over current and earth fault relay

Over/Under voltage relay.

Over current and Over/Under voltage.

Over current, Earth fault and Over/Under voltage.

Under/Over frequency relay

All the functions of the relay. (i.e. over current, Earth fault relay, Under/Over voltage relay, Under/Over frequency)

Characteristics provided for over current and earth fault are Very Inverse. Extremely Inverse, Definite time and Inverse definite minimum time. Characteristics provided for Over/Under voltage and Over/Under frequency relay are Inverse definite minimum time and definite time.

Programming for implementing all the relays is done on a MATLAB platform and an Executable file (.exe) is generated which is a standalone windows application. The multifunctional relay is tested practically for different standard settings and compared with standard characteristics and the results are tabulated. The effect of noise transients and harmonics is also considered in the design and development of multifunctional relay.

The effect of harmonics on the relay is studied by using Electrical Power Standard Fluke make. The equipment provided variable frequency and harmonics with respect to fundamental frequency of 50 Hz.

List of figures

List of Tables

Contents

CHAPTER-1

Introduction

Protective relays play a critical role in the operation of the electrical power system. The protective relays are designed to take action when abnormal conditions occur on the power system. These abnormal conditions may be short circuits, overload conditions, and loss of system synchronism. Elaborate protection schemes have been developed to detect these various conditions using trial error and system operating experience. The protection schemes have typically been made up of discrete components such as over current relays, distance relays, auxiliary relays, and re-closing relays. Modern Power Systems use different types of relays for the protection of the total power system during faults, the modern relay which is used for the protection of power systems are the microprocessor relays.

A microprocessor-based system can be used for detecting faults in the Power system. The real time data monitoring of various electrical parameters in the Power system helps us in detecting electrical faults. In this system the abnormal conditions are detected by the microprocessor and necessary initiation of the trip signal to the circuit breaker is given. For this process to happen, real time monitoring of the data is required. Since the microprocessor understands only binary language we need to convert our analog signal to digital by using ADC.

After getting this data based upon the programming in the memory (ROM/RAM) the microprocessor takes the decision of the tripping of electrical system i.e. it detects faults based on the conditions of the program written. For e.g. if the input data maximum value over the cycle is 7FH and if a program would have been written, that issue trip command when input data maximum value exceeds 6FH, then by comparing 6FH and 7FH a trip command would be initiated i.e. a high signal to an output port address xxxxH would be given. This signal is amplified and sent to the circuit breaker for tripping. This process is just for understanding in brief but it has lot of hardware/software, interfacing I/O, timing signals, machine cycles and decision-making programs involved. Based on the microprocessor used, (Intel/Motorola) hardware/software programming instructions vary.

Microprocessor based multifunctional relay acquires the data from certain number of inputs based on the functions which is being carried out by it. For e.g. Over current relay operation for a three phase system requires three input data's form each phase, these data needs to be acquired from the three phases and need to be fed into the computer memory for decision making. The input from the three CT's is a current which is converted into a voltage and this voltage is fed to the three channels of an ADC card in which the analog signal is converted into the digital form. After this acquisition of the digital signal from the ADC card the data is used for decision making in which the microprocessor follows a suitable algorithm or a program by which it detects the condition of the system and takes the necessary corresponding action.

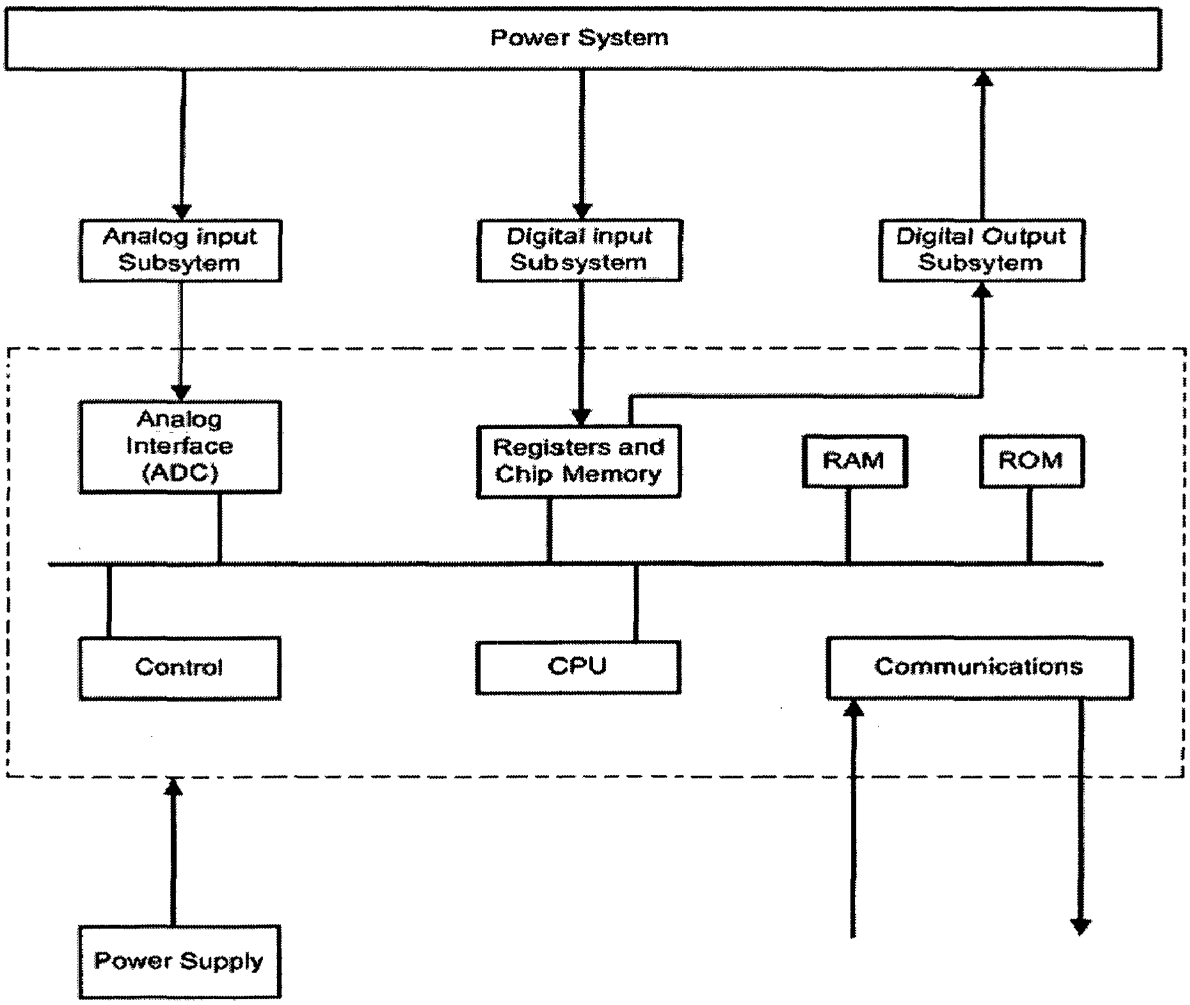

Figure 1.1 Functional block diagram of a typical-microprocessor-based relay.[5]

The figure shown in Fig 1.1 describes the typical microprocessor based relay in which analog input subsystem is used for acquiring the real time signals from the power system i.e. from C.T's and P.T's. The signal which is an analog is converted into a digital form by the analog interface (ADC). The data acquired is the sampled data from the real time signal, the number of samples acquired depends on the sampling rate of the Analog interface (ADC). The number of minimum samples required is two times the maximum frequency given by the Nyquist criteria.

The data which is acquired is stored in a RAM and it is sent to the registers, CPU processes the data according to the instructions i.e. program and stores intermediate results in the chip memory. The control unit controls the flow of data and controls the action of write and read operations. When there is a fault the CPU sends a high output data i.e. a Data output in terms of voltage to the Digital output subsystem. ROM is used for the initialization of the CPU. A function of Communications is to give the input settings and the various inputs required for the program to run. The Central processing unit gives the output through communication functional block in the form of display, sound etc...If multifunctional relay is to be implemented by the microprocessor, it processes the time multiplexed data in order to find out the faults.

1.1 Literature Review

Interest in computer-based protection preceded the emergence of microprocessor itself. It is widely accepted that *Rockefeller* [1] in the year 1969 published the first work that described the possibility of using a computer for protection of various power system elements. This work was followed by development and deployment of the first computer based distance relay that remained in service for eight years providing excellent performance. Other experimental systems followed and were developed using the class of computer known as mini-computers. At the same time, new algorithms and techniques for computer based protection were being developed.

In the year 1979 ,' The design and test of a digital relay for transformer protection' by *R. R. Larson, A. J. Flechsig, E. O. Schweitzer* [2] published the algorithm for the digital relay to operate in real time and provided outputs correctly, indicating the presence of either inrush, fault, or low differential current conditions.

'A statistical decision theoretic approach to digital relaying' by *Toshiaki Sakaguchi*,[3] in the year 1980 published the ability of the digital systems over analog ones in making decisions in the final process. With the probabilistic natures in the fault condition in mind, his paper presented one of the approaches towards this direction through the statistical decision theory, and also presented a determination method of the sampling rates for the digital relays.

The introduction of 8-bit microprocessor chips gave a boost to the area of microprocessor based relaying. System signals started to appear in the market. New techniques for handling data and new algorithms for protecting power system apparatus started to emerge as research and development activities grew because engineers realized the potential of new technology. Since the advent of early microprocessors, this technology has made tremendous progress. Faster and newer chips have become available. In addition to the remarkable increase in performance, the prices of processors and memory chips have decreased. As a result, the use of microprocessors provides the only economic approach for developing relays with required functionality at reasonable prices. Hence modern power systems are encroaching for the use of microprocessor-based relays.[4]

CHAPTER-2

Description of the Emulated model for multifunctional relay

The description below constitutes the emulated model for a microprocessor based multifunctional relay. Here LEM Module LA-50P current transducer for the electronic measurement of currents with galvanic isolation between the primary (high power) and the secondary (electronic circuits) is used for sensing high currents flowing through the line (wire). The respective voltage input to the DAC card PCI-9111which is proportional to the current in the line is fed from LA-50P transducer. The voltage signals are fed through a D-type 37 Pin connector, in which connections are taken out from the two pins, considering Channel terminal's and the ground terminal for each channel total constitute two, ground being the common for all channels. Similarly the output of the DAC card is taken from the respective two pins of the D-type connector from the connector CN3.

The voltage conversion of the current is done by placing a resistance in series with the 'M' terminal and the ground point. The voltage drop across the resistance is directly proportional to the current. Resistance value here used is the constant of proportionality which equates the flow of current and voltage drop according to Ohms law.

The drop across the resistance is directly fed to the ADC card by connecting the common point of ADC card to ground point ('0') and the other channel terminal to the variable point of the resistor. In a similar way all the current transducers are connected to the ADC card to determine the flow of current in the line.

The figure 2.1 shows the connection diagram of the transducer and the variable resistance is used in order to calibrate the value of voltage attained for a known current flowing across the transducer. Here in this emulated model the variable resistance taken is from 0-1K ohms. The value of the resistance is so adjusted that the voltage drop across the resistance is 1v when the current flowing through the transducer is 5 Amps. Suitable adjustment of voltage can be done by varying the resistance shown in the figure 2.1.

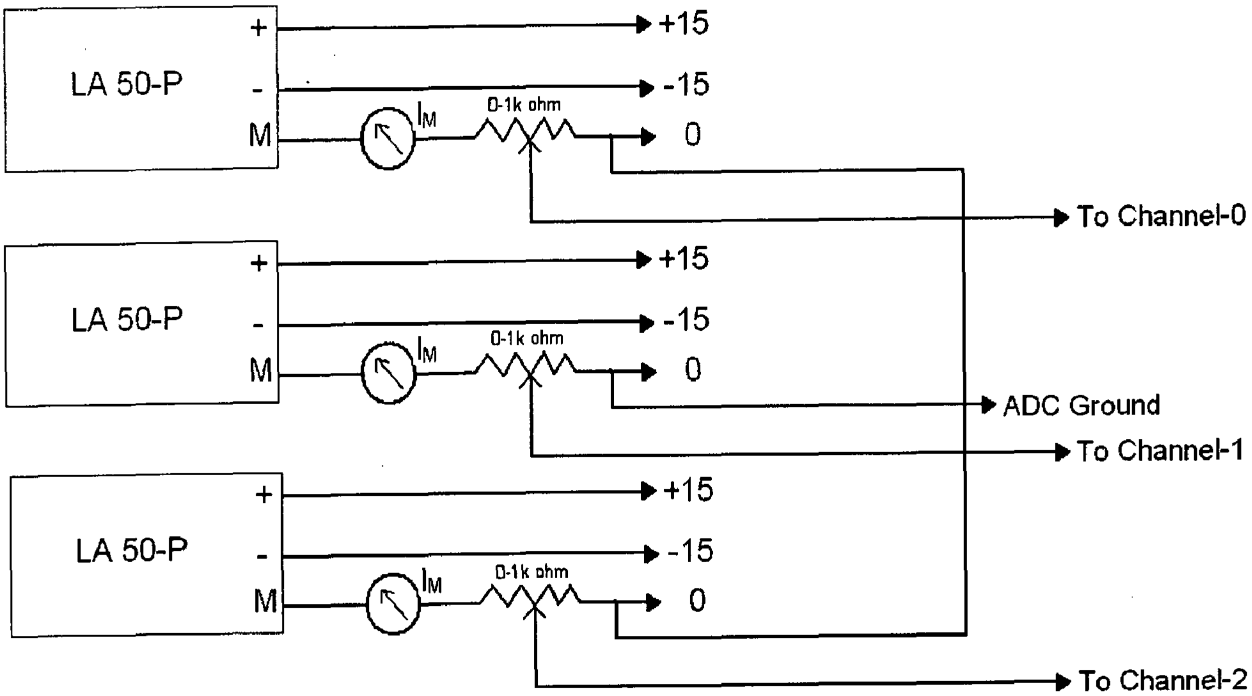

Figure 2.1 LEM Module LA-50P current transducer.

Earth fault current is sensed by the transducer in the same way as stated above for the over current relay and hence not emphasized.

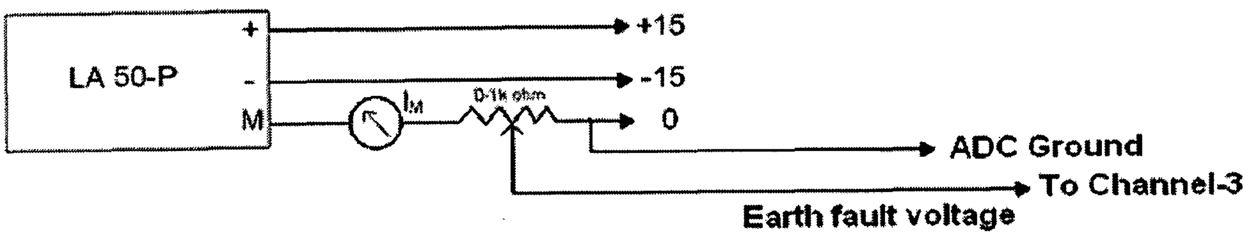

Figure 2.2 Earth fault current conversion into voltage

Step down transformers are used as P.T's in the emulated model. The transformers isolate the voltage at the primary side to the voltage across the secondary side. The voltage rating of primary side is 230V and secondary side is 3V. The connections are shown in the figure below in which common star point is taken as common and connected to the ground and the other three terminals representing each phase voltage is connected to each different channel of the ADC PCI-9111 card. The voltage which comes across the secondary is directly fed into the ADC card by which voltage signals of the three phases are attained.

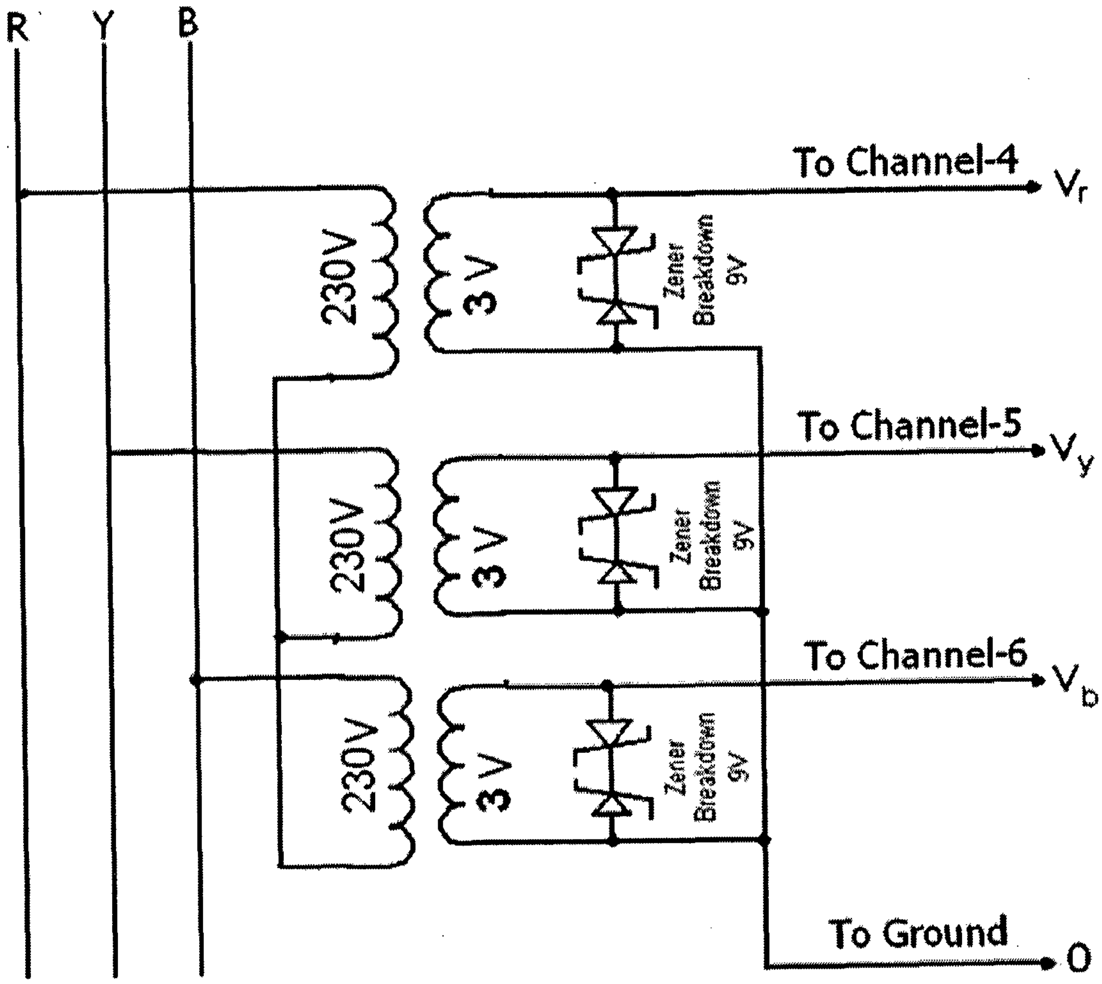

Figure 2.3 Voltage fed to the ADC card PCI-9111 through step down transformer.

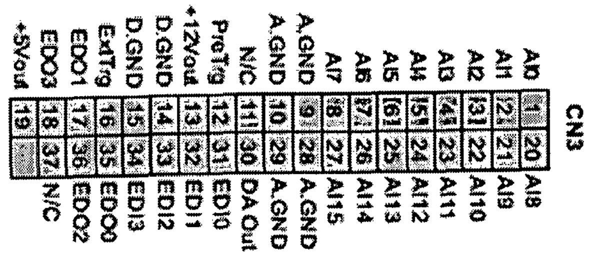

Figure 2.4 Pin Assignment

The figure shown in Fig 2.4 shows the pin assignment of the connector CN3. The connections are made to the connector by considering suitable channels for the different analog inputs. Respective channels for the respective inputs (e.g. current inputs from three phase system Ir, Iy, Ib, Ie, Vr, Vy and Vb) have to be known for the programming.

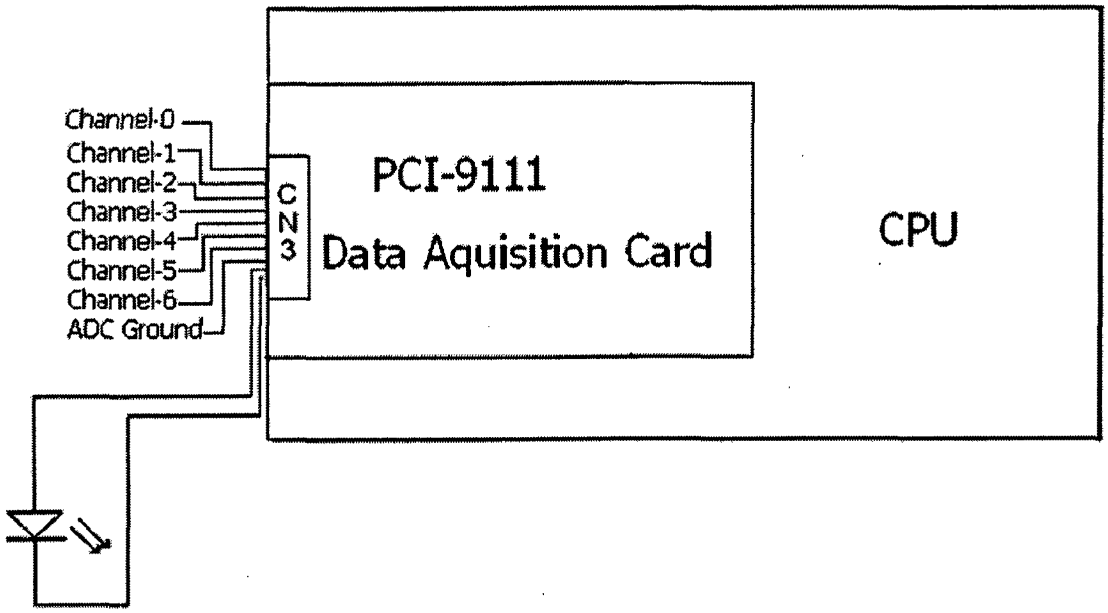

Figure 2.5 Block Diagram of the Emulated model

The figure shown in the Fig 2.5 shows the Input channels and the output which is connected to an LED representing the output from the ADC card. The ADC card is kept in a Peripheral Component Interface (PCI) slot of the Central Processing Unit.

CHAPTER-3

Working of a Multi functional Relay

In this thesis 'Design and development of microprocessor based multifunctional relay' a Pentium processor is considered. The programming is done on a MATLAB platform. The relays which are implemented are over current, Earth fault relay, Under/Over voltage relay, Under/Over frequency.

The combination of relays which the user can operate are

:

Table 3.1. Type of relay operation

S.No	Type of relay operation.
1.	Over current and earth fault relay
2.	Over/Under voltage relay.
3.	Over current and Over/Under voltage.
4.	Over current, Earth fault and Over/Under voltage.
5.	Under/Over frequency relay
6.	All the functions of the relay. (i.e. over current, Earth fault relay, Under/Over voltage relay, Under/Over frequency)

3.1 Over Current and Earth fault relay

If the user goes on the operation of over current and earth fault relay i.e. 'S.No.1' the options of selecting the characteristics are provided. The characteristic which the user can select are Very Inverse, Extremely Inverse, Definite time, and IDMT.

The pick up current in the range 0.5-2 Amperes, Time setting Multiplier in the range 0.1-1 and the high set are provided for very inverse and extremely inverse characteristics.

For definite time the pick up current in the range 0.5-2 Amperes and Definite time at which the relay has to be tripped are the options which are provided with a high set. For an IDMT relay the current setting value in the range 0.5-2 Amperes and the Time Setting Multiplier in the range 0.1-1 are provided with a high set option.

Similar way of selecting the characteristics for earth fault relay is also provided, and it follows the same pattern as stated for over current relay.

According to the respective set values provided the program constantly monitors the input signal and when a fault occurs in the system it starts the clock and corresponding to the relay characteristics chosen, the relay will trip at the trip time given by the chosen relay characteristics. The ADC-card initiates a DC output across the output of CN3 connector when it trips the circuit. Flow charts are presented in which the working of the program of the relay can be easily understood. At the beginning of the program the flowchart presented in figure 3.1 is executed in which the user can operate any one of the '6' types of operation. At first working of the over current and earth fault relay is considered and the flow charts are presented accordingly.

The channels which are used for the input is shown in the Fig 2.5. For the flow charts presented the respective input to the channels is as follows.

Table 3.2 Channel allocation of the analog inputs

Analog Input	Channel
Current, I_r	0
Current, I_y	1
Current, I_b	2
Earth fault current, I_e	3
Phase voltage, V_a	4
Phase voltage, V_b	5
Phase Voltage, V_c	6

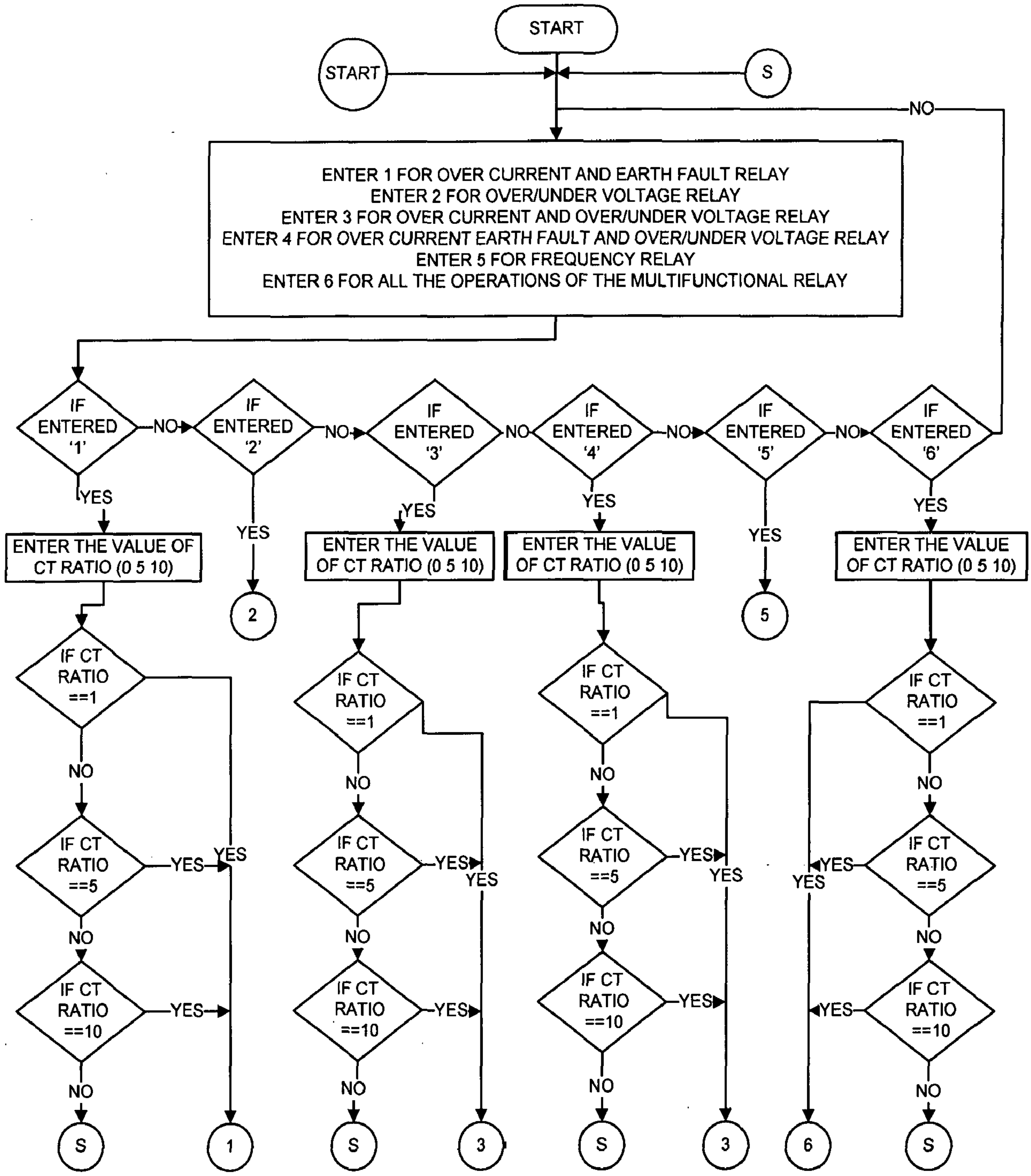

Figure 3.1 Flowchart for selecting the type of operation of the multifunctional relay.

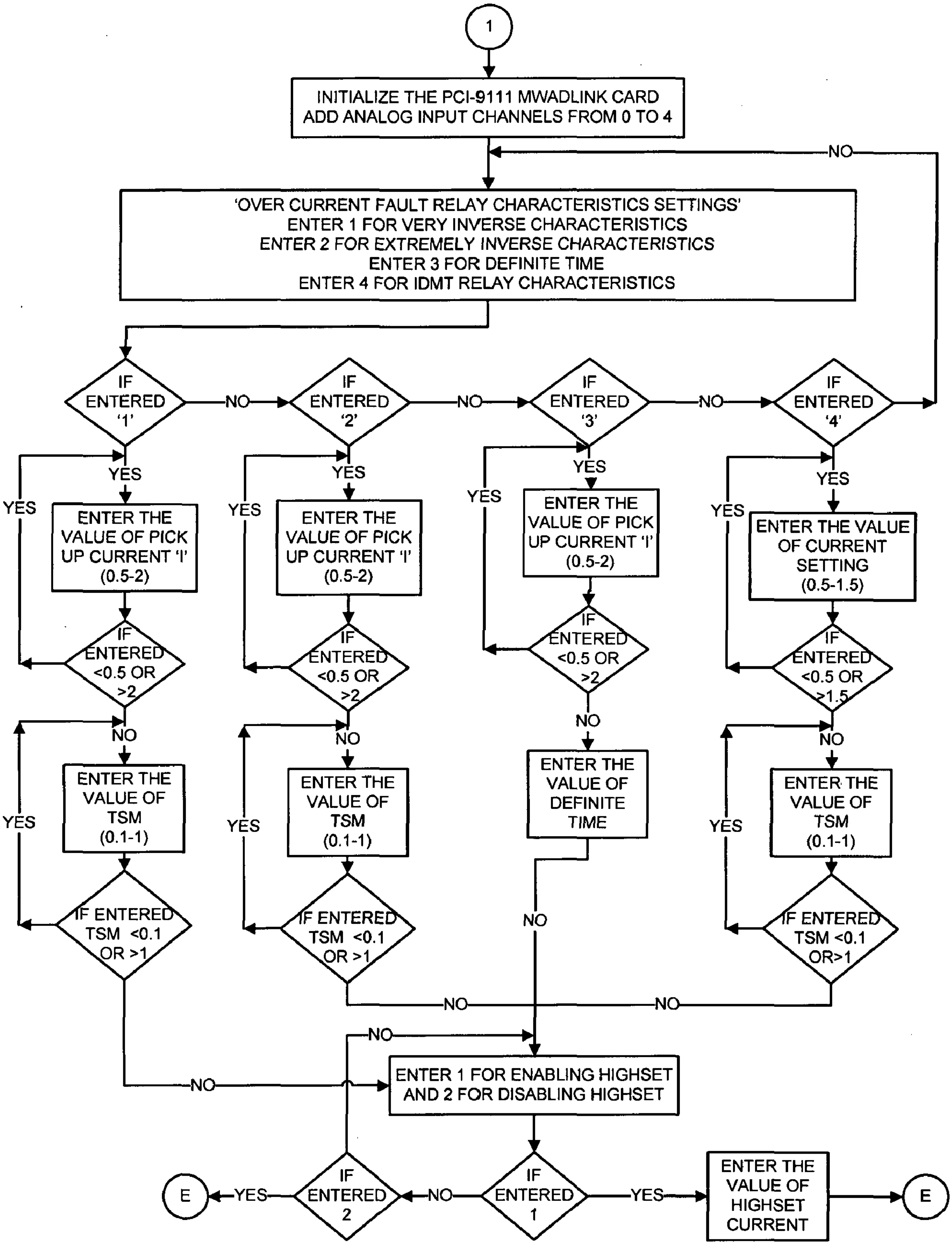

Figure 3.2 Flow chart representing the settings of an over current relay.

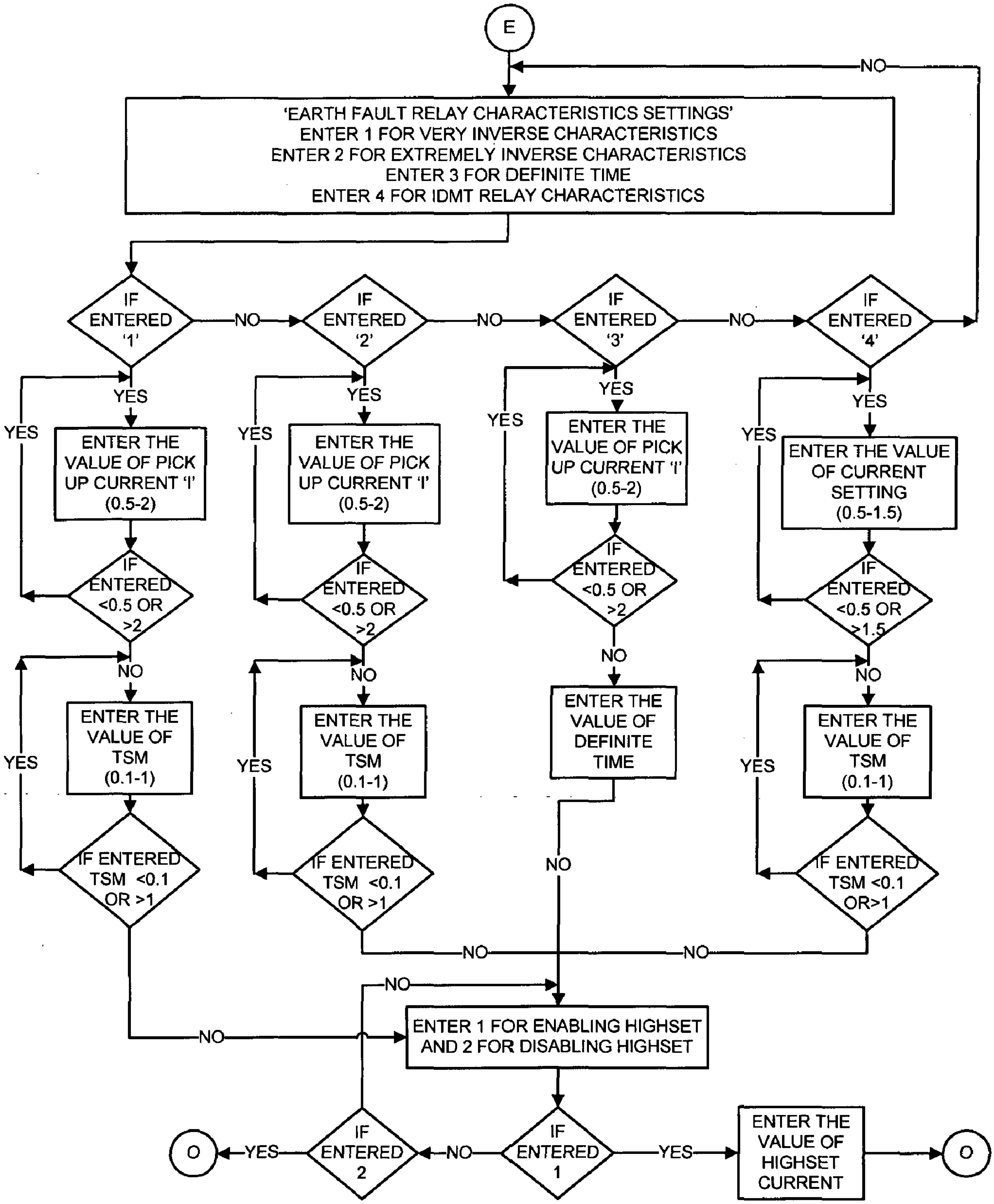

Figure 3.3 Flow chart representing the settings of earth fault relay.

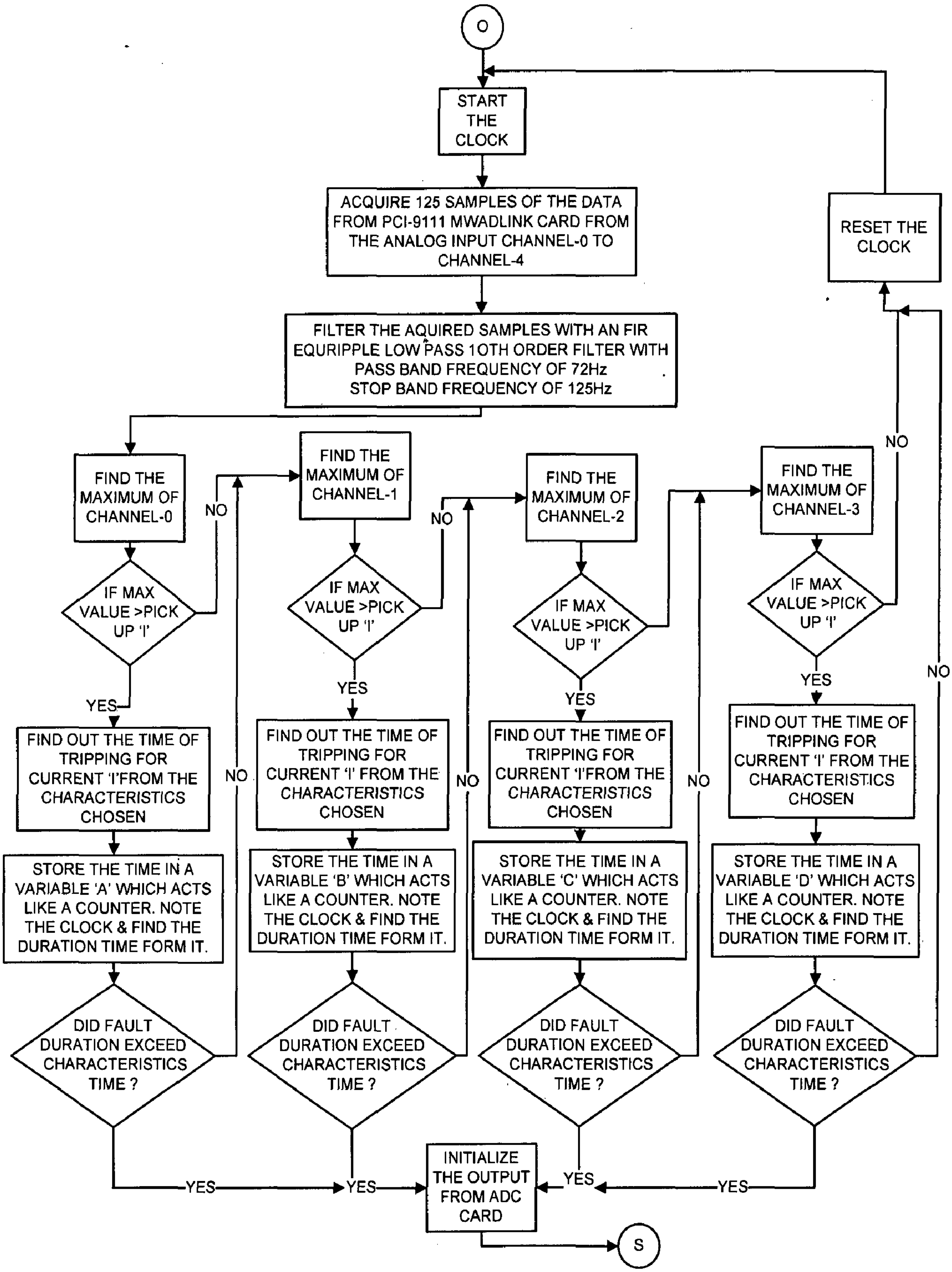

Figure 3.4 Flowchart representing the operation of over current and earth fault relay.

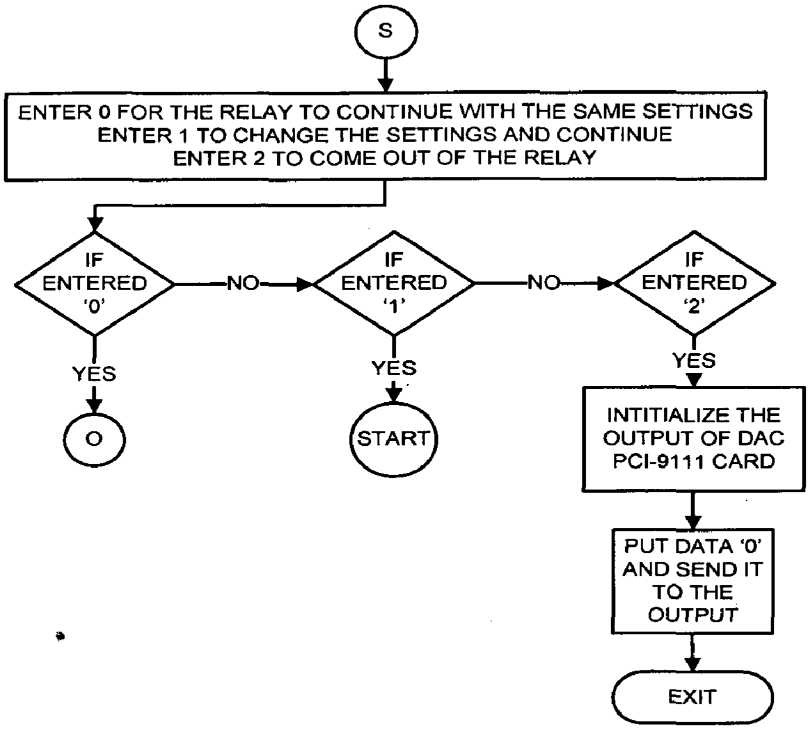

Figure 3.5 Flow chart representing the resetting options for Over current and earth fault relay.

3.2 Over/under voltage relay

If the operation of the multifunctional relay is considered for an Over/under voltage relay operation then the following flowcharts provide the operation of the program. The nominal voltage here considered is 5v and the set value set for over and under voltage relay is multiplied with the nominal voltage and these are taken as the limits. When the relay exceeds the limits the relay will trip according to the user defined and set relay characteristics.

The characteristics which are defined for Over/Under voltage relay are definite time and Inverse definite minimum time relay characteristics.

A high set is also provided for over voltage setting, since over voltage is the main cause of failure of power equipment high set is provided only for over voltage relay. The set value provided for high set over voltage is 1.5-3.

User has a choice of enabling or disabling the high set. Resetting options are also provided after tripping of the relay.

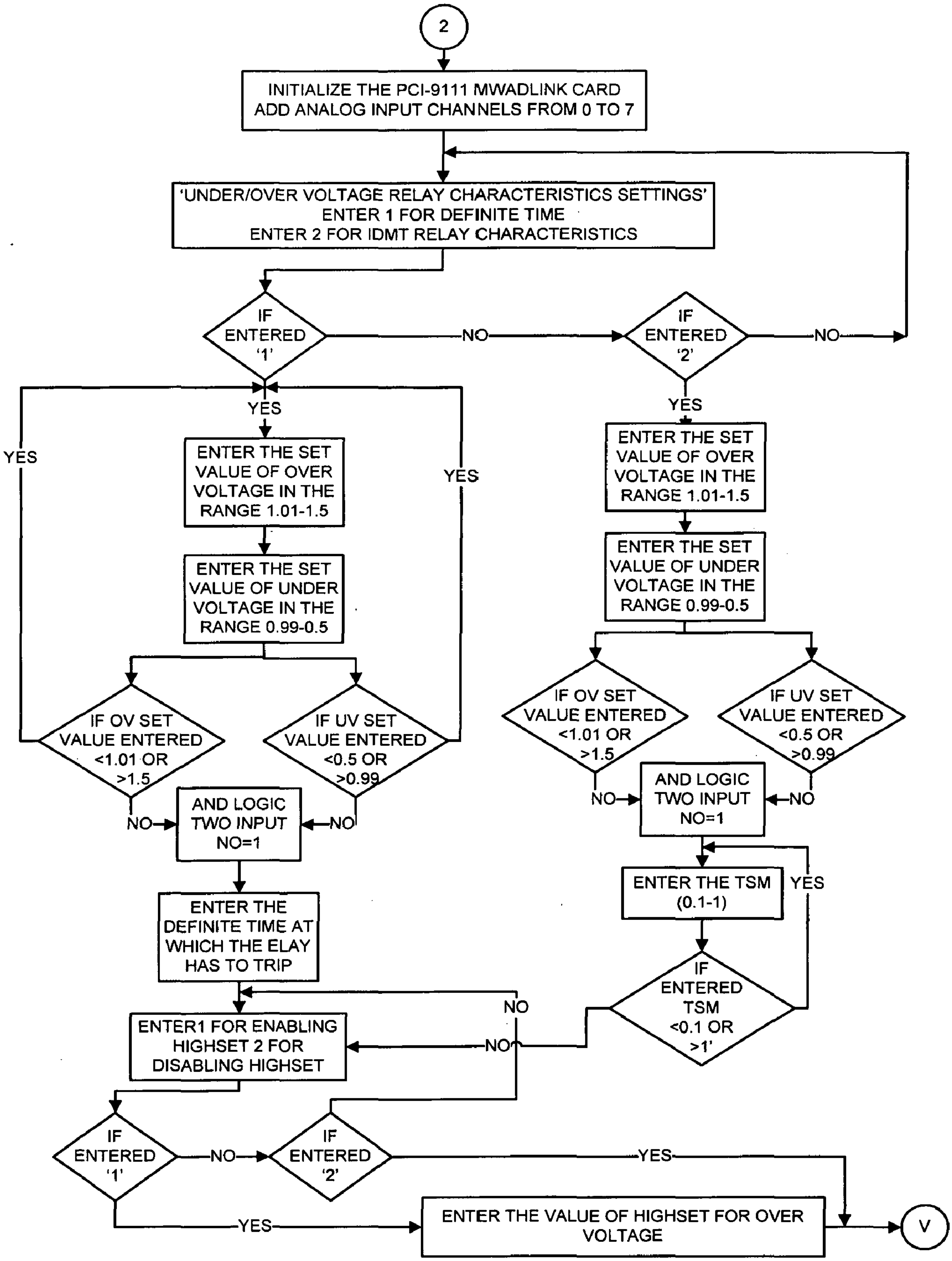

Figure 3.6 Flow chart representing Under/Over voltage relay settings.

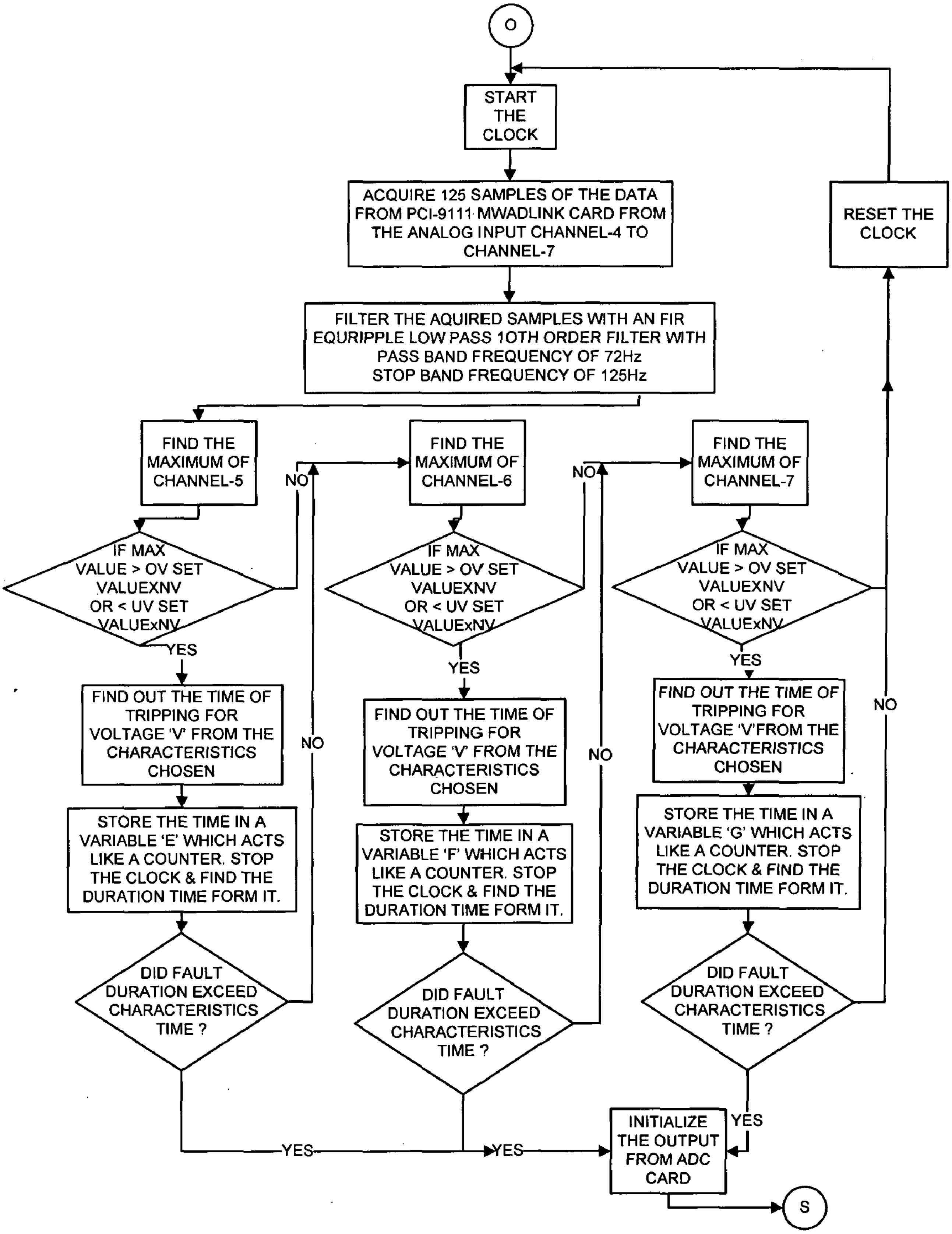

Figure 3.7 Flow chart representing the operation of U/O voltage relay.

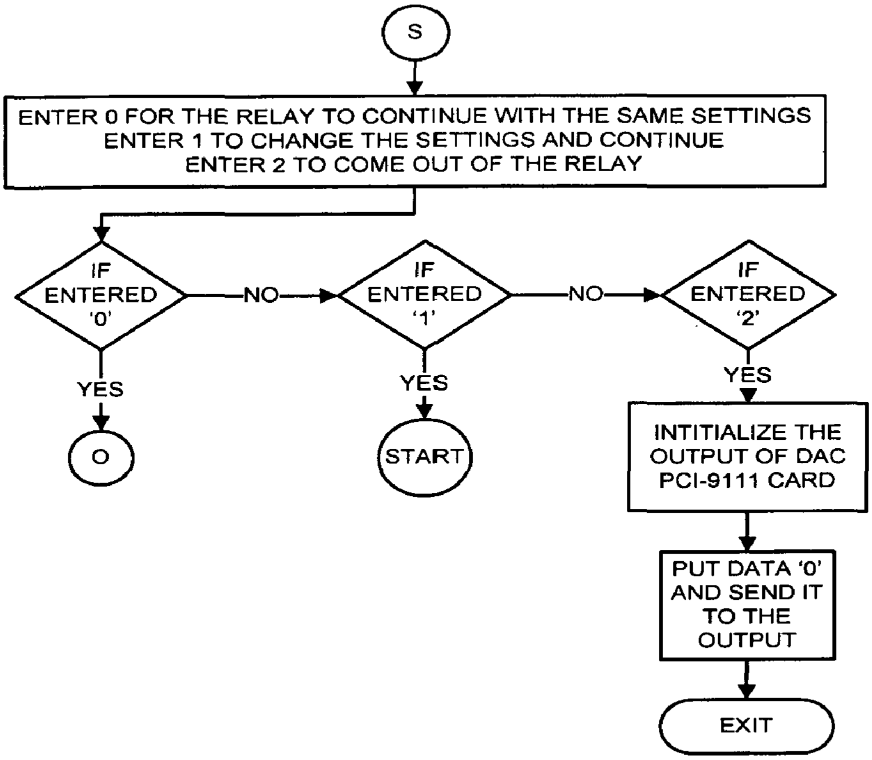

Figure 3.8 Resetting options for U/O voltage relay.

3.3 Over Current and Over/Under voltage relay

If the operation of the multifunctional relay is considered for an Over current and Over/under voltage relay operation then the following flowcharts provide the operation of the program. The settings of the current relay and over/ under voltage relay need to be carried out in the similar way of settings shown in flowcharts of over current relay setting and Over/under voltage relay.

The flow chart sequence is as follows:

Figure 3.1 Flow chart for selecting the type of operation of the multifunctional relay.

Figure 3.2 Flow chart representing the settings of an over current relay

Figure 3.6 Flow chart representing Under/Over voltage relay settings

After processing all the flow chart's stated above the operational flowchart differs where in the continuous monitoring of all the required respective channels are carried out. The operational flow chart is shown in figure 3.9 and after the tripping resetting options are the same as stated in Fig 3.8. In the resetting options if the relay is to continue with the same settings then from Fig 3.9 the process continues.

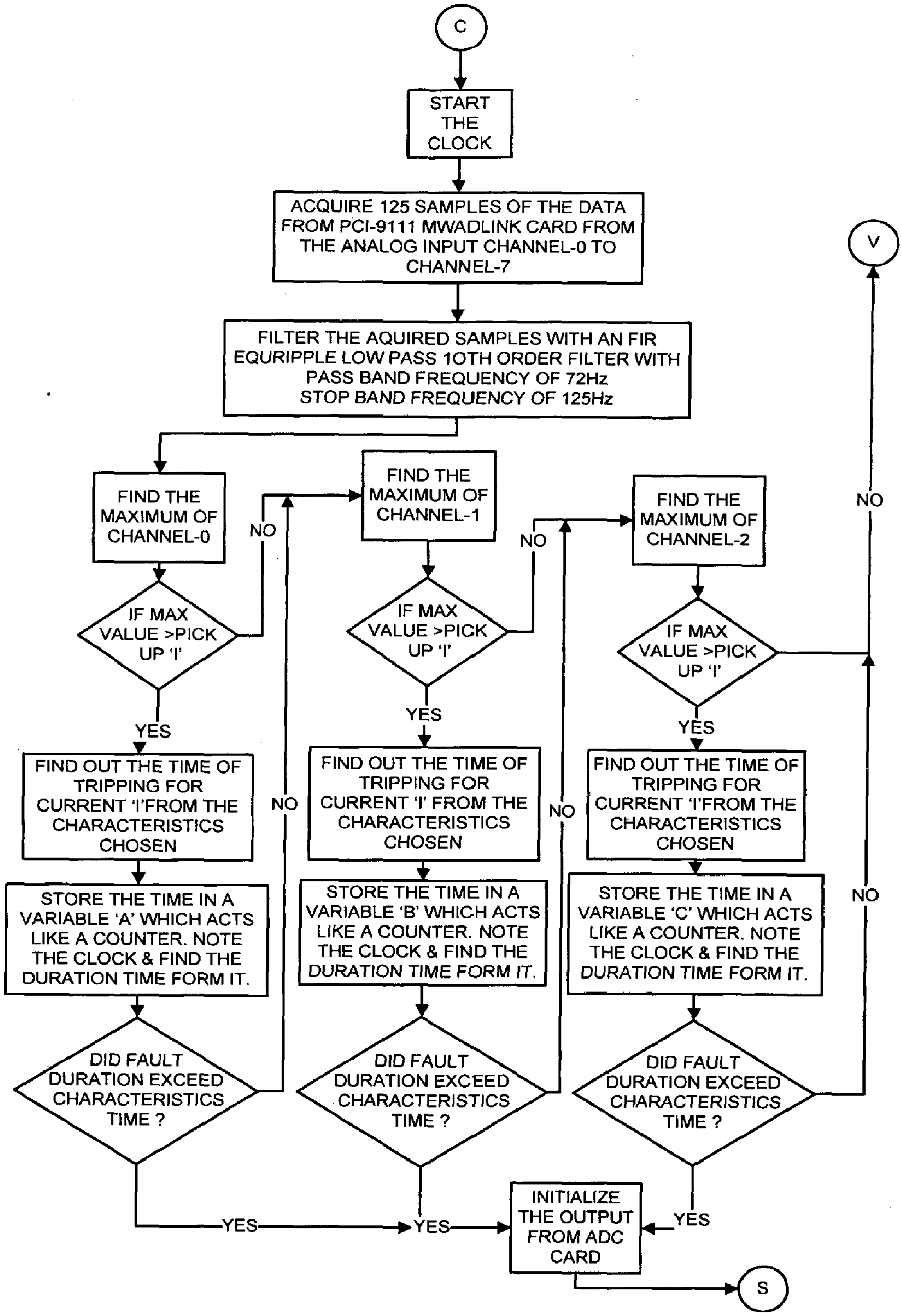

Figure 3.9 Flow chart representing the operation of over current relay connected to voltage relay.

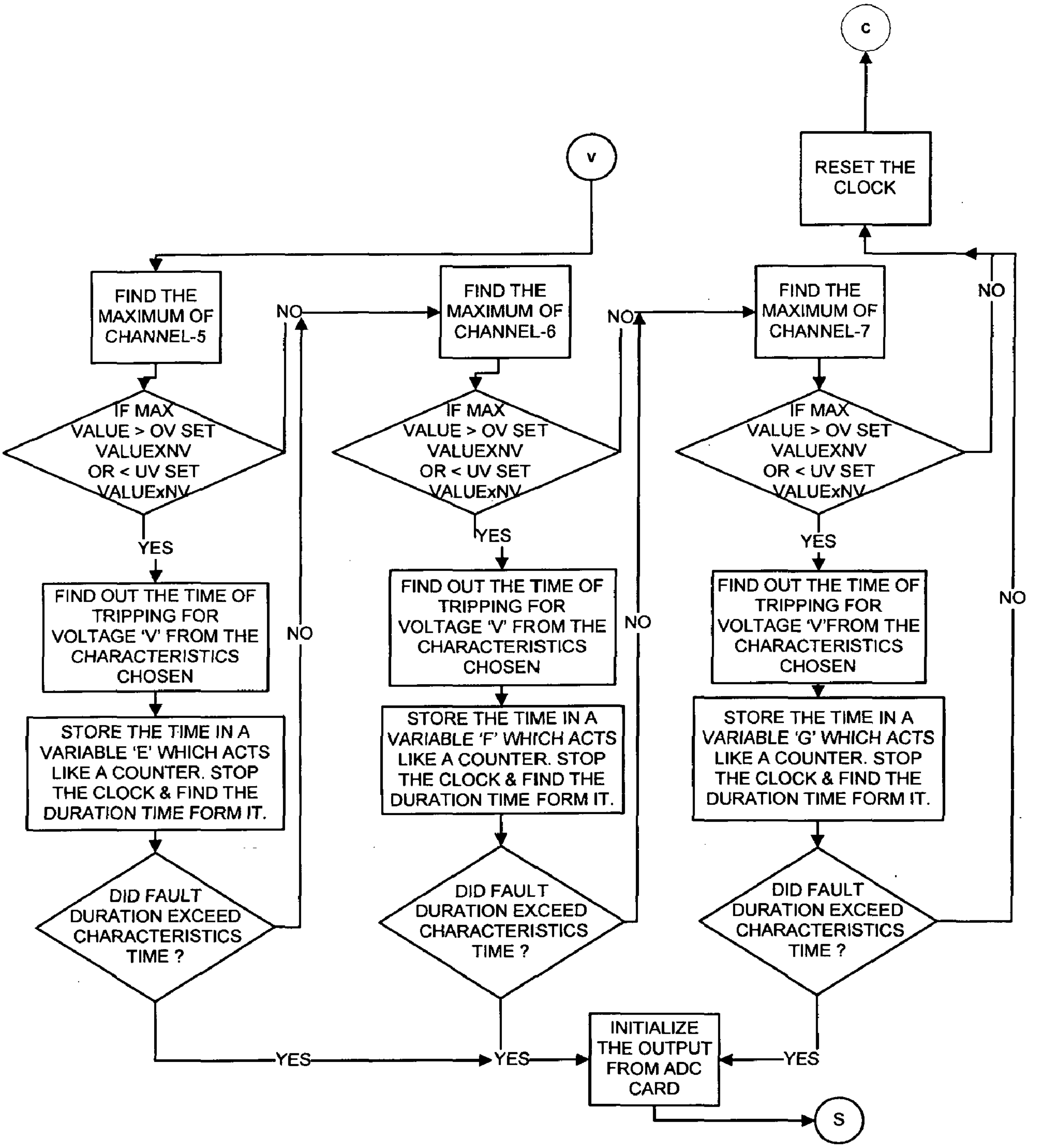

Figure 3.10 Flow chart representing the operation of voltage relay connected to over current relay.

3.4 Over Current, Earth fault and Over/Under voltage relay

If the operation of the multifunctional relay is considered for an Over current Earth fault and Over/under voltage relay operation then the following flowcharts provide the operation of the program. The settings of the current relay and over/ under voltage relay need to be carried out in the similar way of settings shown in flowcharts of over current relay setting and Over/under voltage relay.

The characteristics of the over current, earth fault relay and the settings have been stated in over current earth fault relay operation. The characteristics of Over/Under voltage relay is also stated in the Over/Under voltage relay and the same settings and characteristics are applicable over here in this relay operation.

The flow chart sequence is as follows:

Figure 3.1. Flow chart for selecting the type of operation of the multifunctional relay.

Figure 3.2. Flow chart representing the settings of an over current relay.

Figure 3.3. Flow chart representing the settings of an earth fault relay.

Figure 3.6. Flow chart representing Under/Over voltage relay settings.

After processing all the flow chart's stated above the operational flowchart differs where in the continuous monitoring of all the required respective channels are carried out. The operational flow chart is shown below and after the tripping resetting options are the same as stated in Fig 3.8. In the resetting options if the relay is to continue with the same settings then from Fig 3.11 the process continues.

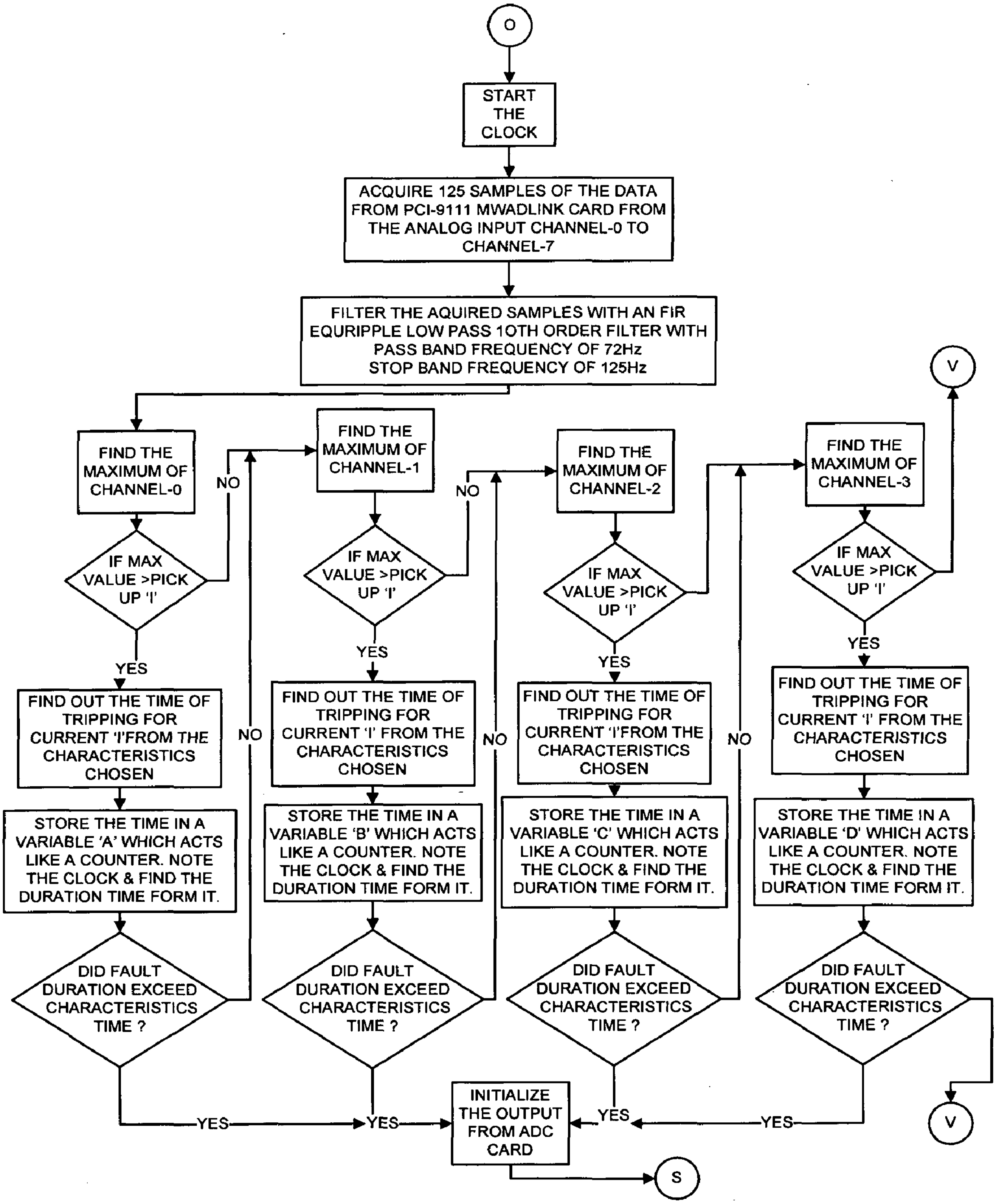

Figure 3.11 Flow chart representing the operation of over current and earth fault relay connected to voltage relay.

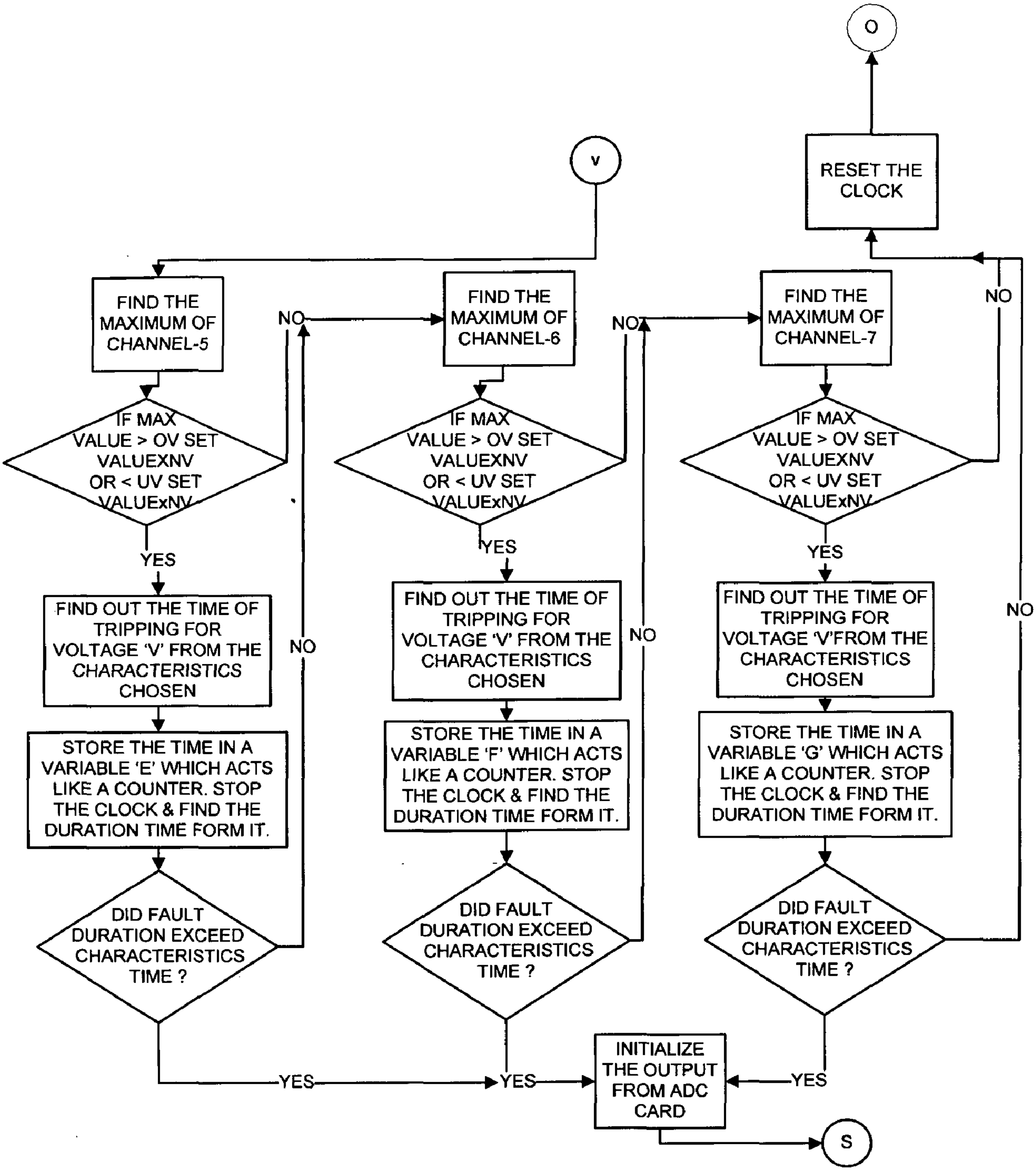

Figure 3.12 Flow chart representing the operation of voltage relay connected to over current and earth fault relay.

3.5 Over/ Under frequency relay

If the operation of the multifunctional relay is considered for an Over/under frequency relay then the following flowcharts provide the operation of the program. The settings of the frequency relay need to be carried out, after which the processing of the program is carried out. The flow chart in figure 3.13 shows the operation of the program. After the tripping of the relay the same flow chart shown in Fig 3.8 continues with the resetting options. In the resetting options if the relay is to continue with the same settings then from figure 3.14 the processing of program continues.

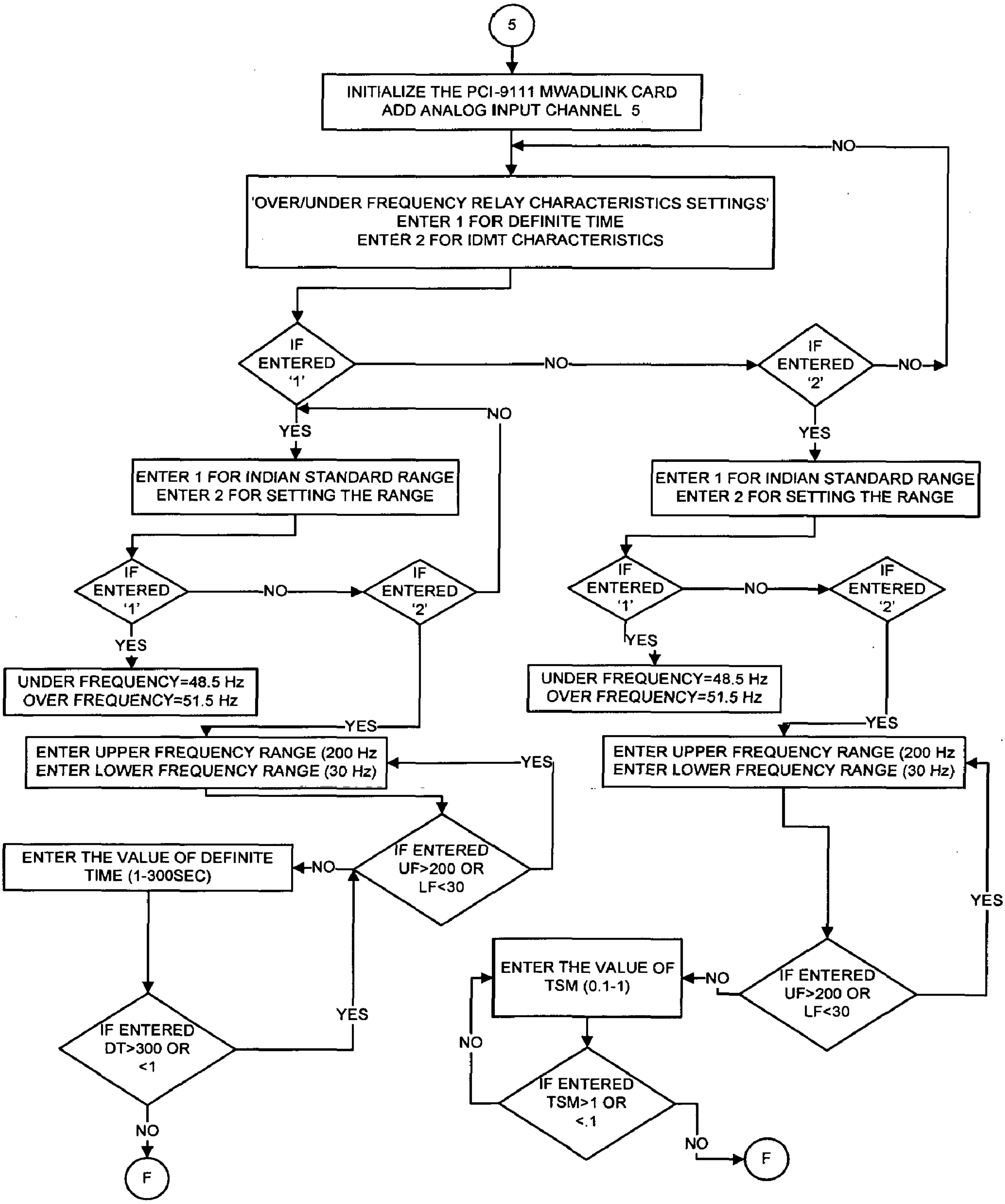

Figure 3.13 Settings of the Under/Over frequency relay

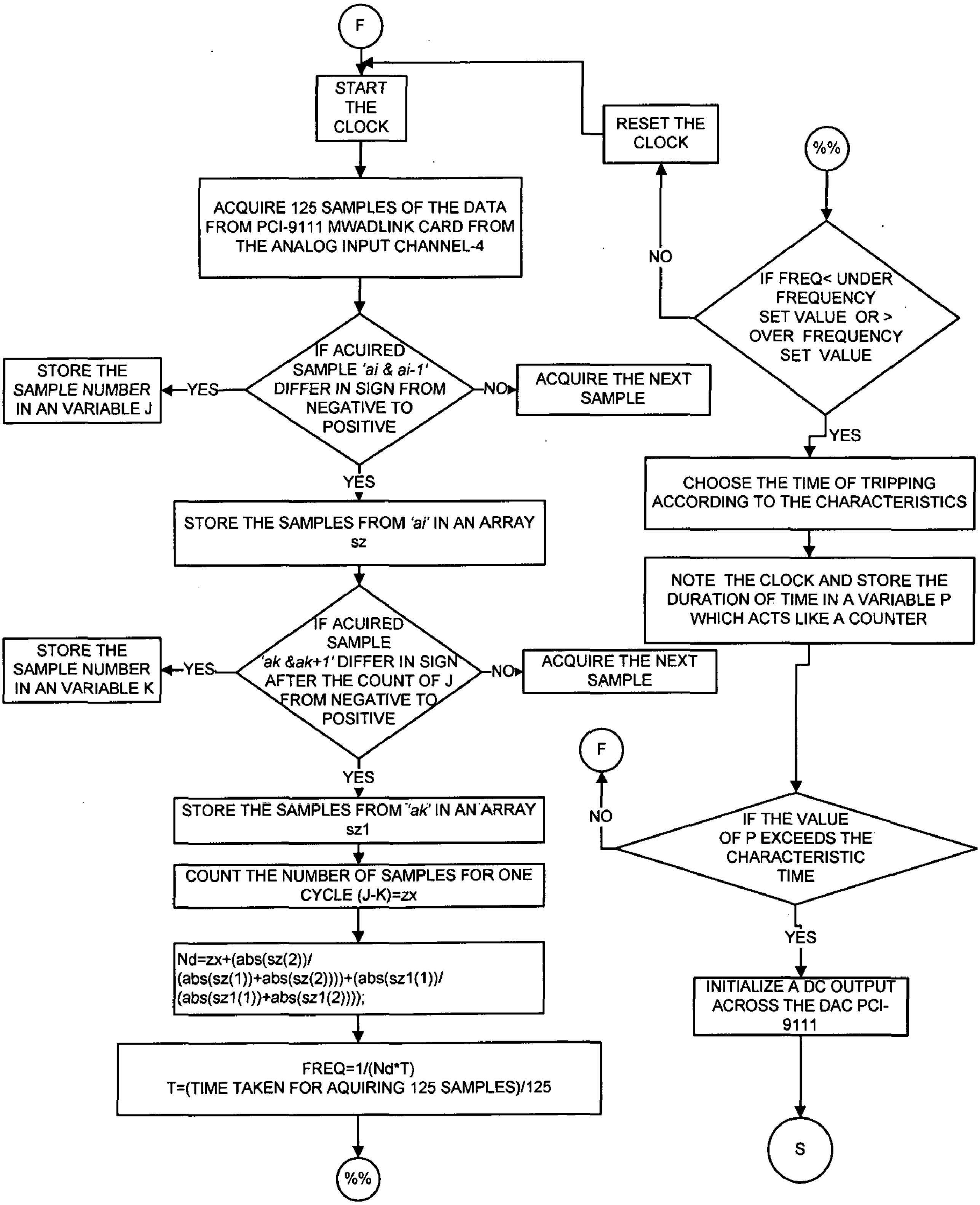

Figure 3.14 Flow chart representing the operation of frequency relay

3.6 Over Current, Earth fault, Over/Under voltage and Over/Under frequency relay

If all the operations of the relay need to be carried out the settings of the over current, earth fault, Under/Over voltage relay and Under/Over frequency are to be carried out in the beginning of the program. The sequence of flow charts is presented from the beginning of the program.

Sequence of flow charts:

Figure 3.1 Flow chart for selecting the type of operation of the multifunctional relay.

Figure 3.2 Flow chart representing the settings of an over current relay.

Figure 3.3 Flow chart representing the settings of an earth fault relay.

Figure 3.6 Flow chart representing Under/Over voltage relay settings.

Figure 3.13 Flow chart representing the settings of under/over frequency relay.

Figure 3.11 Flow chart representing the operation of over current and earth fault relay.

The flow chart operation of the relay which will incorporate voltage and frequency relay is shown in figure 3.15 and figure 3.16. The operation of the program up to the flow chart shown in figure 3.16 constitutes the operation of all types of relay. The flow chart processing sequence is as follows over current, earth fault, over/under voltage and over/under frequency relay, after the service routine of all the relays the processing is again operated from the beginning of over current, earth fault relay operation. If the system trips the resetting options are the same which are shown in flow chart of Figure 3.8. In the resetting options if the relay is to continue with the same settings then from figure 3.11 the processing of program continues.

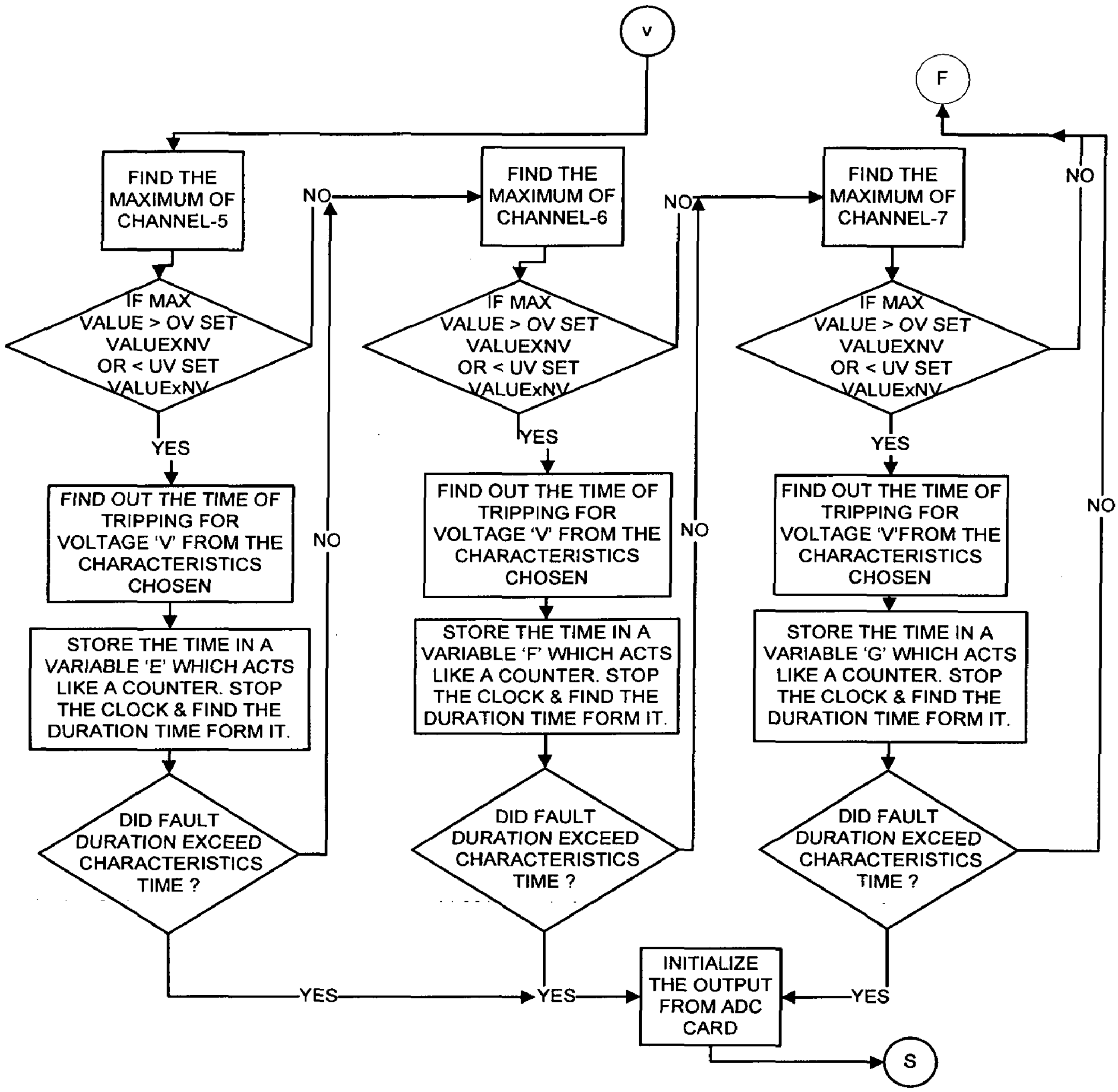

Figure 3.15 Flow chart representing the operation of voltage relay connected to the frequency operation.

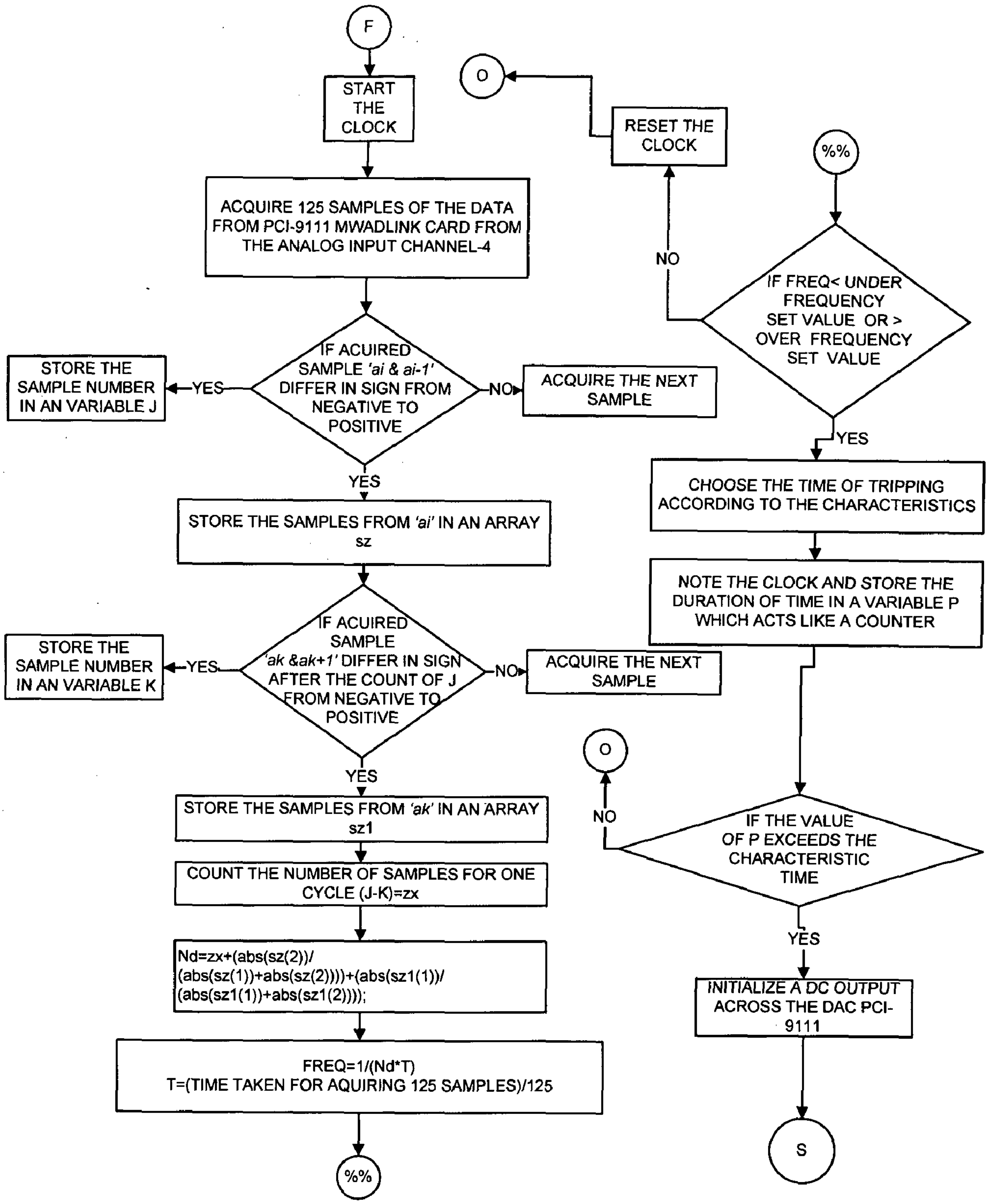

Figure 3.16. Flow chart representing the operation of frequency relay connected to the operation of over current and earth fault relay.

CHAPTER-4

Operating principle and operation of relays

The operation of over current relay and the tripping time of the relay is given as $t*I^n = G$. Here t represents the tripping time, 'I' represents the current after exceeding the thresh hold value, which is set as a digital pick up by providing a reference in the microprocessor based system, n represents the number which has to be selected for different characteristics of the relay and G is a constant [6].

The functions of the microprocessor based relay system are stated as

Analog to digital conversion.

Fault detection.

Function generation.

Automatic variable time delay achievement.

Pulse generation.

The value of n represents the characteristics of the relay, if n=1 characteristic followed by the relay is inverse type characteristics, if n=2 characteristic is very inverse type and if n=0 the characteristic obtained by the relay is definite time [6].

The time of tripping of the relay can't be calculated for each and every value of 'I' after exceeding the reference value stored in the system. If calculation is done the time of tripping of the relay would be effected this is since certain number of machine cycles are used for calculating the tripping time. While the calculation the current may drastically increase, and this may effect the system being protected. In order to avoid this, look up table is used in order to find out the tripping time [6]. In the look up table various values of current which starts from the value exceeding the reference value set and their corresponding trip times accordingly are stored.

The microprocessor when senses the fault, i.e. when it compares the value acquired and the reference value, if actual value is greater than reference value it goes into the look up table to find out the corresponding tripping time. After finding out the fault it starts the timer and stores the duration of acquiring data and the program in a variable which acts like a counter. The tripping signal that is a pulse or a dc output is sent to the output port if the variable value is equal to or greater than the tripping time acquired from the look up table.

If the fault current goes below the reference value the variable which acts like a counter is set to zero and the process continues. This operation is for over current relay the same logic can be implemented for the other relays. Modeling of time current characteristics [16] for the over current relay is not so used in practical real time systems since it is time consuming for calculating the coefficients in approximating the curve by an nth order equation hence look up table is the best suitable one for real time operation.

The said operation of the microprocessor relay does not follow a standard inverse time characteristics as stated in IEEE inverse time characteristics. The relay characteristic followed is according to the equation stated above. IEEE inverse time characteristics can easily be obtained by knowing the equation governing the type of characteristic. For e.g. Very Inverse type relay according to IEEE standard characteristics is given as [11]:

$$t = TDS \times ((19.61/(I^2-1))+0.491)$$

Where t= tripping time

I=actual value after exceeding pick up value, if pick up value is considered as '1' or else it is the ratio of actual value to pick up value and the equation is only applicable when actual current exceeds the pick up current i.e. when I is greater than pickup value.

TDS= Time Dial Setting, ranging from 0.1-1.

The time of tripping following the above equation when stored in the look up table along with the corresponding current values we would get the IEEE characteristics of Very Inverse type relay. Hence current values and there corresponding time values stored in look up table decides the characteristics of the relay [7]. A look up table is simply a part of memory in which one can store different values in the form of an array, the program can refer to those values when said to refer and this reduces the runtime computation with a simpler array indexing operation. The speed gain can be significant, since retrieving a value from memory is often faster than undergoing an expensive computation.

If the same type of relay is considered i.e. over current relay operation for four different types of equipment, all the over current relays can be incorporated in one microprocessor based system protecting all the four equipments. Here the logic of incorporating four relays is to take the data form the four CT's convert them into voltage feed to ADC and follow the same operation as stated above for over current relay, after servicing relay 1 the service routine has to go to service relay 2 this needs to be continued until all the service relays are serviced and the operation is to continue in the cyclic process. Look up table is used for finding the tripping time but here in this case the operation time of each service relay is to be known for correct tripping of the relay. After the fault incipient in equipment 1 the microprocessor also services the other service relays hence the time of operation of servicing the other relays is to be known which is elapsed, and accordingly tripping has to be carried out i.e. the variable which stores the duration of fault time, the summing up of elapsed time of servicing the other relays also need to be done in order to correctly follow the tripping time of operation [8].

The flow charts showing the operation of four relays is shown below.

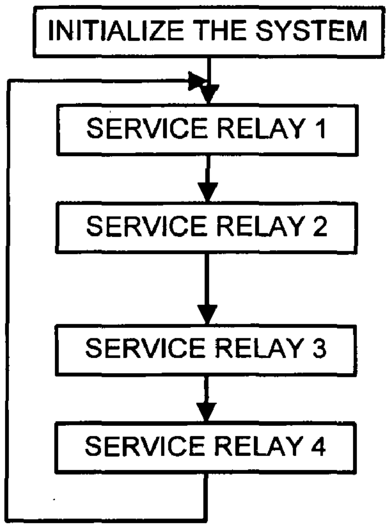

Figure 4.1 Tasks of the microprocessor relay. [8]

Here in the system only over current relays are considered. The same logic can be applied for multifunctional relay. The same technique is used for generating software models of microprocessor-based relays and their performance was compared against results obtained from the standard characteristics. The comparisons proved the generated models to be very accurate in calculated parameters and trip timings. Results are also included accordingly.

Here in the above case four similar types i.e. over current relays are considered i.e. all the service relays are over current relays. When we replace the over current relays with different type of relays the whole system becomes a microprocessor based multifunctional relay.

In this thesis over current relay, earth fault relay, Over/Under voltage relay and Over/Under frequency relay are considered as service relay 1, 2, 3 and 4 each has its own service subroutine in detecting the fault. The same process as stated for the multiple over current relays is applicable here in the multifunctional relay.

4.1 Current Measurement

As stated in Fig 2.1 the current transducers, have three terminals two for the dc power supply (+15V,-15V) and one for the measurement of current flowing through the line (M). The measurement terminal is connected to the ground through a variable resistance of 1K-ohm. The LEM LA 50-P current transducer is used for measuring a maximum current of 1000 Amps. When 1000 Amps current flow in the line there would be 1A current flowing from M terminal to ground. This 1A current is converted into voltage to give as an input to the ADC card. Hence a suitable value of resistance connected across suffices the requirement.

Here in the practical consideration, a flow of 5A current produces a voltage drop of 1v across the resistance. This is achieved by suitable adjustment of variable resistance. The variable resistance adjusted is given as:

For the flow of 1000A in the line 1A flows from M to ground. For 5A the flow of current form M to ground is 5/1000 Amps i.e. 5 mA. For the drop to be 1v for 5mA the resistance value adjusted will be 200 Ohms. Hence one can easily calibrate the pick up value of current based on the calculations done above and accordingly adjust the value of resistance to the pick up value sensed by the relay. For e.g. if the relay has to sense an over current fault when it exceeds a current of 500 A then the resistance value adjusted should be 2 Ohms. Here the pick up value considered in all the cases for the relay is 1v fed to the analög input.

In the similar way pick up value of current of the earth fault relay and accordingly the voltage drop across the resistance is also adjusted by knowing the suitable amount of fault current for the earth fault.

The total process stated above is used after knowing the normal rated current values of the equipment or the line to be protected, i.e. the values both in over current and earth fault case in the system. In the practical consideration the root mean square value considered is 0.7071v where the peak value of the wave would be 1v. The value of the resistance is adjusted accordingly to attain the peak value as 1v for a flow of 5A current in the line.

4.2 Voltage Measurement

For the Over / under voltage relay PT's are used in order to step down the voltage which is fed to the ADC and moreover to isolate the high voltage system for the ADC. Here the nominal voltage considered is 5v peak value. i.e. 3.53v root mean square value. Suitable transformers are to be used for the correct operation of the relay. The measurement transformer accuracy class and their magnetic characteristics are to be known before the installation in a practical system. Since the error mostly introduced by the relay would be based on the characteristics observed by the transformer.

4.3 Frequency Measurement

A simple, fast and accurate method is used for the measurement of the system frequency. The method is based upon counting the number of strips (or samples) between zero crossings during one complete cycle of the sinusoidal waveform. Since the number of strips is usually not an integer, an estimate is derived that is very close to the actual value. The frequency is directly calculated from the number of strips. Since the number of samples is usually not an integer, some simple geometrical relations are used to compute a very close estimate of this number.[12]

The operational frequency of a power system can be measured using the technique mentioned below, which is based upon the concept of zero crossings, from either one- half or one complete cycle of the sinusoidal waveform. We will consider one complete cycle because this gives lower estimation errors, and the measurement time is reasonably short. The measurement method is based upon counting the number of samples in one complete cycle (i.e., in an interval containing three adjacent zero crossings). The duration of one cycle of the power system waveform does not necessarily divide evenly (i.e. without a remainder) over the sampling interval [12]. The difference between the (measured) number of samples in one cycle and the exact figure could lead to errors in the estimated value of the frequency. We overcome this problem by applying a method to compute the effect of this difference on the estimated value of the frequency. The value of the frequency is estimated is explained. Consider the following sinusoidal waveform for the purpose of measurement:

$y(t) = A \sin(\omega t)$.........(4.1)

Where A is the amplitude, $\omega = 2\Pi f$ is the radian frequency and f is the frequency in cycles. We first assume that the signal is a pure sinusoid. When y (t) is sampled at $t = kT$ where T is the sampling interval, Equation (1) is expressed as:

$y(k) = A \sin(\omega kT)$..... (4.2)

For the sinusoidal power signal, instead of dealing with the sampling interval T, it is more appropriate to deal with the angle between every two successive samples defined as: incremental angle

$\Delta\theta = \omega T$...... (4.3)

Moreover, when working with sinusoidal signals, a convenient and useful parameter to be used is the number of samples per cycle of the waveform. Let this be denoted by N samples per cycle, then it is related to the frequency f by

$f = 1/(NT)$..... (4.4)

The measurement method described is based upon one complete cycle of the power signal sinusoidal waveform. Assuming that the samples y_{-1}, y_0, y_1, y_2, ... , y_i ,y_{i+1} , ... y_k, y_{k+1} are obtained from a sinusoidal waveform at the sampling angles θ_{-1}, θ_0, θ_1 , θ_2, ... , θ_i, θ_{i+1} , ... ,θ_k , θ_{k+1} respectively. Without loss of generality, it is hereby assumed that the samples y_0, y_1 , y_2 , ... , y_k are within an interval of one complete cycle of the waveform, and that the two samples y_{-1} and y_{k+1} are outside this interval. The frequency of the power signal will be estimated from Eq. (4) Mentioned above. In order to do that, we must determine the value of N, i.e., the number of samples in one complete cycle of the waveform. The average number of samples in one cycle of the sinusoid is equal to the number of strips of width $\Delta\theta$ in an interval of 2Π radians, since every two samples surround one strip and vice versa. The value of N will most likely not be an integer because this depends upon the sampling interval and the frequency to be measured.

The value of N is [12]:

$$N = K + \delta_2/\Delta\theta + \delta_3/\Delta\theta .... (4.5)$$

Where $\delta_2 = \theta_0$, $\delta 3 = 2\Pi - \theta_k$. Since the values of δ_2 and δ_3 are not available, and only the values of the samples (y_i) are available from the output of the sampler, the exact value of N is therefore:

$$N = K + (\sin^{-1} |y_0| + \sin^{-1} |y_k|) / \Delta\theta .... (4.6)$$

The computation of the exact value of N is rather complicated. We will compute an estimate of N, that is as close as possible to the exact value of N. Assume that N' is the estimated value of N according to the procedure illustrated below. Then the measured value of the

frequency is:

$$f' = 1/(N'^*T) ....(4.7)$$

The value of N' is estimated as follows. The measurement starts either when a zero is encountered or when the signs of two samples alternate. The measurement is performed over an interval that includes one complete cycle of the waveform, as determined from the zero crossings. Assuming that the sine function in the neighborhood of a zero crossing is approximated by a straight line, and using some trigonometric identities, the number of strips in one cycle can be approximated by [13]

$$N' = K + |y_0| / (|y_0|+|y_{-1}|) + y_k / (|y_k|+|y_{k+1}|) ....(4.8)$$

It should be noted that the same formula can be applied if $y_0 = 0$ (i.e., the measurement starts at a zero) or $y_k = 0$ (i.e., the measurement ends at a zero). The value of the frequency is thus estimated by first computing N' from equation (8), and then using equation (7) to estimate the value of the power frequency. It should be noted that the value of the frequency depends upon the following

The values of the two samples surrounding the first zero crossing,

The values of the two samples surrounding the last zero crossing,

The number of samples between these zero crossings (and not the values of the samples themselves),

The sampling interval.

Accuracy of the measurement of frequency by the above method stated is ± 1 Hz.

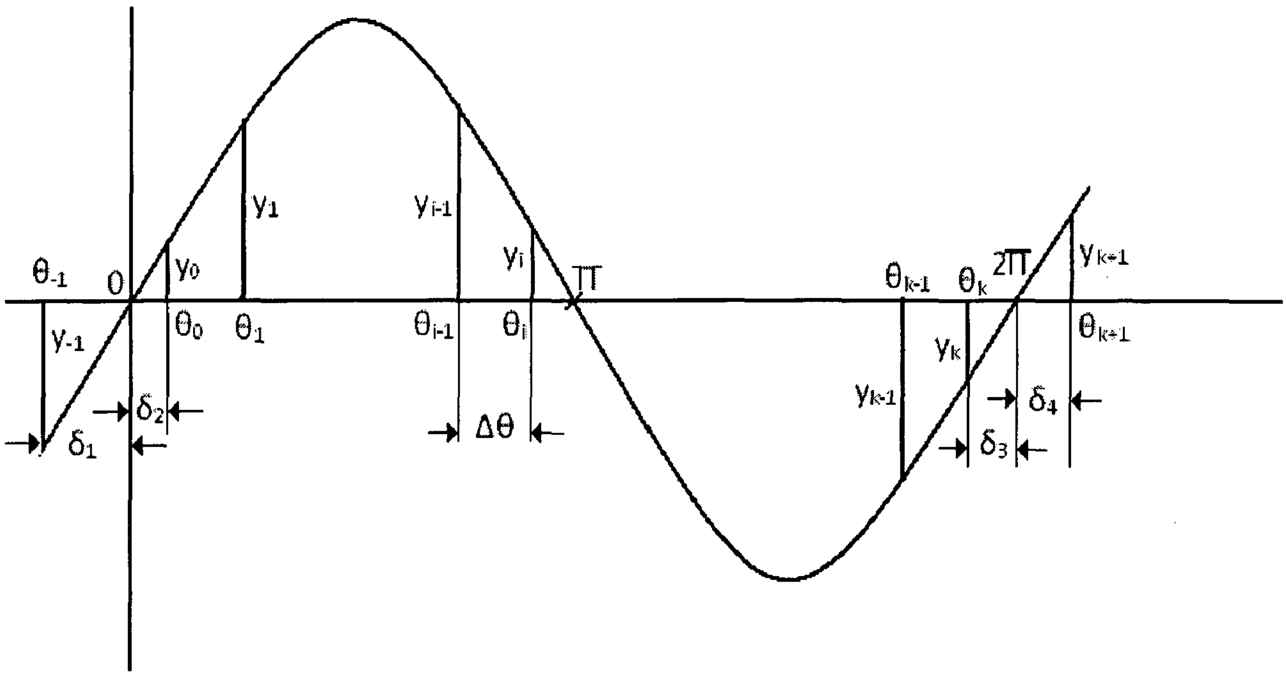

Figure 4.2 Sine wave considered for measurement. [12]

CHAPTER-5

Characteristics of different type of relays

The different type of characteristics of the relays are obtained by choosing the appropriate values of A, B and P given by the IEEE standard equation for the characteristics of the relay. The relay characteristics are shown below.

5.1 IDMT Characteristics for the current setting of 1A and for a TSM of 1.0.

The only relay standard given by the Indian standard is an IDMT characteristic IS 3231:965.The corresponding relay standard BS 142 and which is also give in IEC Publications 255-4, follow the similar characteristic of the IDMT relay standard provided by the Indian standards[10].

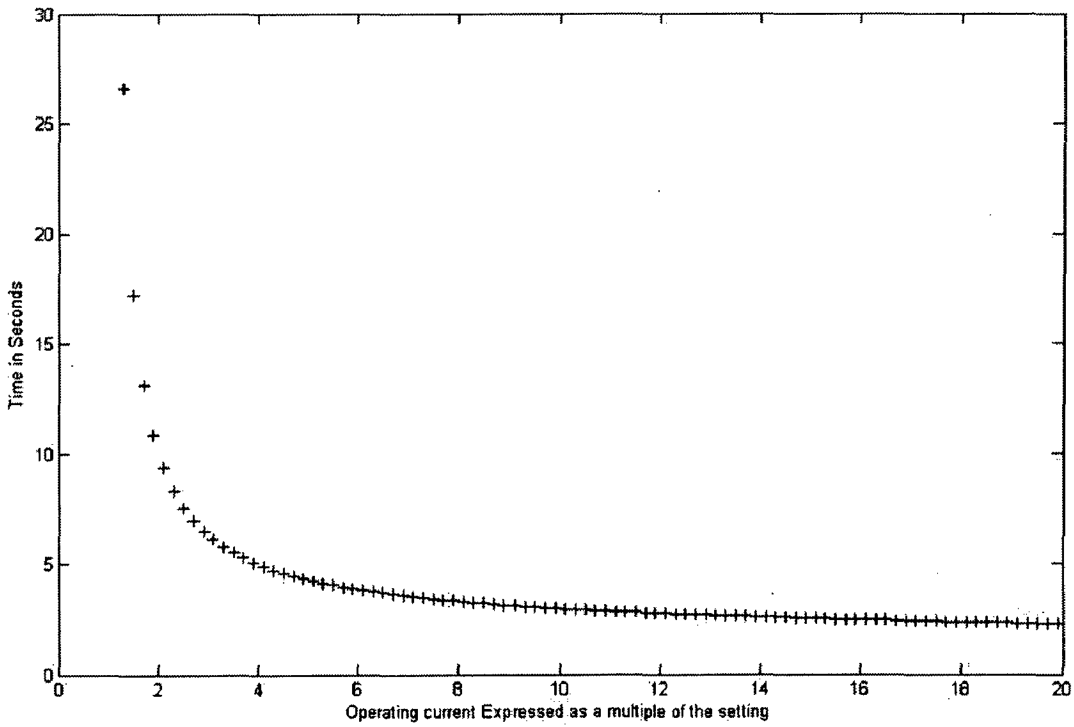

Figure 5.1 IDMT characteristics of over current relay

Accordingly by the standard BS142 the relationship between the operating time of the relay 't' to the plug setting multiple 'I' is given by [10]:

$$t = 0.14/(I^{0.02} - 1)$$

5.2 Very Inverse Characteristics for pick up value of 1A and for a TSM of 1.0.

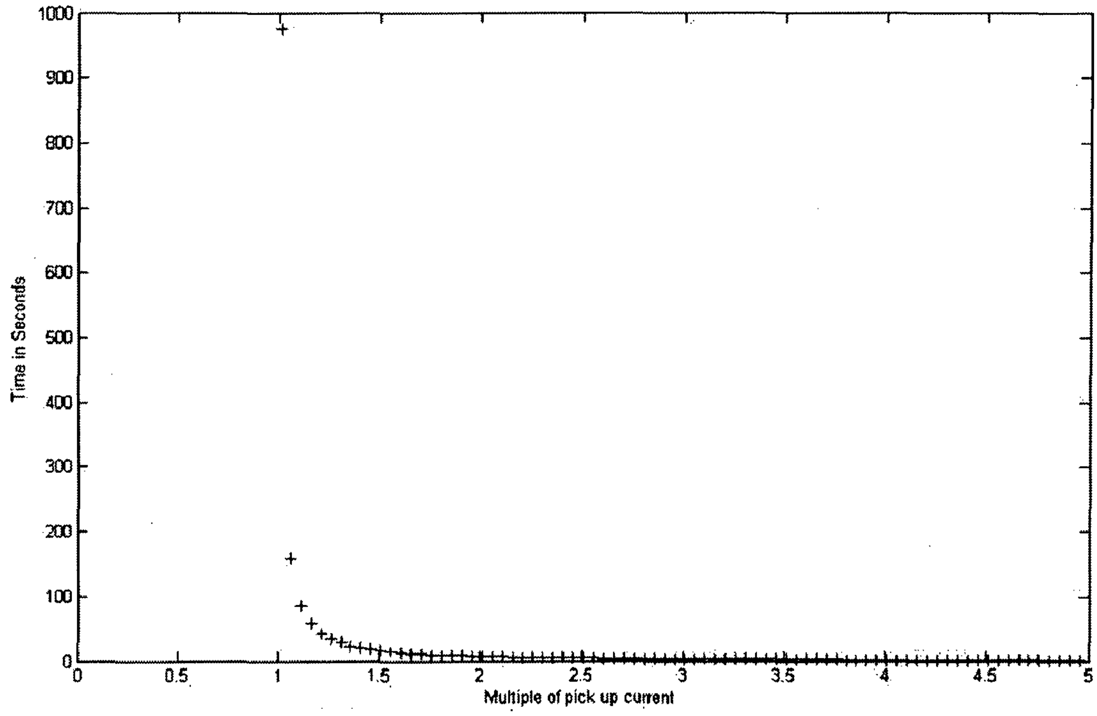

Figure 5.2 Very Inverse characteristics of over current relay

The equation used for finding out the Very inverse characteristics of the relay is [11][17]

$$t\,(I) = \frac{A}{(M^{p}-1)} + B$$

Where A=19.61, B=0.491 & p=2.000 .... (5.1)

Equation 5.1 and the constant values i.e. A, B and p are given by the IEEE standard inverse time characteristic equations.

5.3 Extremely Inverse Characteristics for pick up value of 1A and for a TSM of 1.0.

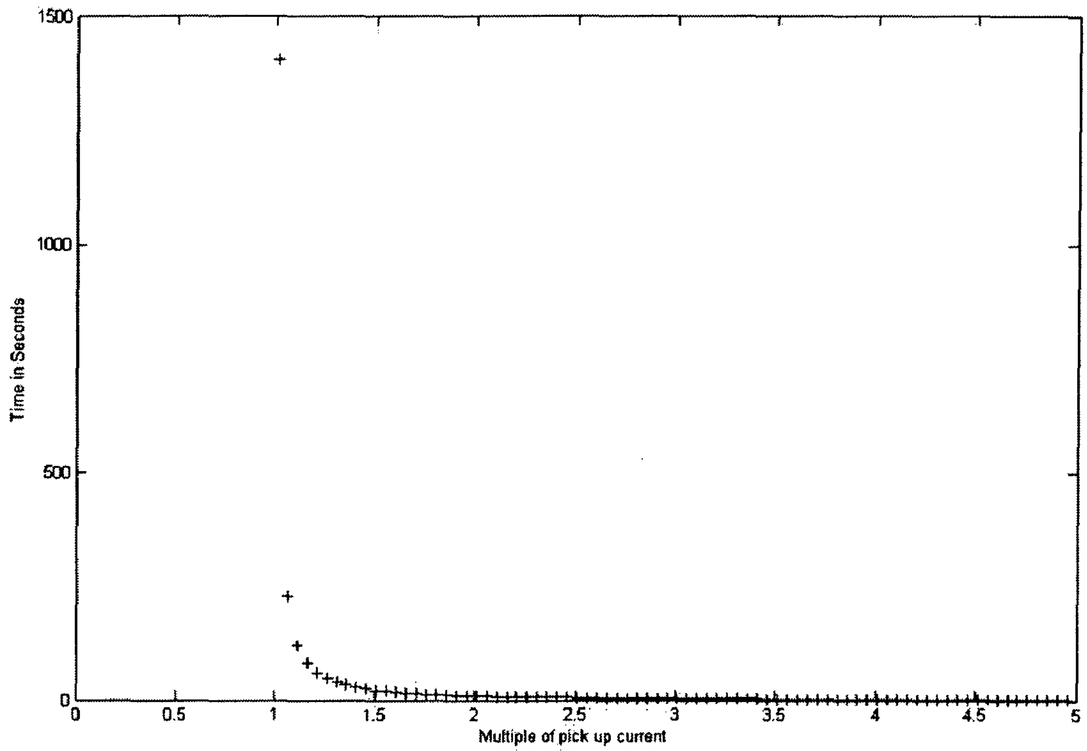

Figure 5.3 Extremely Inverse characteristics of over current relay

The equation used for finding out the Very inverse characteristics of the relay is [11][17]

$$t\,(I)= \frac{A}{(M^{p}-1)} + B$$

Where A=28.2, B=0.1217 & p=2.000 .... (4.1)

Equation 4.1 and the constant values i.e. A, B and p are given by the IEEE standard inverse time characteristic equations.

5.4 IDMT Characteristics of the under voltage relay for a TSM of 1.0

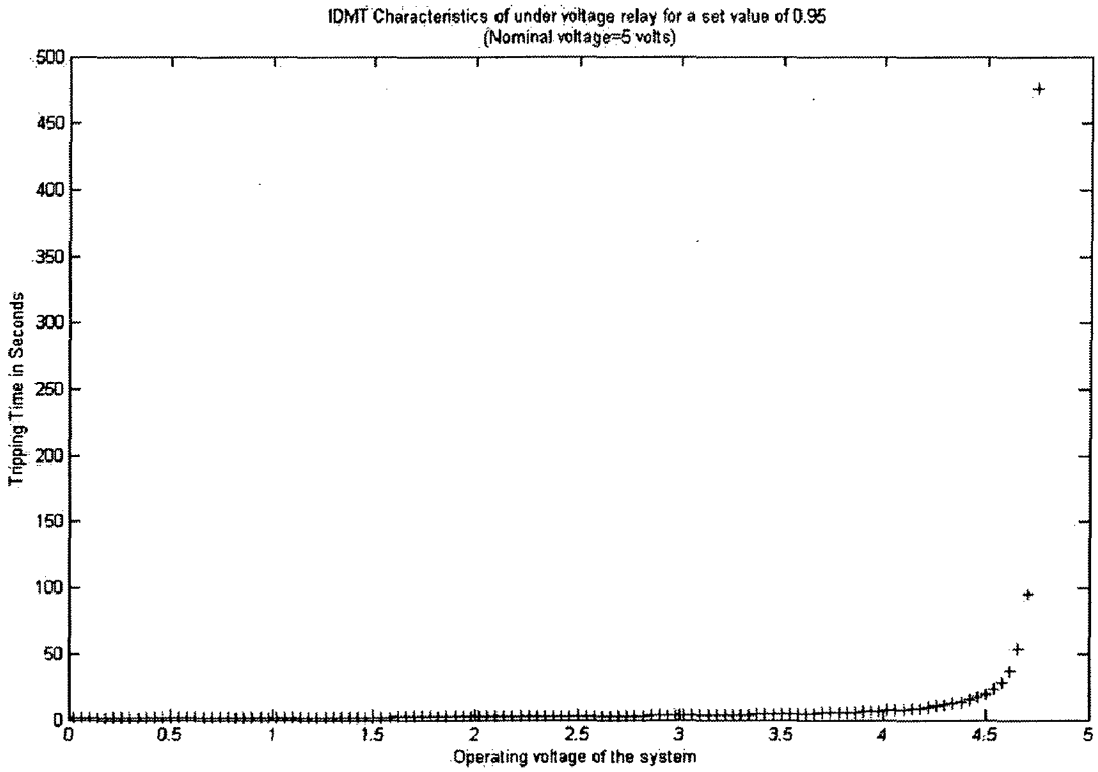

Figure 5.4 IDMT characteristics of the under voltage relay for a set value of 0.95

The equation used for finding out the Inverse Definite minimum time characteristics of the under voltage relay is

$$t\,(v) = \frac{K}{\log(2-uvf)}$$

Where K= time dial setting with range 0.1-1 sec

uvf = Measured value of voltage / (Set value x Rated voltage).

5.5 IDMT Characteristics of the over voltage relay for a TSM of 1.0

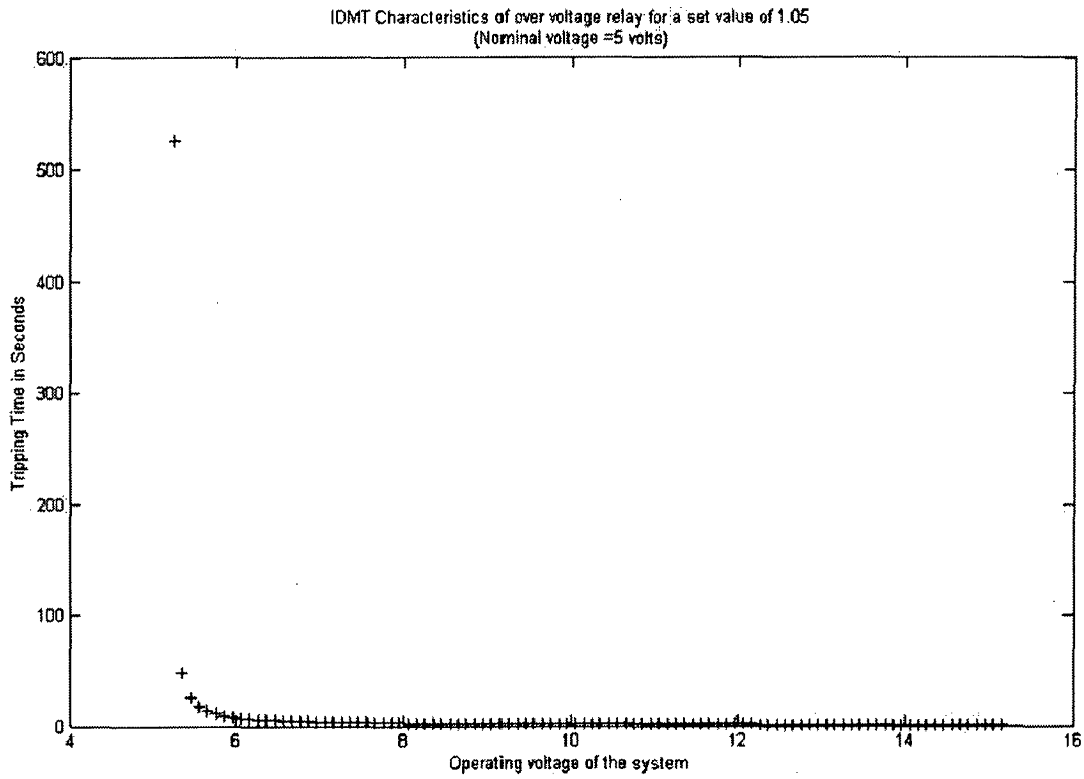

Figure 5.5 IDMT characteristics of the over voltage relay for a set value of 1.05

The equation used for finding out the Inverse Definite minimum time characteristics of the over voltage relay is

$$t(v) = \frac{K}{\log(ovf)}$$

Where K= time dial setting with range 0.1-1 sec

ovf = Measured value of voltage / (Set value x Rated voltage).

5.6 IDMT Characteristics of the over frequency relay for a TSM of 1.0

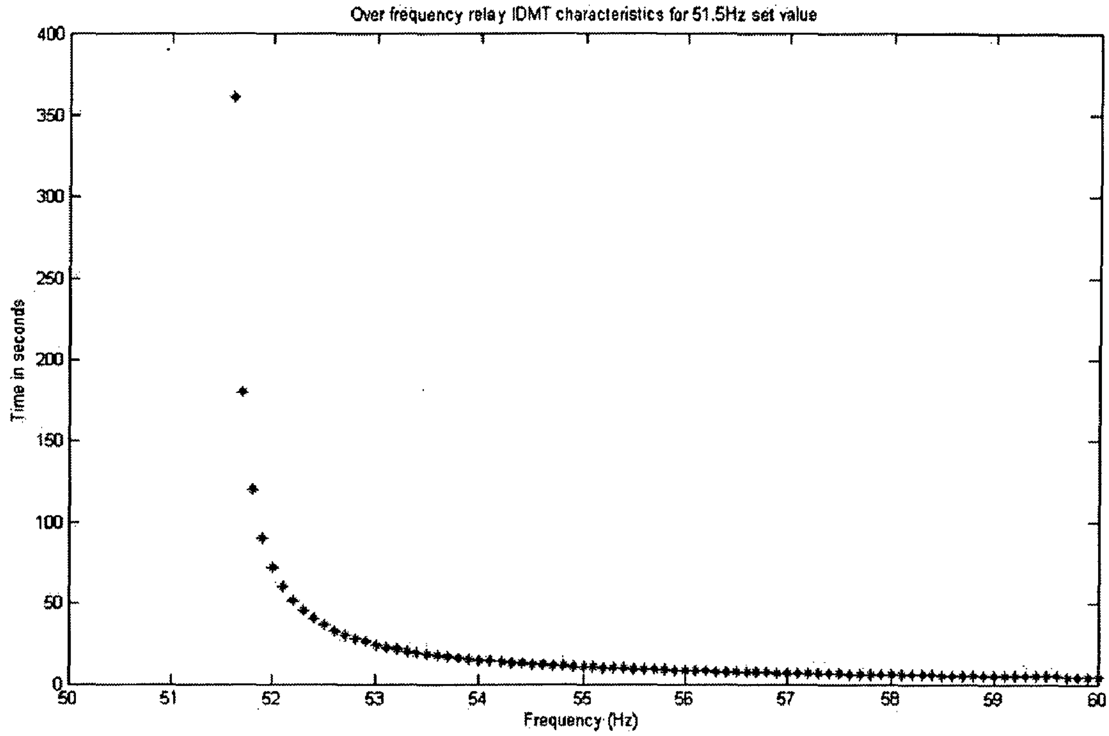

Figure 5.6 IDMT characteristics of the over frequency relay for 51.5Hz set value.

The equation used for finding out the Inverse Definite minimum time characteristics of the over frequency relay is

$$t(f) = \frac{K}{(\frac{f}{f_S})^{\alpha} - 1} + C \quad \ldots\ldots\ldots$$

Where K=0.014;

$\alpha = 0.02$;

C=0;

f = fault frequency;

f_S =set frequency of the system.

5.7 IDMT Characteristics of the under frequency relay for a TSM of 1.0

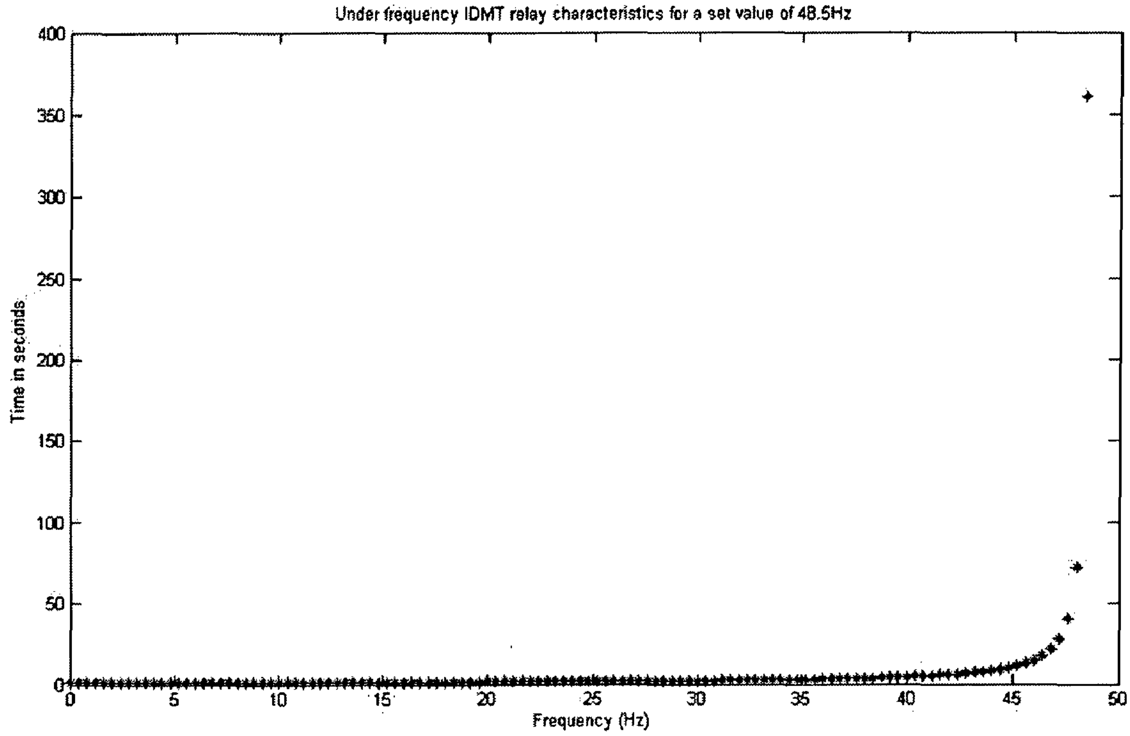

Figure 5.7 IDMT characteristics of the under frequency relay for 48.5Hz set value.

The equation used for finding out the Inverse Definite minimum time characteristics of the under frequency relay is

$$t\,(f) = \frac{K}{(\frac{f_S}{f})^{\alpha} - 1} + C$$

Where K=0.014;

$\alpha = 0.02$;

C=0;

f = fault frequency;

f_S =set frequency of the system.

CHAPTER-6

TEST RESULTS

6.1 Filter Response:

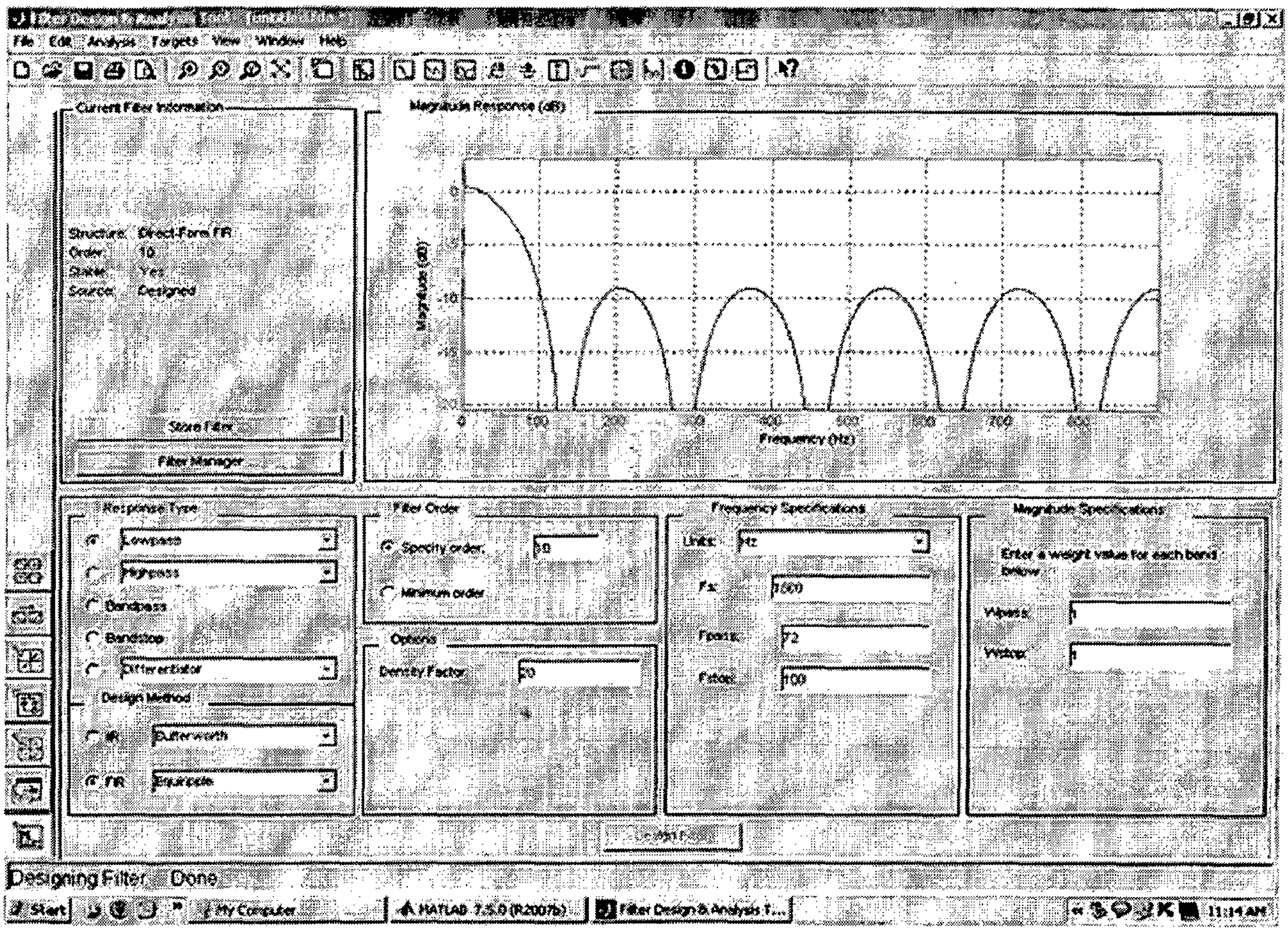

Figure 6.1 Digital FIR low pass filter design using fdatool in MATLAB.

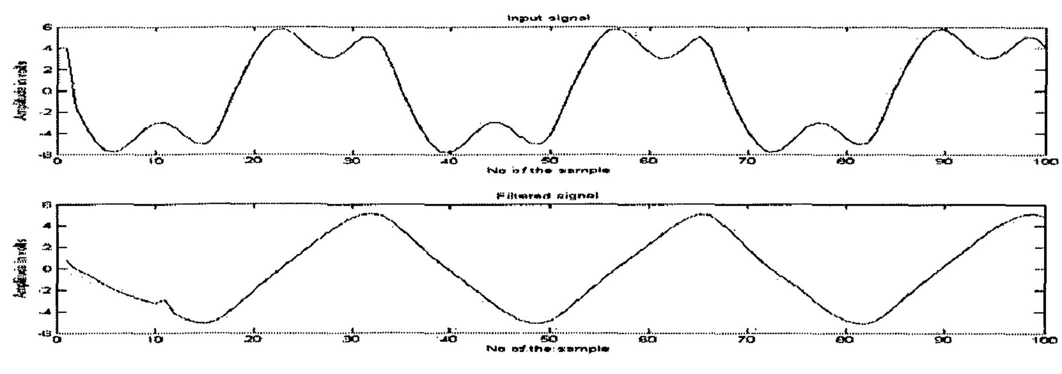

Figure 6.2 Response of the filter for third harmonic onto the fundamental wave

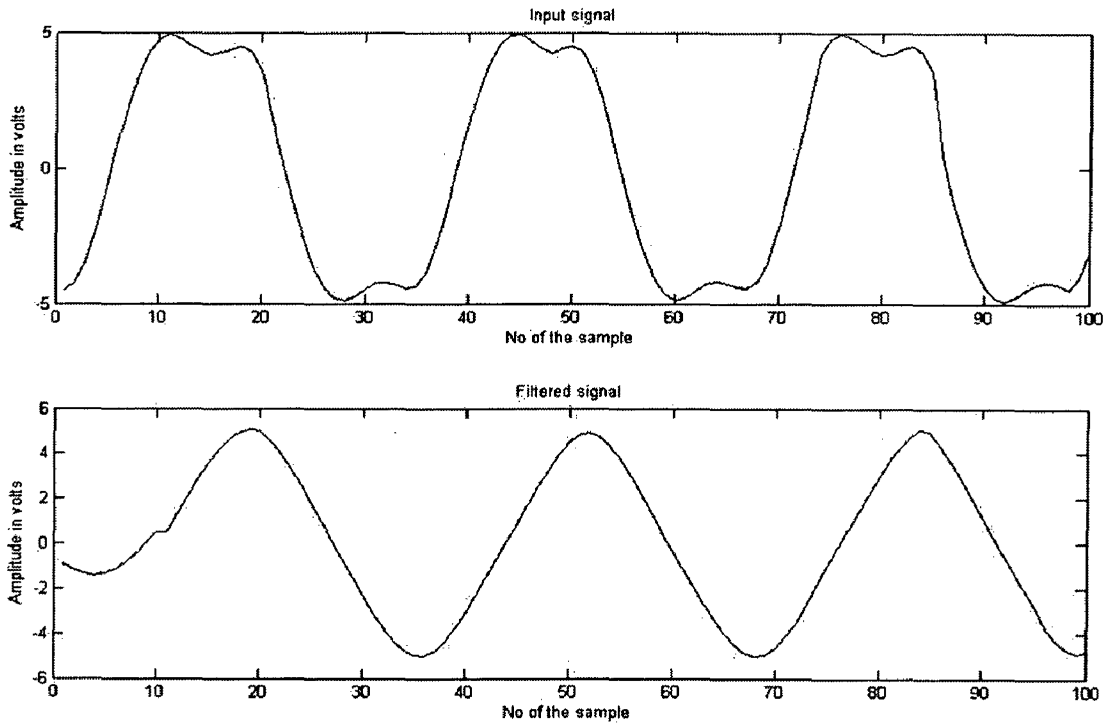

Figure 6.3 Response of the filter for fifth harmonic onto the fundamental wave

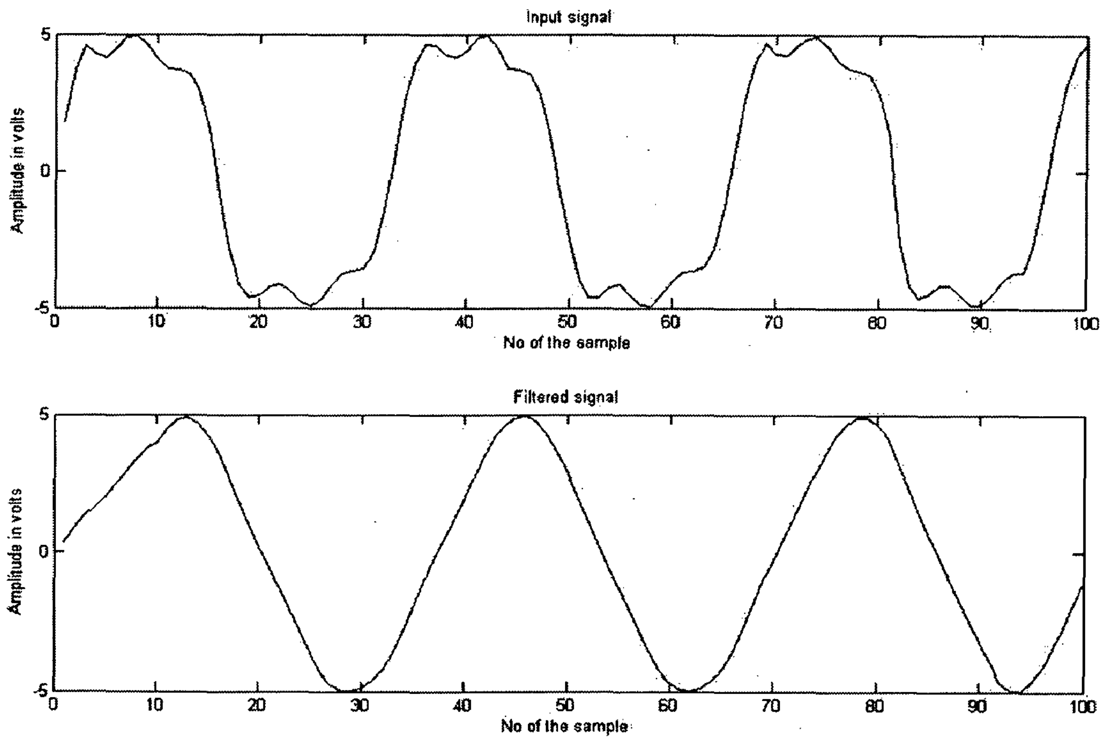

Figure 6.4 Response of the filter for third and fifth harmonics onto the fundamental wave

6.2 Results of Very inverse over current relay for a pick up value of 1A and TSM value of 1.0

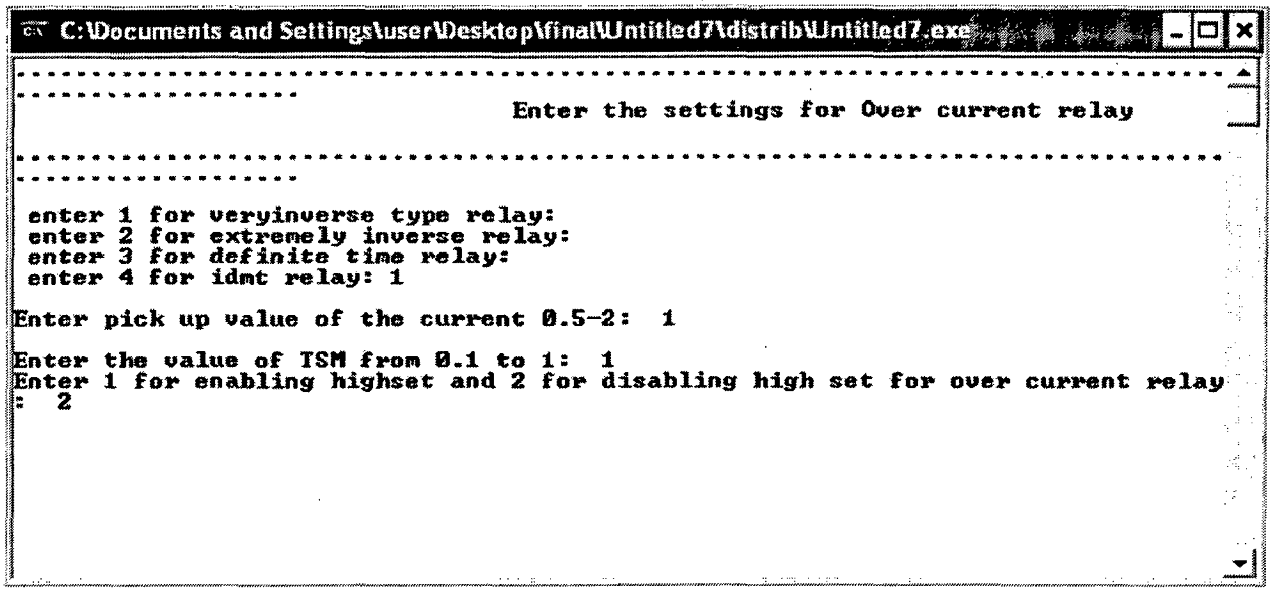

Figure 6.5 Settings of over current relay for Very inverse type

Table 6.1 Results of Very Inverse type Over current relay for a pick up value of 1A and TSM=1.0 for phase 'a'

Ia (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
1.31116	*28.18333*	*27.75966*	*0.423666*
1.3300	*26.10929*	*25.9949*	*0.107933*
1.5604	*14.3439*	*14.1579*	*0.186*
1.8307	*8.97358*	*8.8304*	*0.14318*
2.11257	*6.3224*	*6.1537*	*0.1687*
2.359	*4.93169*	*4.7855*	*0.14619*
2.605	*4.03539*	*3.8802*	*0.15519*
2.7832	*3.50141*	*3.3978*	*0.10361*
1.6200	*12.5763*	*12.563*	*0.0133*
1.9408	*7.65567*	*7.5788*	*0.07687*
2.1551	*5.92571*	*5.8712*	*0.05451*
2.5156	*4.26350*	*4.1713*	*0.0922*
2.8233	*3.4134*	*3.3040*	*0.1094*

2.202955	7.024284	6.778124	0.24611
3.512308	2.229978	2.2208401	0.009137
4.260384	1.691068	1.634382109	0.05668589
5.5470475	1.3203172	1.149722761	0.170594529
6.655039	0.986134	0.943996223	0.04213777
7.9732546	0.988011	0.804395	0.183616
9.6574401	0.77250	0.703537319	0.071462681
10.39073	0.763811	0.674327105	0.089483895

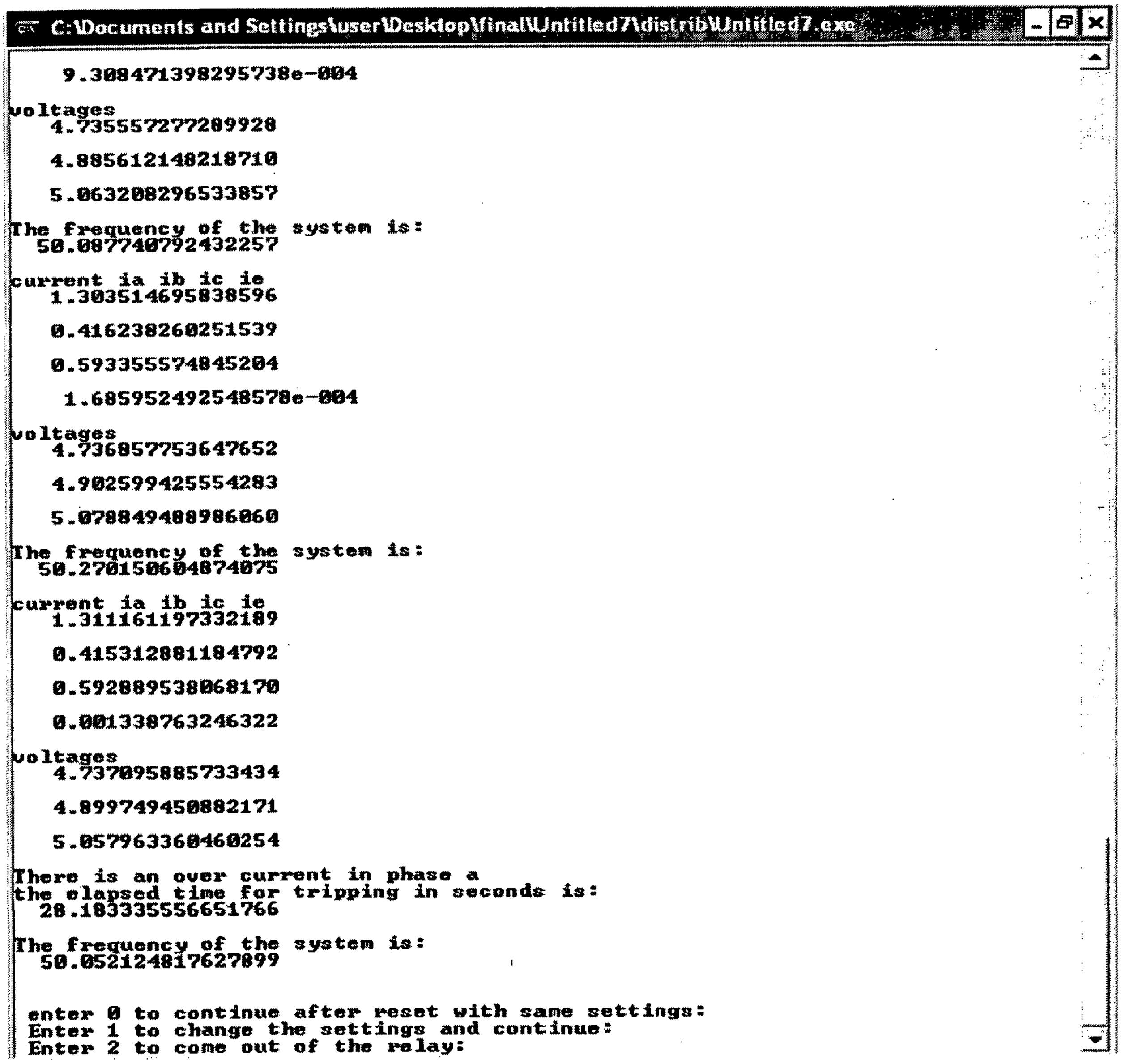

Figure 6.6 Result of Very Inverse type Over Current relay for over current in Phase 'a' for a TSM of 1.0 & Pick up value of 1A

```
C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe
    0.001281462001202

voltages
    4.744509074301667

    4.936418858486466

    5.067236712536401

The frequency of the system is:
  49.951971320725718

current ia ib ic ie
    1.092332388127564

    1.773998177996393

    0.595981461514355

    0.001383818112654

voltages
    4.739957154425951

    4.933407930157765

    5.083467561736597

The frequency of the system is:
  50.208945754461247

current ia ib ic ie
    1.089547901948737

    1.779346442084475

    0.593499769260455

    0.001281566366049

voltages
    4.741241019699984

    4.921699876721220

    5.061616641812486

There is an over current in phase b
the elapsed time for tripping in seconds is:
    9.732716101420918

The frequency of the system is:
  50.226309455014423


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:
```

Figure 6.7 Result of Very Inverse type Over Current relay for over current in Phase ‘b’ for a TSM of 1.0 & Pick up value of 1A

Table 6.2 Results of Very Inverse type Over current relay for a pick up value of 1A and TSM=1.0 for phase 'b'

Ib (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
1.779346	9.7327161	9.5442532	0.1884629
1.401548	21.07831	20.39127	0.68672985
1.25185	35.4222	35.0763	0.3459
1.7203	11.08763	10.4990	0.58863
2.17479	5.94614	5.74877	0.19737
2.28612	5.35625	5.13094	0.22531
2.45355	4.47208	4.39744	0.07464
2.94045	3.23589	3.05565	0.18024
3.04541	2.91960	2.86146	0.05814
3.48019	2.29841	2.2558	0.04261
1.41431	20.36322	20.0956	0.26762
1.97837	7.33212	7.22070	0.11142
2.06501	6.6069	6.49847	0.10843
3.28631	2.507208	2.492054	0.015154
2.3325	5.0433	4.907113409	0.137186591
3.09861	2.98158	2.7708656	0.210714323
4.365622	1.667929	1.576905873	0.091023127
5.525422	1.321142	1.55064451	0.166077549
6.313318	1.164766	0.995658191	0.169107809
7.41001	0.9832055	0.854766226	0.12844324
8.4991099	0.781479	0.766286531	0.015192469
9.652001	0.770594	0.703779524	0.066814476
10.42355	0.769239	0.673163754	0.096075246

Table 6.3 Results of Very Inverse type Over current relay for a pick up value of 1A and TSM=1.0 for phase 'c'

Ic (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
1.59900	13.46231	13.08721	0.3751
1.57536	14.006	13.7269835	0.27904
2.3432	5.017121	4.85782	0.159301
1.33207	26.195916	25.8198	0.376336
1.68017	11.38236	11.2495	0.1328114
2.41662	4.6035775	4.542690	0.060887
3.18165	2.69536	2.64053	0.05483
3.8149	2.11704	1.9378628	0.1791772
2.96970	3.08010	2.998955	0.081145
2.4665	4.4307	4.34848	0.08222
1.863676	8.6823	8.41872	0.263588
1.21368	27.165	26.748	0.417
2.77114	3.46168	3.42695	0.034731
3.34981	2.506944	2.40955	0.09739
2.260178	5.3761948	5.264142363	0.112052437
3.42444	2.426139	2.31913323	0.10700577
4.75286	1.5717368	1.399304415	0.172432385
5.9189591	1.184738	1.067187217	0.117592783
6.9586238	1.0067	0.904517268	0.102182732
8.1797436	0.794197	0.788535032	0.00566198
9.363255	0.7837659	0.717259107	0.066506793
10.665910	0.772434	0.664906664	0.107527346
10.44975	0.756361	0.672243011	0.084117989

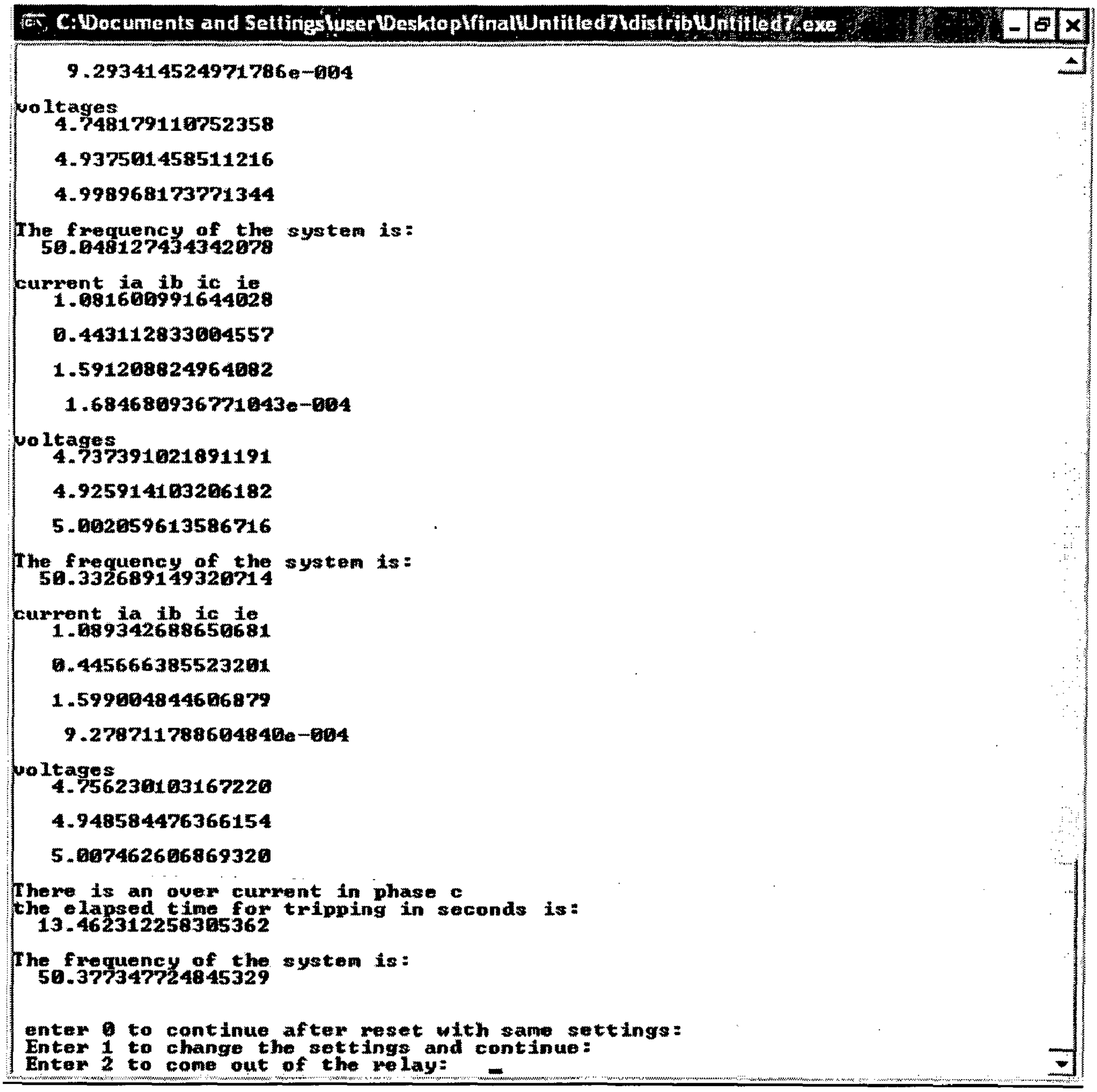

Figure 6.8 Result of Very Inverse type Over Current relay for over current in Phase 'c' for a TSM of 1.0 & Pick up value of 1A

6.3 Results of Extremely inverse over current relay for a pick up value and TSM value of 1

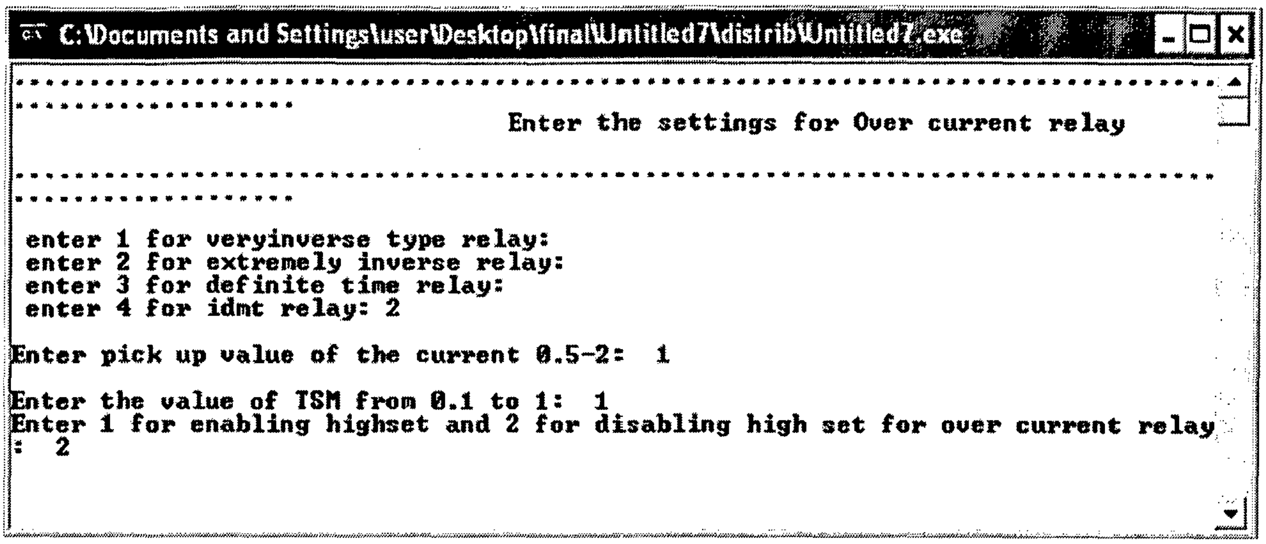

Figure 6.9 Settings of Extremely Inverse Over current relay

Table 6.4 Results of Extremely Inverse Over current relay for a pick up value of 1A and TSM=1.0 for phase 'a'

Ia (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
1.454483	25.4048	25.86328	-
1.5475685	20.73682	20.33721369	0.399606
1.244818	51.7161	51.62516	0.09094
1.65025	16.79748	16.48541	0.31207
2.083391	8.87900	8.563504	0.315496
2.330124	6.5483181	6.48813	0.0601881
2.76840	4.623612	4.35336	0.270252
3.1404	3.5038814	3.30378	0.2001014
3.5775	2.74257	2.51183	0.23074
3.944961	2.1572836	2.05815	0.0991336
3.49912	2.694713	2.6297	0.065013
3.36900	2.869801	2.84629	0.023511
2.19236	7.94496	7.53019	0.4147728
1.91983	10.76035	10.62143	0.13892

1.9201777	10.7829976	10.61635398	0.16664362
3.783192	2.487434	2.240003222	0.247430788
4.135001	1.918152	1.855587251	0.062564749
4.90356	1.5296978	1.345398049	0.184299751
6.472541	0.81206256	0.811291306	0.000771194
7.412308	0.8042935	0.649480727	0.15448623
9.396859	0.58788	0.444720506	0.143159494
9.88570741	0.5933171	0.413241539	0.180075561
9.11548	0.5861533	0.465217131	0.120936169

```
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    9.278844813110958e-004

voltages
   4.755225062854088

   4.958368584696115

   5.123841939016409

The frequency of the system is:
  50.033763553145107

current ia ib ic ie
   1.456834258779202

   0.016000595145422

  -0.001493471710878

    9.280301980826389e-004

voltages
   4.763300984921263

   4.969683445642027

   5.170210789253162

The frequency of the system is:
  50.025974971791591

current ia ib ic ie
   1.454483762275405

   0.015610126637222

  -0.001495385617480

    9.287706748714634e-004

voltages
   4.754370694287260

   4.972633390354406

   5.174642851726589

There is an over current in phase a
the elapsed time for tripping in seconds is:
  25.863288688307673

The frequency of the system is:
  49.926740561311426


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:  _
```

Figure 6.10 Result of Extremely Inverse type Over Current relay for over current in Phase 'a' for a TSM of 1.0 & Pick up value of 1A

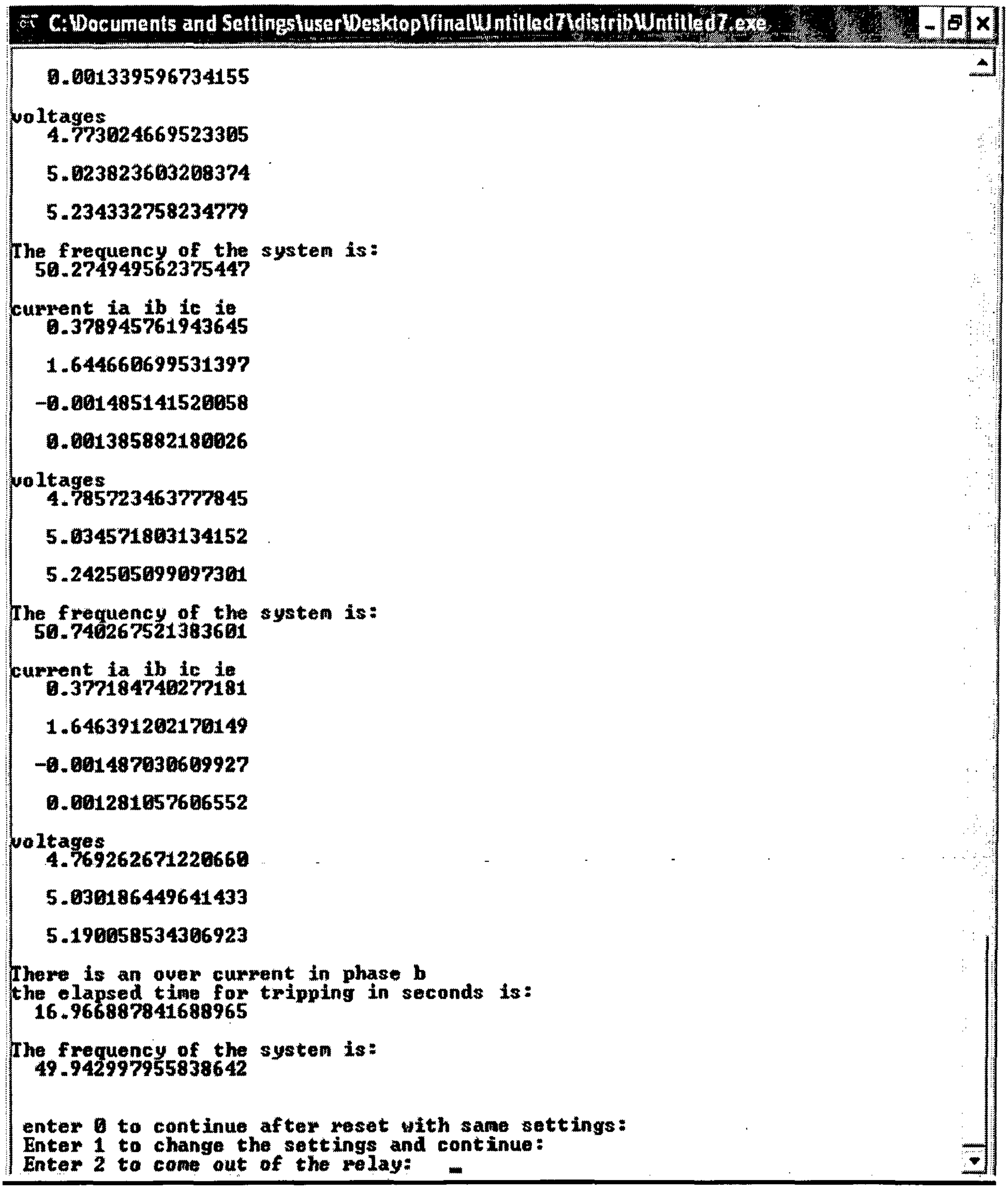

Figure 6.11 Result of Extremely Inverse type Over Current relay for over current in Phase 'b' for a TSM of 1.0 & Pick up value of 1A

Table 6.5 Results of Extremely Inverse Over current relay for a pick up value of 1A and TSM=1.0 for phase 'b'

Ib (Amps)	*Tripping time Practical (sec)*	*Tripping time standard(sec)*	*Error (sec)*
1.64639	16.9688	16.60714	0.36166
1.342696	35.6805373	35.2586136	0.421923
2.34091	6.59595	6.421279	0.174671
1.72518	14.63216	14.39117	0.24099
1.257523	48.63313	48.156362	0.476768
2.2530682	7.1688066	7.039710	0.1290966
2.33715	6.62355	6.441353	0.182197
2.505628	5.5925126	5.464459	0.1280536
3.052201	3.861286	3.512781	0.348505
3.06134	3.69433	3.49015	0.20418
3.49730	2.702814	2.63258	0.070234
2.724861	4.70098	4.51089	0.19009
2.654342	4.871803	4.786302	0.085501
2.522921	5.455601	5.37782	0.0777786
1.901927	11.00751	10.89605391	0.11145609
2.79528	4.4159458	4.260487116	0.155458634
4.1262454	2.1044223	1.881351443	0.223070857
5.44489	1.19096	1.106102213	0.084857877
6.6902	0.78564	0.766142156	0.018898505
7.874	0.604969	0.583996021	0.020972979
8.493719	0.5735036	0.518083283	0.055420317
9.46625	0.6054857	0.439948903	0.165536797
9.66324	0.59548	0.426966802	0.168513198

Table 6.6 Results of Extremely Inverse Over current relay for a pick up value of 1A and TSM=1.0 for phase 'c'

Ic (Amps)	*Tripping time Practical (sec)*	*Tripping time standard (sec)*	*Error (sec)*
1.90049	*10.987769*	*10.9185491*	*0.06922*
1.5723178	*19.551548*	*19.2776522*	*0.273895*
3.24607	*3.04144*	*2.92682*	*0.11462*
2.823329	*4.2791066*	*4.166922*	*0.112184*
2.263997	*7.052526*	*6.956932*	*0.095594*
1.70148	*15.47296*	*15.002698*	*0.470262*
1.992898	*9.769015*	*9.612649*	*0.156366*
1.44147	*26.3941*	*26.2901*	*0.104*
2.69865	*4.692823*	*4.61020*	*0.082623*
3.261327	*3.121018*	*3.048148*	*0.07287*
2.61503	*5.193717*	*4.95180*	*0.241917*
2.1054	*8.63192*	*8.33678*	*0.29514*
1.654814	*16.64639*	*16.3434*	*0.30299*
1.406972	*29.53026*	*28.9098*	*0.62046*
2.312166	*6.671715*	*6.610258629*	*0.061456371*
3.491628	*2.709589*	*2.641477103*	*0.06811897*
4.802371	*1.5577495*	*1.399871488*	*0.440965281*
6.024068	*0.95924926*	*0.920806921*	*0.038442339*
7.258610	*0.8116247*	*0.66728731*	*0.14433739*
7.09150	*0.783395*	*0.693831449*	*0.089563551*
9.608579	*0.58764688*	*0.430488006*	*0.157158794*
9.868548	*0.425476875*	*0.414266812*	*0.011210063*

```
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   9.297137135290366e-004

voltages
   4.749673064949526

   4.974760770448625

   5.050103127200333

The frequency of the system is:
  50.053533863643231

current ia ib ic ie
   0.376792580372849

   0.208443809194801

   1.902869995516127

   0.001339245542308

voltages
   4.759565738932985

   4.991190505744348

   5.030059744648998

The frequency of the system is:
  50.154985216403759

current ia ib ic ie
   0.373494250227750

   0.208628773067138

   1.900494162756249

   9.295374463379792e-004

voltages
   4.751592033355054

   4.978794800590178

   5.058669399884707

There is an over current in phase c
the elapsed time for tripping in seconds is:
  10.987769872373898

The frequency of the system is:
  49.944517408449855


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:
```

Figure 6.12 Result of Extremely Inverse type Over Current relay for over current in Phase 'c' for a TSM of 1.0 & Pick up value of 1A

6.4 Results of IDMT Characteristics of the relay for a TSM of 1.0 and for a current setting of 0.5 A

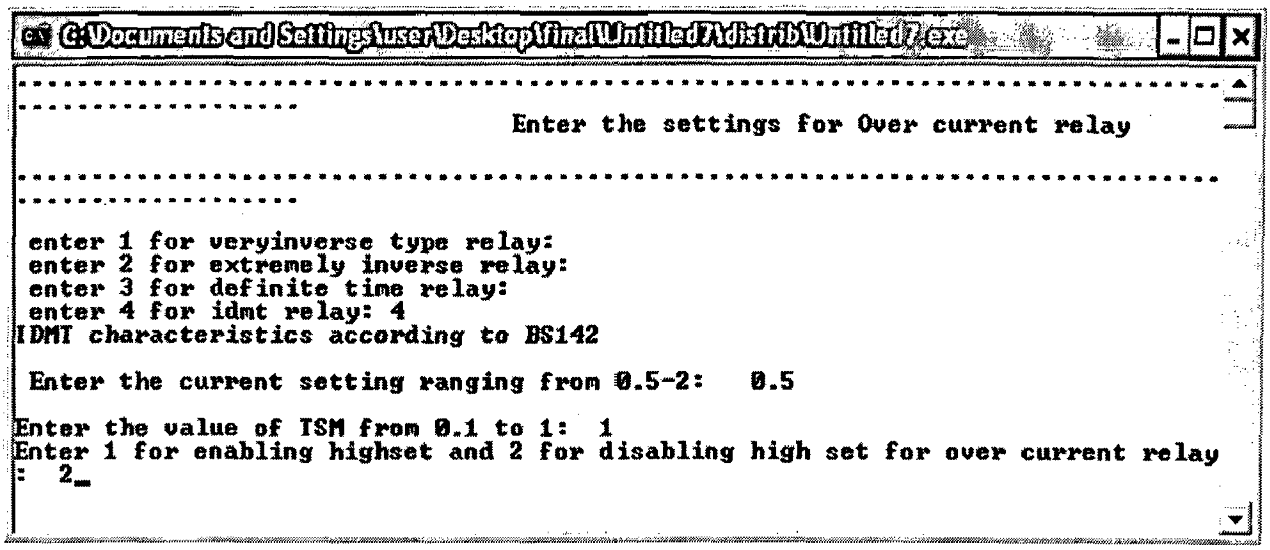

Figure 6.13 Setting of IDMT characteristics for over current relay

Table 6.7 Results of IDMT Over current relay for a current setting of 0.5A and TSM=1.0 for phase 'a'

Ia (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard(sec)*	*Error (sec)*
0.9693591	*10.61481*	*10.503742*	*0.11109*
0.936266	*11.1359369*	*11.0892322*	*0.04670*
0.9123496	*11.784625*	*11.56935491*	*0.2157009*
0.7103458	*20.239706*	*19.8649351*	*0.3747709*
1.1291541	*8.6437052*	*8.52328*	*0.1204252*
1.2579927	*7.72714*	*7.5175439*	*0.2095961*
1.451219	*6.7194651*	*6.4996193*	*0.2198458*
1.66599569	*5.753337*	*5.74631081*	*0.00702619*
0.838330	*13.72*	*13.47491475*	*0.24508525*
3.063278	*3.9476066*	*3.79220903*	*0.15539757*
2.2108	*4.743888*	*4.639389809*	*0.104498191*
3.93823	*3.36859711*	*3.322153976*	*0.046443134*
5.254276	*2.97206*	*2.906499653*	*0.065560347*

4.797091	*3.1619346*	*3.026288027*	*0.135646573*
6.1380	*2.8002158*	*2.722047531*	*0.078168269*
7.91789	*2.604879*	*2.46479036*	*0.14008864*
8.59908	*2.5642075*	*2.391291596*	*0.172783404*
9.19901	*2.37368*	*2.334325.19*	*0.039354981*
9.71908	*2.36601*	*2.289794162*	*0.076215838*

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```
    9.257000861737419e-004

voltages
   4.779013090848836

   5.051005903216231

   5.165092744633024

The frequency of the system is:
  50.123198507032015

current ia ib ic ie
   0.968806254143689

   0.212458477885731

   0.452031555884028

   0.001415162734943

voltages
   4.783887778363748

   5.064303341574877

   5.208362023866637

The frequency of the system is:
  50.086359589945125

current ia ib ic ie
   0.969359186260247

   0.212705062350052

   0.454853865377819

    9.241673479199501e-004

voltages
   4.784954346243664

   5.072838863838465

   5.199948198721023

There is an over current in phase a
the elapsed time for tripping in seconds is:
  10.614813653226316

The frequency of the system is:
  50.656314077180674


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:  _
```

Figure 6.14 Result of IDMT over Current relay for over current in Phase 'a' for a TSM of 1& current setting of 0.5

```
C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe

    9.246680867638672e-004

voltages
   4.734671037265708

   5.065789672294278

   5.225665054736153

The frequency of the system is:
  50.173486560338688

current ia ib ic ie
   0.143987598568756

   1.486070494335340

   0.452985686823615

    1.704517695142950e-004

voltages
   4.758494663971087

   5.009116258284469

   5.227309822218460

The frequency of the system is:
  50.307440721124856

current ia ib ic ie
   0.144318383576839

   1.499002957246927

   0.453328317683531

    9.226000551339983e-004

voltages
   4.769280975648965

   5.069979250305427

   5.226028802497456

There is an over current in phase b
the elapsed time for tripping in seconds is:
   6.500215187139396

The frequency of the system is:
  49.887878278083207


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:
```

Figure 6.15 Result of IDMT over Current relay for over current in Phase 'b' for a TSM of 1& current setting of 0.5

Table 6.8 Results of IDMT Over current relay for a current setting of 0.5A and TSM=1.0 for phase 'b'

Ib (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
1.49900	6.50021518	6.305800	0.19441518
1.3817229	6.919026	6.816762	0.10226311
0.819453	14.328756	14.0993255	0.2294305
1.12147	8.634412	8.595833	0.038579
1.42674228	6.669714	6.606377	0.063337
1.51648	6.299908	6.239185	0.060723
1.62654	5.9528375	5.864478	0.0883595
1.954966	5.1266368	5.06408	0.0625568
1.920701	5.223108	5.131536683	0.091571317
2.79504177	4.1138258	3.997817864	0.116007936
4.1120769	3.48111269	3.252631846	0.228480844
5.396816	2.981646	2.873172195	0.04328805
4.775488	3.187337	3.032478821	0.154858179
6.01056	2.9662735	2.745595373	0.220679627
7.1449	2.7203	2.562648709	0.157651291
8.43213	2.50907	2.408362862	0.100707138
8.92958	2.52935	2.359106142	0.170243858
8.3813	2.549746	2.413675509	0.136070491
9.42259	2.472383	2.314672448	0.157710552

Table 6.9 Results of IDMT Over current relay for current setting of 0.5A and TSM=1.0 for phase 'c'

Ic (Amps)	*Tripping time Practical (sec)*	*Tripping time Standard(sec)*	*Error (sec)*
2.1046108	4.8624032	4.80065	0.0617532
1.24623216	7.6451656	7.594962161	0.0502034
2.4623858	4.7164005	4.31703	0.4056705
1.788533	5.540524	5.42246	0.118064
1.3972324	6.920843	6.741959	0.178884

0.9702655	10.6304369	10.4888	0.1416369
0.7860399	15.45513	15.40315	0.051398
0.672828	24.121599	23.8478	0.273799
2.317555	4.63951	4.494603062	0.144906938
3.50970	3.6139621	3.522634055	0.0875566
6.031743	2.923927	2.741619174	0.182307826
4.712701	3.1618959	3.050775668	0.111120232
7.1941	2.732457	2.555876363	0.176580637
9.565038	2.471411	2.302555463	0.168855537
9.591348	2.51322	2.300350558	0.50971442

Table 6.10 Result of very inverse Earth fault relay for a pick up value of 0.5A and a TSM of 0.75

Ie (Amps)	*Tripping time practical (sec)*	*Tripping time standard (sec)*	*Error (sec)*
1.02	5.1216941	4.4774238	0.644270
0.8895	7.2978455	6.9352688	0.362527
3.300	0.78209	0.768415	0.01367421
2.9257	0.93329	0.88200	0.05129

Table 6.11 Result of Extremely inverse Earth fault relay for a pick up value of 1A and a TSM of 1.0

Ie (Amps)	*Tripping time practical (sec)*	*Tripping time standard (sec)*	*Error (sec)*
3.315	3.06891	2.944741	0.1250
2.59607	5.1108	5.034950	0.075848
1.8297	12.5599	12.1329	0.426066
1.4663	25.200	24.6426	0.55732

Table 6.12 Result of IDMT Earth fault relay for a current setting of 0.5 and a TSM of 1.0

Ie (Amps)	*Tripping time Standard (sec)*	*Tripping time practical (sec)*	*Error (sec)*
1.473346	6.425314	6.407636	0.0176778

0.8622624	12.89486	12.7753	0.119553
0.976217	10.4502326	10.39233	0.057866
5.1367926	3.074194255	2.9353821	0.138807

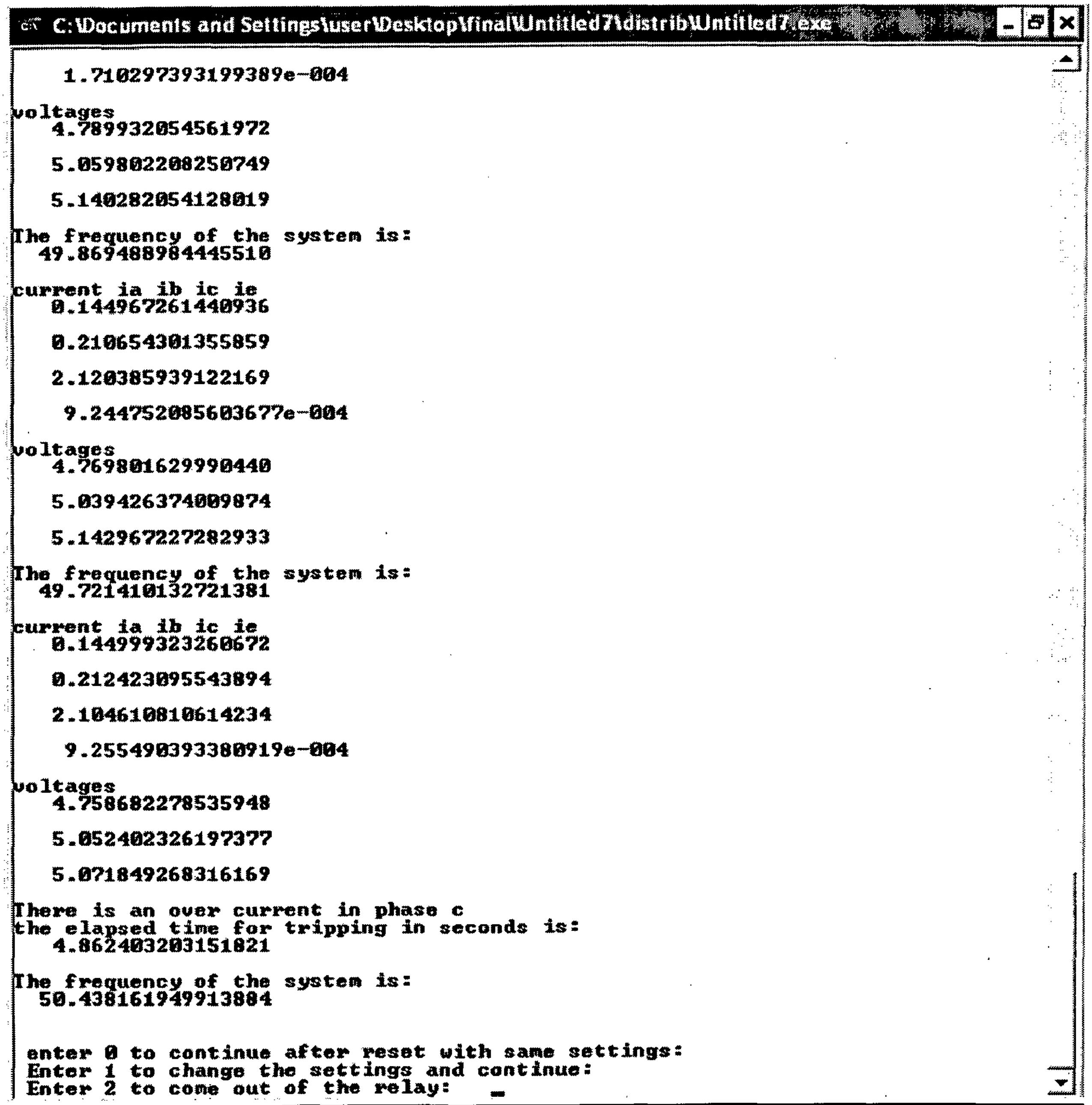

Figure 6.16 Result of IDMT over Current relay for over current in Phase ‘c’ for a TSM of 1& current setting of 0.5

6.5 Results of Under/Over voltage IDMT relay for a set value of 1.05 for over voltage and 0.95 for Under voltage

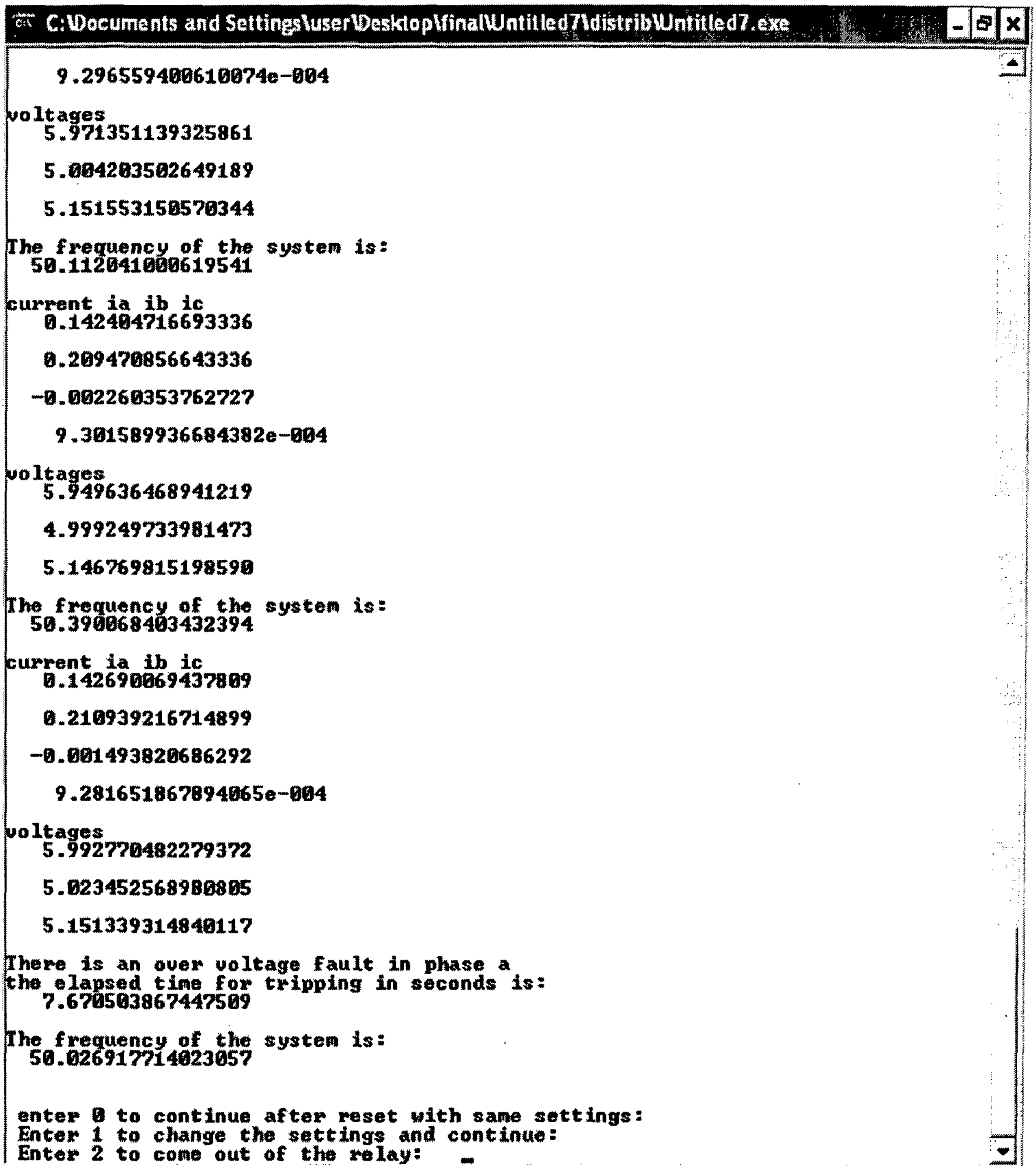

Figure 6.17 Result of IDMT over voltage relay for over voltage in Phase 'a' for a TSM of 1& set value of 1.05 (Nominal voltage=5 Volts)

```
C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe
    9.235115044061513e-004

voltages
   3.932138970710559

   5.045959028902511

   5.186445916312018

The frequency of the system is:
  50.013893904209347

current ia ib ic ie
   0.048023130286882

   0.214835614568009

  -0.001473877964149

    9.204706794954996e-004

voltages
   3.964926470093964

   5.106904156353291

   5.172379406603955

The frequency of the system is:
  50.642436535837533

current ia ib ic ie
   0.047216497055631

   0.214043896955506

  -0.001480882074660

    1.709744528871168e-004

voltages
   3.936555646787988

   5.089707819005386

   5.164948794120395

There is an under voltage fault in phase a
the elapsed time for tripping in seconds is:
   6.397356072155911

The frequency of the system is:
  50.166465874916128

 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:  _
```

Figure 6.18 Result of IDMT under voltage relay for under voltage in Phase 'a' for a TSM of 1& set value of 0.95 (Nominal voltage=5 Volts)

C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe

```
    9.257459643187574e-004

voltages
   4.978817067554948

   5.554397803042568

   5.142848867810912

The frequency of the system is:
  50.042957690222906

current ia ib ic ie
   0.046996062953392

   0.212241169611135

  -0.001486754949083

    9.254344394148642e-004

voltages
   4.969442460380806

   5.552393595995357

   5.166489954604995

The frequency of the system is:
  50.053658912137465

current ia ib ic ie
   0.045552422362430

   0.211816159140856

  -0.001484222226325

    9.244568200221486e-004

voltages
   4.996155479390661

   5.567694012181735

   5.167701622424230

There is an over voltage fault in phase b
the elapsed time for tripping in seconds is:
  17.852549097551133

The frequency of the system is:
  49.833973066529168


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:
```

Figure 6.19 Result of IDMT over voltage relay for over voltage in Phase 'b' for a TSM of 1& set value of 1.05 (Nominal voltage=5 Volts)

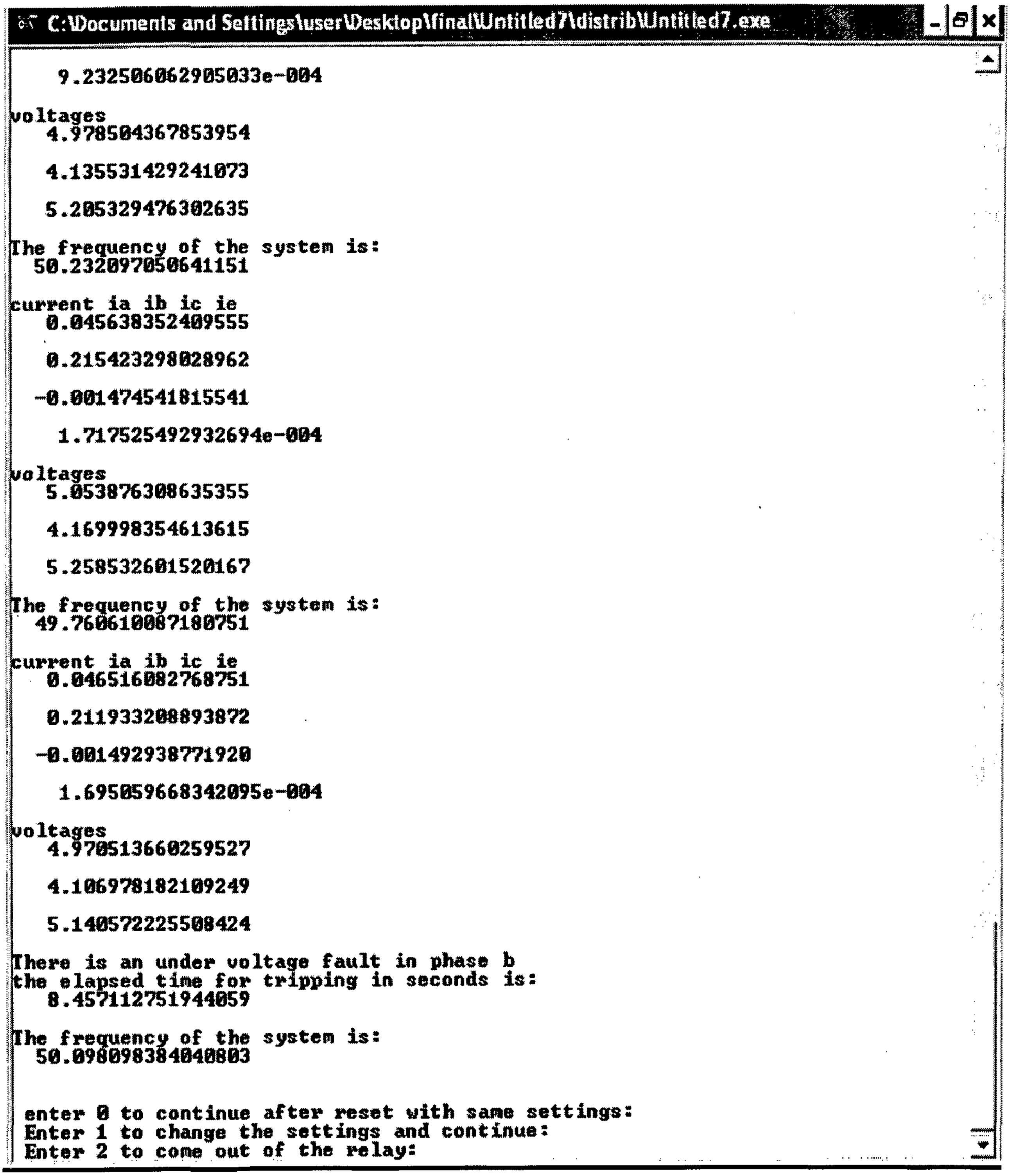

Figure 6.20 Result of IDMT under voltage relay for under voltage in Phase ‘b’ for a TSM of 1& set value of 0.95 (Nominal voltage=5 Volts)

Table 6.13 Results of IDMT Over/Under voltage relay for set value of 1.05 and 0.95 for Va'

(Nominal voltage =5 volts)

Va(volts)	*Tripping time Practical (sec)*	*Tripping time Standard (Sec)*	*Error (sec)*	*Va(volts)*	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
5.99277	7.670503	7.55778	0.1127	3.93655	6.397356	6.326158	0.07119
6.03568	7.726789	7.21922	0.5074	4.34197	12.46559	12.34366	0.12193
5.91037	9.01344	8.4408	0.5726	4.44588	16.54105	16.11366	0.42739
5.7448	11.25578	11.102843	0.1529	4.46690	17.994234	17.27369	0.72054
5.6496	14.025277	13.72144	0.3038	4.23846	9.89301	9.77716	0.11815
5.6608	13.5309	13.27366	0.0794	4.06853	7.7728348	7.459108	0.31372

Table 6.14 Results of IDMT Over/Under voltage relay for set value of 1.05 and 0.95 for Vb'

(Nominal Voltage= 5 volts)

Vb (volts)	*Tripping time Practical (sec)*	*Tripping time standard(sec)*	*Error (sec)*	*Vb (volts)*	*Tripping time Practical (sec)*	*Tripping time Standard (sec)*	*Error (sec)*
5.5676	17.85254	17.02064	0.8319	4.1069	8.457112	7.876325	0.5807
5.5848	16.75176	16.1758	0.57596	4.2049	9.46549	9.20622	0.25927
5.9266	8.354979	8.2487	0.10627	4.5146	21.2380	20.67953	0.55847
6.0869	6.9437433	6.76022	0.18352	3.5542	4.787316	4.45380	0.33351
5.9382	8.95171	8.11766	0.83411	4.0202	7.077584	7.00211	0.07547
5.8669	9.17651	8.97337	0.20314	3.1818	3.59333	3.5052687	0.08806

Table 6.15 Results of IDMT Over/Under voltage relay for set value of 1.05 and 0.95 for Vc'

(Nominal voltage= 5volts)

Vc(volts)	*Tripping time Practical (sec)*	*Tripping time standard(sec)*	*Error (sec)*	*Vc (volts)*	*Tripping time Practical (sec)*	*Tripping time Standard(sec)*	*Error (sec)*
5.53158	19.816722	19.14104	0.6756	4.1571	8.575392	8.502481	0.0729
6.21421	6.123786	5.93082	0.1929	4.3997	14.18344	14.05426	0.12918
5.55330	18.20808	17.804914	0.4031	4.4588	17.07576	16.8079	0.2677
5.95526	8.283277	7.933466	0.349	4.1246	8.3065969	8.08514	0.22145
5.58565	16.37468	16.1362	0.2384	3.7290	5.27279	5.13649	0.1363
5.71115	14.186249	13.87749	0.3087	4.0697	7.55311	7.47157	0.08154

```
C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe

    9.271130516412083e-004

voltages
   4.988714727354331

   5.017990261170148

   5.509722711943272

The frequency of the system is:
  49.942128437198988

current ia ib ic ie
   0.045305516096565

   0.212395264657994

  -0.001490177664455

    9.267566155756028e-004

voltages
   4.977629974847275

   5.003764505501752

   5.495400059624952

The frequency of the system is:
  50.082223412529572

current ia ib ic ie
   0.045827465809579

   0.214060835442911

  -0.001481997147842

    9.235984818778350e-004

voltages
   4.983846699757653

   5.039738117707771

   5.531584587854021

There is an over voltage fault in phase c
the elapsed time for tripping in seconds is:
  19.816722131745863

The frequency of the system is:
  50.302900725193680


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:
```

Figure 6.21 Result of IDMT over voltage relay for over voltage in Phase ‘c’ for a TSM of 1& set value of 1.05 (Nominal voltage=5 Volts)

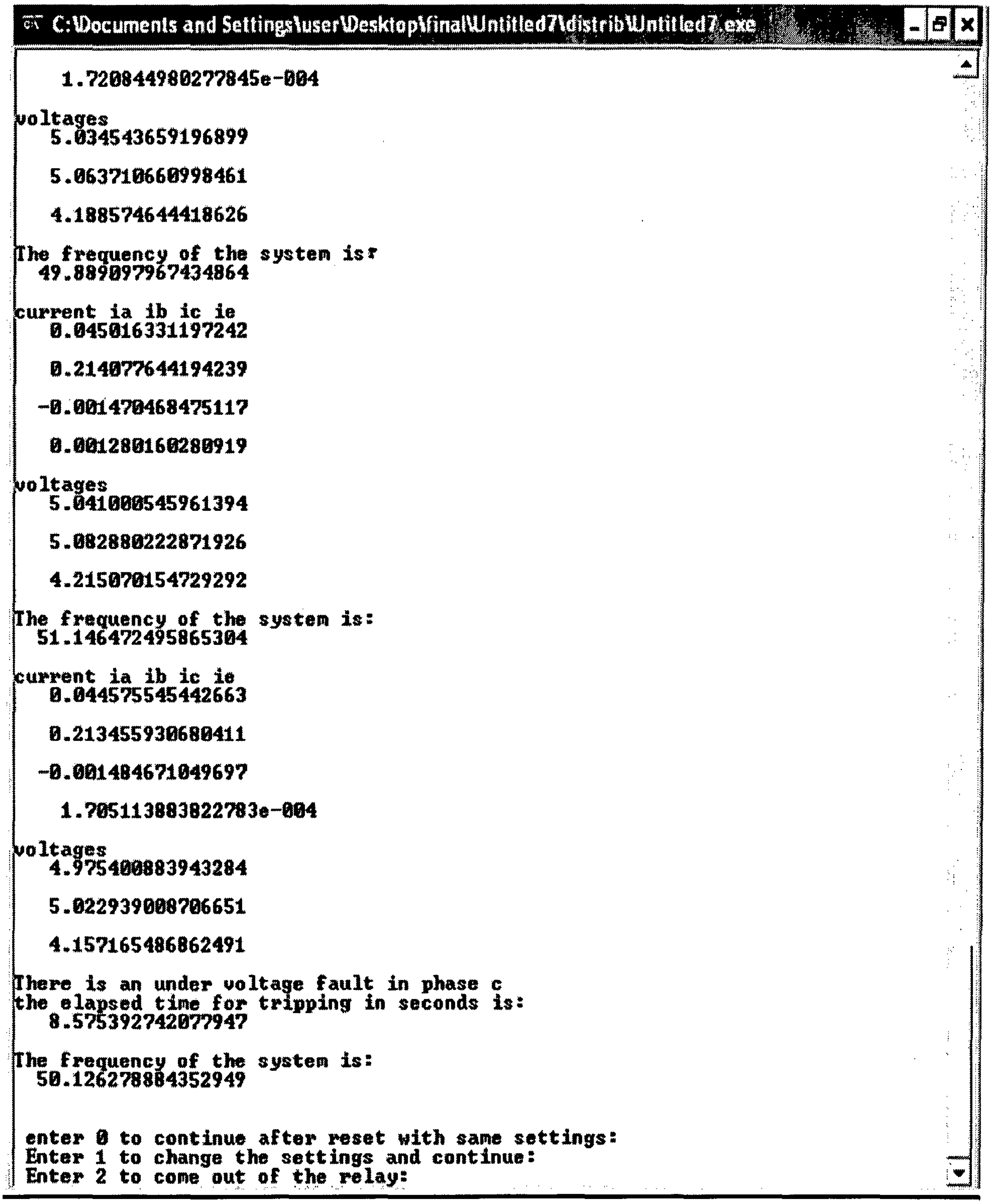

Figure 6.22 Result of IDMT under voltage relay for under voltage in Phase ‘c’ for a TSM of 1& set value of 0.95 (Nominal voltage=5 Volts)

6.6 Results of Under / Over Frequency relay for Indian standard setting and for a TSM of 1.0

```
C:\Documents and Settings\user\Desktop\final\Untitled7\distrib\Untitled7.exe

voltages
   4.642722724911276

   4.853097380127744

   4.548293369100922

The frequency of the system is:
  54.829537104396316

current ia ib ic ie
   0.045887245154481

  -0.001482853824734

  -0.001482853824734

    9.239288915021992e-004

voltages
   4.649964064688375

   4.880727378984004

   4.524315179773620

The frequency of the system is:
  55.084269871719435

current ia ib ic ie
   0.046559616335288

  -0.001489276591789

  -0.001489276591789

    9.264084220793296e-004

voltages
   4.627773650947721

   4.892260638643579

   4.524451922442832

The frequency of the system is:
  55.257523692549697

There is an Under/Over frequency fault. Frequency of the system is
  55.257523692549697

the elapsed time for tripping in seconds is:
  10.094636587926678


 enter 0 to continue after reset with same settings:
 Enter 1 to change the settings and continue:
 Enter 2 to come out of the relay:   _
```

Figure 6.23 Result of IDMT under/Over frequency relay for over frequency in the system for a TSM of 1& set value of 51.5 Hz

Table 6.16 Results of IDMT under/over frequency relay at set frequency of 51.5Hz for over frequency and set frequency of 48.5Hz for under frequency.

Frequency (Hz)	*Tripping time Practical sec)*	*Tripping time standard(sec)*	*Error (sec)*	*Frequency (Hz)*	*Tripping time Practical (sec)*	*Tripping time Standard(sec)*	*Error (sec)*
54.01146	14.77585	14.69441839	0.0814	45.3097	10.68421	10.28089211	0.40331
55.54222	9.8676859	9.25696106	0.6107	46.2786	15.202816	14.92362748	0.27918
56.3413	8.10521	7.784108853	0.3211	46.0266	13.705631	13.36599307	0.33963
55.25752	10.0946	9.932988	0.1616	45.0667	9.67570359	9.527164771	0.14853

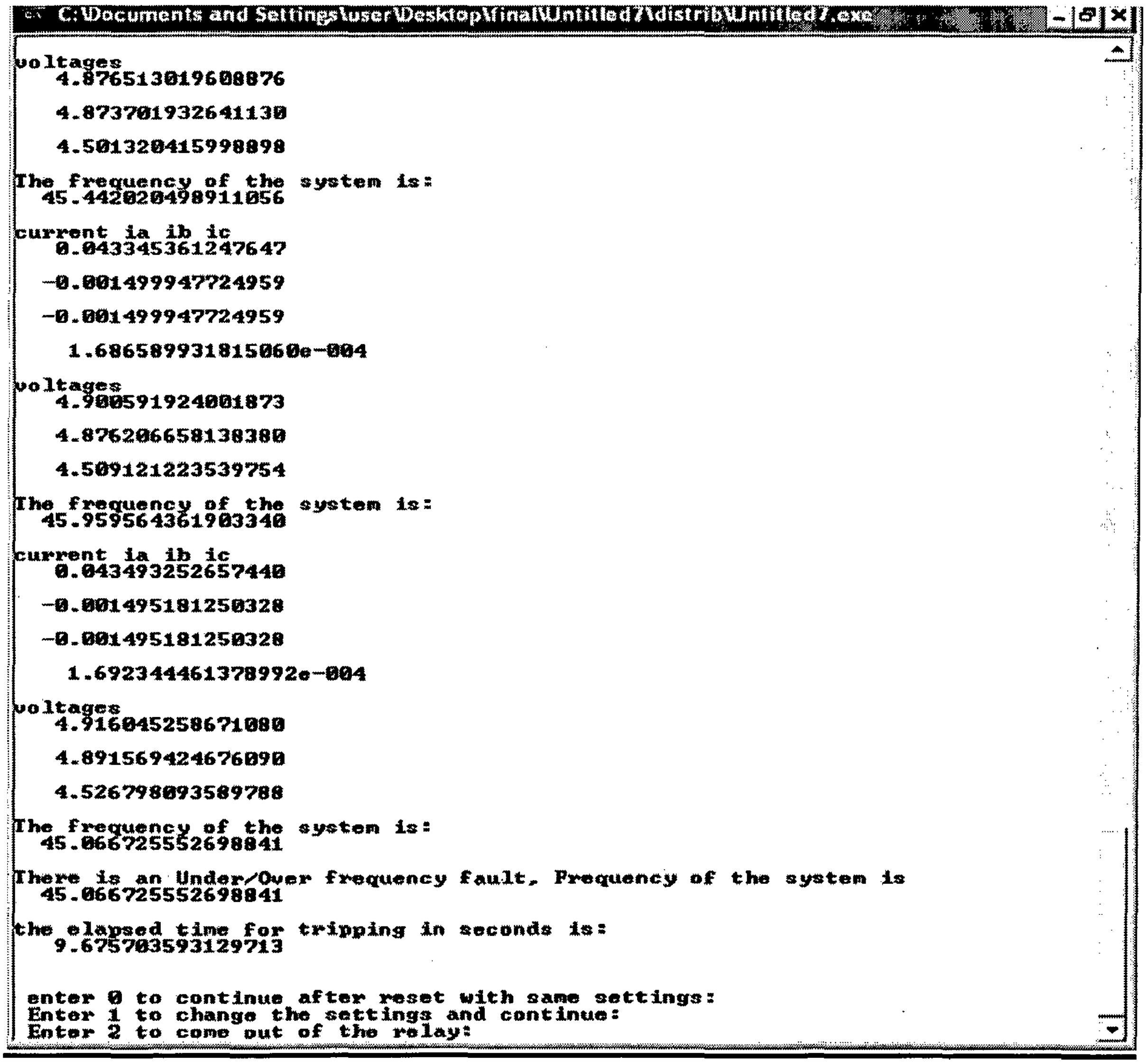

Figure 6.24 Result of IDMT under/Over frequency relay for under frequency in the system for a TSM of 1& set value of 48.5 Hz

CHAPTER-7

Advantages and disadvantages of the processor based multifunctional relay

To protect the power system from abnormal conditions typical protection schemes are employed in which discrete components such as over current relays, distance relays, auxiliary relays and re-closing relays are used. All of the devices must be wired together to have a complete, functional scheme, which means time and money in the design, development, and installation process. Due to the number of components that make up these protection schemes, detailed installation tests, and routine maintenance programs must be performed to ensure that the schemes are functioning correctly. Again, this requires a significant investment in time, money, and manpower. For example, a typical step time distance transmission line protection scheme must be maintained every one to three years to ensure that it is performing within specific guidelines. [14]

Microprocessor-based multi functional relays offer many advantages over schemes using discrete components. The overall scheme takes up less panel space. The number of components is greatly reduced. The design and wiring is simpler and less costly to implement. Installation testing and maintenance testing can be greatly reduced. Microprocessor-based multi functional relays also offer many features and functions in addition to the base protection functions.[14]

Microprocessor-based relays may be used in all electromechanical relay applications. The added benefits of simple scheme design and improved reliability [19] make them a very attractive option. Microprocessor-based relays also make new applications and protection philosophies available. We can implement more flexible protection schemes, reduce maintenance, and obtain more information to increase our understanding of the power system, and improve the reliability of the protection system as a whole at a cost less than conventional electromechanical relays.[15]

The space requirement for the microprocessor-based relay scheme is much less than the electromechanical relay scheme. Given that the cost of all the relays for the electromechanical scheme is 1 per unit (p.u.), the cost of the microprocessor-based relay scheme is 0.35p.u.[14]

Microprocessor-based relays offer many other features that electromechanical relays do not offer such as fault locating, event reporting, advanced metering functions and control capability. Fault locating has become a standard feature in nearly all microprocessor-based relays. The fault locating information reduces patrol time on permanently faulted lines. The fault locating information can also be used to evaluate problem areas on transmission lines.[14]

The event record [18] provides data on the internal relay element operation and the currents and voltage waveforms at the time of operation. This is similar to having a fault recorder on every breaker where a microprocessor-based relay is installed. The microprocessor-based relay also provides analog metering quantities such as three-phase currents, voltages, megawatts, and megavars. In many cases, analog transducers are not required. The data can also be directly interfaced digitally to the SCADA RTU[20] .We can also send the fault locator information to the system control center for dispatching a patrol crew.

Many microprocessor-based relays include communications scheme logic. In most cases, the relays include all of the required logic to operate in a particular communications-aided scheme. This saves design and materials cost since external auxiliary relays are not required for the scheme operation. The microprocessor-based relay also includes much of the logic that would be provided in the communications equipment. [14]

Microprocessor-based relays now offer programmable logic. The programmable logic allows the user to define the operation of the relay and invent unique protection schemes. The relays also offer a large variety of protection elements and schemes. The flexibility offered in these relays allows application at many voltage levels [14]

In Power System Analysis most microprocessor-based relays record the system conditions when protective elements operate or when user-defined conditions occur. [14]

The event data can be used to evaluate the relay performance. Reviewing the event data is a valuable maintenance tool. The event report shows the ac and dc signals the relay measures during the disturbance and also shows when the relay closes the circuit breaker trip contact. Analyzing the event data is more useful and accurate than simulated tests because the relay is responding to an actual system fault. Therefore, the true relay performance can be better evaluated. The event report can also show problems in control inputs and outputs. Analyzing the event reports can also provide valuable information leading to improvement in the overall protection scheme.[15]

CHAPTER-8

Conclusions and Scope for future work

Conclusions

The multifunctional relay has been implemented on the microprocessor. Results of the relay operation at various settings and standard characteristics are presented. The error in the time of tripping is due to the slow operation of the 12-bit ADC card and due to the error in LSB. It can be reduced by the use of high speed high bit high precision ADC cards. The combinations of the relays that are implemented are:

1. Over current and Earth fault relay
2. Over/Under voltage relay
3. Over current and Over/Under voltage relay
4. Over current, earth fault and Over/Under voltage relay
5. Over/Under Frequency relay
6. Over current, Earth fault, Over/Under voltage and Over/Under frequency relay

For over current and earth fault the characteristics implemented are Very Inverse, Extremely Inverse, definite time and Inverse Definite Minimum time. For Over/Under voltage and Over/Under frequency relay the characteristics implemented are Definite time and Inverse definite minimum time.

Electrical Power standard is used for generating harmonics. The relay is tested practically for the harmonics with respect to the fundamental wave.

Scope for future work

Recent advancements in protection of power system are using multi functional relays which are based on the processors. The number of functions implemented can be increased with the use of high speed processors. It can be best implemented on a Digital Signal Processor, since digital signal processor has MAC (Multiply and Accumulate in single instruction) dual port RAM's for read write modify in one machine cycle which are best for realizing filters and the total system of protection can be directly integrated to the SCADA.

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Appendix

PCI-9111 Series:
16-CH 12/16-Bit 100 kS/s Low Cost Multi-Function DAQ Card

Introduction:

ADLINK PCI-9111 series are 16-CH, 100 kS/s low cost multi-function DAQ card. The PCI-9111 series feature flexible configurations on analog inputs. A RC filter is implemented on each A/D input channel for user to attenuate or filter input signal. The PCI-9111 series provide analog inputs with 5 programmable input ranges for bipolar inputs. The PCI-9111 series also support automatic analog input scanning. PCI-9111DG provides 12-bit A/D resolution while PCI-9111HR provides 16-bit A/D resolution. The PCI-9111 series also feature 1-CH 12-bit analog output, 16-CH TTL digital inputs and 16-CH TTL digital outputs. ADLINK PCI-9111 series deliver cost-effective and reliable data acquisition capabilities, and is ideal for a broad variety of applications.

Features:

Supports a 32-bit 5 V PCI bus
12-bit A/D resolution (PCI-9111DG)
16-bit A/D resolution (PCI-9111HR)
16-CH single-ended analog inputs
Up to 100 kS/s sampling rate
On-board 1 k-sample A/D FIFO
Programmable gains of x1, x2, x4, x8, and x16
Bipolar analog input ranges
On-board low-pass filtering capability for
Analog inputs
Automatic analog inputs scanning
One 12-bit multiplying analog output

Operating Systems

- Windows 98/NT/2000/XP/2003
- Linux
- DOS

Recommended Software

- VB/VC++/BCB/Delphi
- DAQBench
- DAQCreator

Driver Support

16-CH TTL digital inputs and 16-CH TTL Digital outputs

4-CH TTL extended digital inputs and 4-CH TTL extended digital outputs

Compact, half-size PCB

- DAQ-MTLB for MATLAB
- DAQBOY for Windows
- PCIS-DASK for Windows
- PCIS-DASK/X for Linux

Specifications

Analog Input

Number of channels: 16 single-ended

Resolution

12 bits (PCI-9111DG)

16 bits (PCI-9111HR)

Conversion time: 8 µs

Maximum sampling rate: 100 kS/s

Input signal ranges (software programmable)

Input coupling: DC

Over voltage protection: continuous ±35 V

Input impedance: 10 MΩ

Trigger modes: software, pacer, and external trigger

(5 V/TTL compatible)

FIFO buffer size: 1 k samples

Data transfers: polling, interrupt

Gain	Input Range
	Bipolar
1	±10V
2	±5V
4	±2.5V
8	±1.25V
16	±0.625V

Accuracy

Gain	Accuracy
1,2	0.01% of FSR ± 1 LSB

4,8	0.02% of FSR ± 1 LSB
16	0.04% of FSR ± 1 LSB

Analog Output

Number of channels: 1 voltage outputs

Resolution: 12 bits

Output ranges (jumper selectable)

Output Range	
Bipolar	± 10V
Unipolar	± 5V

Output driving capacity: ±5 mA max

Settling time: 30 μs

Data transfers: programmed I/O

General Specifications

I/O connector

37-pin D-sub female

20-pin ribbon male x 2

Operating temperature: 0 to 60 °C

Storage temperature: -20 to 80 °C

Relative humidity: 5 to 95%, non condensing

Power requirements:

Device +5v	
PCI 9111	570mA typical

Dimensions (not including connectors)

175 mm x 107 mm

Digital I/O

Number of channels: 16 inputs and 16 outputs

Compatibility: 5 V/TTL

Data transfers: programmed I/O

LEM Module LA 50-P

Definition

The Lem Module LA 50-P is a current transducer for the electronic measurement of currents: DC,AC,IMPL...etc with galvanic isolation between the primary (high power) and the secondary (electronic) circuits.

Electrical Data:

Nominal Current I_N	: 50 A rms	
Measuring range	: 0 to ±70 A	
Measuring resistance :	R_m min.	R_m max
With ±15 V at ±50A max	: 50 ohm	100ohm
At ±70A max	: 50 ohm	70 ohm
Nominal analog output current:	50 mA	
Turns ratio	: 1:1000	
Overall accuracy at ±25°C	: ±0.5% of I_N	
Supply Voltage	: + and -15 V (±5%)	
Isolation	: between primary and secondary: 2kV rms/50Hz/1 min	

Accuracy-Dynamic performance

Zero offset current at ±25°C	: max. ±0.2mA
Thermal drift of offset current	: typical ±0.3mA
(between 0°C and +70°C)	: max ±0.6mA
Linearity	: better than 0.1%
Response time	: better than 1 μs
di/dt accurately followed	: better than 50A / μs
Bandwidth	: 0 to 150kHz (-1dB)