DETECTION OF FAULT LOCATION IN OVERHEAD TRANSMISSION LINE USING PSCAD

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation titled **"DETECTION OF FAULT LOCATION IN OVERHEAD TRANSMISSION LINE USING PSCAD"** in partial fulfillment of the requirement of award of Degree of Masters of Technology in **WATER RESOURCES DEVELOPMENT** (Electrical) submitted to the Department of Water Resource Development & Management, Indian Institute of Technology, Roorkee, India is an authentic record of my own work carried out during a period from July 2010 to June 2011 under the supervision of **Prof. Devadutta Das,** Professor in Department of Water Resource Development & Management, Indian Institute of Technology, Roorkee and **Dr. Barjeev Tyagi,** Assistant Professor in Department of Electrical Engineering, Indian Institute of Technology , Roorkee.

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

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Place: Roorkee

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CERTIFICATE

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

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ABSTRACT

Transmission lines at any voltage level are subject to faults. To expedite repairs and restoration of power, it is important to know the location of fault. With a view to achieve this objective a lot of methods have been developed to increase the accuracy. Several methods use voltage and current measurements to find the location of fault. In this method, fault detection technique based on the voltage synchronize method has been proposed. The proposed technique is based on bus voltage measurement of two terminal transmission lines. Advantages of the proposed technique are, the fault detection is independent from the fault resistance, and inception angle of the transmission line.

In the proposed method, fault voltage, pre fault voltage and post fault voltages are used to detect symmetrical and unsymmetrical fault. To determine these voltages, a Thevenin model of the transmission line has been developed. In the proposed technique, current has been eliminated in the problem formulation. Therefore in this technique the values of the current are not required. Another advantage of this method is non requirement of current transformer. There by eliminating the attendant issue of saturation of current transformer. The proposed technique has been tested on a 100 km transmission line. Simulation studies have been carried out using PSCAD and MATLAB software packages.

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CHAPTER 1

INTRODUCTION

1.1. General

The rapid growth of electrical power system observed over the last several decades has resulted in a large increase in the number of transmission lines in operation in the world. At the same time , free marketing and deregulation introduced all over the world imposes more and more restrictive requirements on providing a continuous and good quality power supply , without a significant increase in cost of energy being delivered .term such as the continuity of power supply , dependability and reliability play very important roles for contemporary power system. As a result of the imposed restrictive requirement, an increased demand on the high quality of power system protection and control devices together with their supplementary equipments has appeared as prime importance [1].

High voltage grids are constructed on nature basis joining all sources of power, thus enabling a most economical distribution power .transmission line thus grids have to cover large distribution between generating station and substation.

To ensure continuity and reliability of power supply, suitable protective measures are adopted against faults. Such faults are most effectively taken care of by using auto reclosing. In case of stabilized faults, the distance relay operates once again and trips the breakers finally. For efficient operation of system these faults should be located as soon as possible, one of the main advantages of inter connected system is that the spare plant is reduce to minimum .thus advantage would be impaired if the localization of faults could not be performed quickly in order to allow the faulty parts to be removed and the line to be made serviceable quickly. For locating the fault the engineers has to carry out a search operator. Such the lines are long and the damages are minor, the detection of fault point may turn out to be quite a tedious job. The matter is more completed in case of transient fault. Therefore any device which assists the location of fault point can be very useful and saving addition to the engineer's resources.

Transmission lines experience faults that are caused by storms, lighting, snow; short circuits caused by birds an other external object. Fault location techniques provide estimates for both sustained and transient faults. Generally, transient fault cause minor damage that is not easily visible on inspection. Fault location technique help identify these location for early repairs to prevent recurrence and consequent major damage.

Transmission lines at any voltage level are subject to faults. To expedite repairs and restoration of power, it is important to know where the fault is located. Due to this fact, a lot of methods offered to increase the accuracy and decrease cost of distance protection. The majority of offered methods use the measured voltages and currents of faulted system to develop the algorithm and fault location. But excluding ideal behavior of measurement devices and their influence from system conditions during the fault period, eliminating the dependence of fault location algorithm from some measurement devices (such as current transformer CT) can increase the process accuracy. Actually, the over voltage and transient state of power network during fault period, causes inappropriate operation of current transformers. So by these transformers the feeding relays might operate in saturate area in a short period of time and causes incorrect fault location. In addition, operation of current transformer in a saturate area is inevitable in bigger fault currents.

To solve this problem, many methods have been offered. But the problem of CT saturation and inaccurate measurement can increase the protection cost of transmission network. So, in spite of acceptable and high accuracy of these methods which use both of two parameters of the system (voltages and currents), developing the new methods separated from the current is needed for CT inherent problems.

A fault-location method utilizing synchronized measurements of two-end voltages only was proposed in **[2,3]**.By complete rejection of currents from the input signals, the fault location algorithm free from CT errors has been obtained.

Thus, these algorithms appear to be completely immune to CT saturation, which is an important advantage of them. On the other hand, the need for providing source impedances from both line ends appears as a particular limitation of this algorithm. This is so since a mismatch between the data provided and the actual source impedances may happen and thus the fault-location accuracy can be degraded. The algorithms from **[2, 3]** are formulated using a matrix description of the transmission network.

In **[4]**, several algorithms utilizing only the voltages, dispensing with current transformers and thus eliminating the errors caused by saturation of current transformers are presented. The algorithms are applicable to phase-to-ground faults, phase-to-phase faults, and phase-to-phase to-ground faults, thus not to three-phase balanced faults. The algorithms utilize unsynchronized fault voltage measurements from two ends of a line and do not require pre-fault data. Shunt capacitances of the line are fully considered, which is advantageous from the fault-location accuracy point of view.

In turn, in **[5]** Liao introduced an interesting fault-location approach for single-circuit lines utilizing only voltage measurements from one or two buses, which may be distant from the faulted line. An advantage of the bus-impedance matrix technique is utilized for that. With the addition of a fictitious bus where the fault occurs, the transfer impedances of this bus and other buses are revealed as a function of the fault location. It is shown in [5] that based on the relationship between the bus-voltage change due to the fault and the transfer impedance; the fault location can be derived. The shunt capacitance of the line is ignored first and then fully considered based on a distributed-parameter line model.

A method for locating faults on two-terminal transmission lines based on the fundamental components of fault and pre-fault voltage measured at the two ends of a transmission line has been introduced in **[6]**. This methodology allows one to establish a direct calculation procedure that is independent of fault and pre-fault currents, fault type, fault resistance(k), synchronization condition of register devices located on line ends, and pre-fault condition, either balanced or not. This is achieved by defining a new concept called the distance factor in relation to the circuit diagram of the transmission network for the incremental positive sequence.

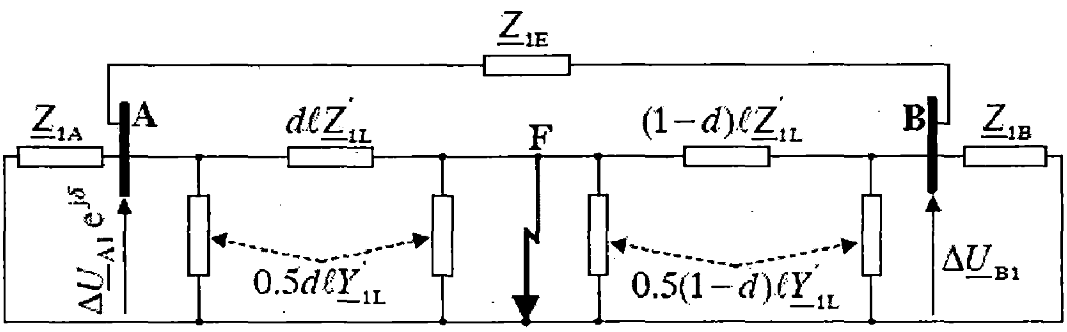

Fig.1.1 Equivalent circuit diagram for two-end unsynchronized measurement of Incremental positive sequence voltage

In the dissertation work the proposed method presents a technique based on voltage measurement of two terminal transmission lines. Advantages of the proposed technique are, the fault detection is independent of fault type, fault resistance and fault inception angle.

In the proposed method based upon the voltage measurement, the fault voltage, pre fault voltage and post fault voltages are used to determine the fault location. The problem of current transformer saturation and inaccurate measurement can increase the protection cost of transmission network. To find the location of fault with the help of voltages only, the current elimination is done in mathematical formulation. Therefore, the problem of current transformer saturation in system is automatically removed. Study is preformed on the thivenine model of faulted section on transmission line. The study has been carried out for three phase to ground fault, line to ground fault, double line to ground fault and three phase fault using Power System Computer Aided Design (PSCAD) and MATLAB softwares.

1.2. Organization of Thesis

The organization of thesis is as follows:

Chapter 1 gives a brief discussion about power system, problem occurring in the system and introduction of the proposed technique. In chapter 2 the overview of power system and literature review for the fault location detection has been discussed. In chapter 3 a brief discussion about PACAD & MATLAB has been given. Chapter 4 is the overview of current transformer and problem arises due to current saturation in system. Chapter 5 describes the proposed methodology and mathematical formulation. Chapter 6 shows the simulation results and some snapshots of output. Finally the conclusion has been discussed in Chapter 7.

CHAPTER 2

LITERATURE OVERVIEW

2.1. General

In power system for design the fault detector and application of fault detection techniques, it is very useful to have an idea of the frequency of occurrence of faults on various elements of a power system and the distance at which fault occurs. Usually the power stations are situated far away from the load canters, resulting in hundreds of kilometers length of overhead lines being exposed to atmospheric conditions.

Table.2.1 Percentage Distribution of Faults in Various Elements of Power System [7]

Element	% of total faults
Overhead lines	50
Underground cables	9
Transformers	10
Generators	7
Switchgears	12
CTs,PTs,Relays etc	12

2.2. Network Configuration and Model [7]

Specific features of lines used in contemporary power systems depend on many factors, such as their construction (overhead or cable, materials used and line geometry), voltage level (generally: high voltage or medium voltage), network configurations (single-circuit, double-circuit, two- or multi-terminal lines, tapped lines), reactance compensation (uncompensated or series compensated) and others. All these details should be taken into considerations when the network mathematical models for steady-state and transients are formulated.

2.3. Overhead Lines

Fault location in transmission networks is based on considering the flow of a fault current. Depending on the availability of measurements for the fault locator, the flow of a fault current within the faulted line itself or also in its vicinity is considered. A particular fault-location method has to be considered in strict relation to the configuration of the power network and its model.

2.3.1Single circuited overhead line:

Single-circuit three-phase overhead lines are the simplest means for transmitting power energy from the generation center to the consumption region. A schematic diagram of a power network with a single-circuit overhead line is presented in fig.2.1

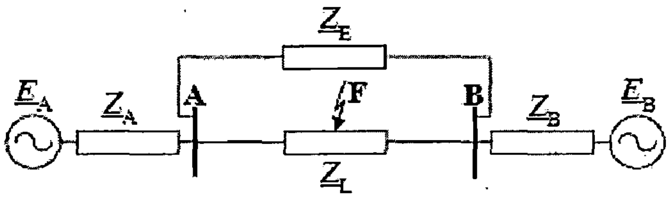

Fig.2.1 general equivalent scheme of single circuited overhead line

Since the load and generation in a power network as well as the network topology undergo changes, the equivalent network of the line external network also changes and is not fixed. As a result, the source impedances (ZA, ZB) are considered in the fault-location process to be the uncertain parameters. Therefore, the fault-location algorithms, which do not require that the source impedances be known, are generally more accurate than the algorithms for which this impedance data is used as the input data. The one-end fault-location algorithms require setting the source impedances and due to dynamic changes of the network it is difficult to provide the actual values of these impedances. Fortunately, in many applications it is sufficient to provide the representative values of the source impedances, which are obtained for the most typical conditions of the network operation. Possible mismatch between the provided representative source impedances and the actual parameters in many applications does not cause considerable errors in fault location. This is so especially in the case of strong sources, which is the case when the source impedance is much smaller than the line impedance.

2.4. Faults in Transmission Line

An electrical power system consisting of generators, transformers, transmission line, etc. short circuits and other abnormal conditions often occur on power system. The heavy current associated with short circuits is likely to cause damage to equipment if suitable protective relays and circuit breakers are not provided for the protection of each section of system. Some defects in power system, are also called fault

2.4.1. Types of Faults

In power system two broadly classification of faults [8] is:

1. Symmetrical faults
2. Unsymmetrical fault

2.4.1.1. Symmetrical Faults

A three phase fault is called a symmetrical type of fault. In a 3-phase fault, all the three phases are short circuited. There may be two situations –all the three phases may be short circuited to the ground or they may be short circuited without involving the ground. A 3-phase short circuit is generally treated as a standard fault to determine the system fault level.

2.4.1.2. Unsymmetrical Faults

Single phase to ground, two phase to ground, phase to phase short circuits, single phase open circuit and two phase open circuit are unsymmetrical types of faults.

2.4.1.2 a. Single Phase to Ground (L-G) Faults

A short circuit between any one of the phase conductors and earth is called a single phase to ground fault. It may be due to the failure of the insulation between a phase conductor and the earth, or due to a phase conductor breaking and falling to the ground.

2.4.1.2.b. Two Phases to Ground (2l-G) Faults

A short circuit between any two phases and earth is called a double line to ground or a two phase to ground fault.

2.4.1.2.c. Phase to Phase (L-L) Fault

A short circuit between any two phases is called a line to line or phase to phase fault.

2.4.1.3. Open Circuited Phases

This type of fault is caused by a break in the conducting path. Such faults occur when one or more phase conductors break or a cable joint or a joint on the overhead lines fails. Such situations may also arise when circuit breakers or isolators open but fail to close one or more phases. Due to the opening of one or two phases, unbalanced currents flow in the system, thereby heating rotating machines. Protective schemes must be provided to deal with such abnormal situations.

2.5. Protective Schemes Used In Power System [8]

A protective scheme is used to protect equipment or a section of the line. It includes one or more relays of the same of different types. The following are most common protective schemes which are usually used for modern power system.

1. Over current Protection
2. Distance Protection
3. Carrier Current Protection
4. Differential Protection

2.5.1. Distance Protection

Distance protection is used for the protection of transmission or sub transmission lines; usually 33kv, 66kv and 132kv lines. It includes a number of distance relays of the same or different types. A distance relay measures the distance between the relay location and point of fault in terms of impedance, reactance etc. The relay operates if the point of fault lies within the protected section of lines. There are various kinds of distance relays. Which are impedance, reactance and mho type .An impedance relay measures the line impedance between the fault point and relay location; a reactance relay measures reactance, and a mho relay measures a component of admittance.

2.5.2. Over Current Protection

This scheme of protection is used for the protection of distribution lines, large motors, equipments etc. it includes one or more over current relays .An over current relay operates when the current exceeds its pick up value.

2.5.3. Carrier Current Protection

This scheme of protection is used for the protection of EHV and UHV lines, generally 132 kv and above .A carrier signal in the range eg 500-500 kc/s is generated for the purpose .A transmitter and receiver are installed at each end of transmission line to be protected . Information regarding the direction of the fault current is transmitted from one end of line section to other.

2.5.4. Differential Protection

This scheme of protection is used for the protection of generators, transformer, motor etc. C.Ts are placed on both sides of each winding of machines. The outputs of their secondary are applied to the relay coils. The relay compares the current entering a machine winding and leaving the same. Thus the relay operates for internal faults and remains inoperative under normal conditions or during external faults. In case of zone protection, C.Ts are placed on the both side of the bus bar.

In order to detection the fault location by voltage measurement we have the different types of references which are briefly discussed below

2.6. Different Types of Methods to Detect the Fault Location [9]

2.6.1. Traditional Methodologies

Often faults are located without the use of any measurements. Location is simply made through physical indications, field methods, and brute force methods such as:

- Restoration through switching
- Restoration through recloser operation
- Indication through fuse and fault locator operation
- Downed wires, customer calls, maps
- Relay targets
- DC thumping of underground circuits
- Smelling burnt cables

2.6.2. Observant Technologies

The ability to collect data further improves upon the success of locating faults through such techniques as:

- Local detection with communications feedback.
- Fault was upstream or downstream
- Intelligent metering with modem, cellular-based devices, LOCATE-type devices
- Detectors sending feedback through SCADA
- Satellite-based location or carrier packages.
- Choice of passing on information to an "interpreter" (i.e., a person) or to an "interpretive device" (i.e., a substation HMI or DMS).
- Fault recorders

2.6.3. Intelligent Technologies

Due to complexity, intelligent technologies are being applied for distribution fault location. These include:

- Artificial intelligence, neural networks to "learn" system characteristics.
- Distributed intelligence in substations to pull together information for best guess, Confidence factors.

2.6.4. Modern Technologies

- Fault Location Principle Based On the Periodical Characteristic of Voltage Traveling.
- A new and accurate fault location algorithm for combined transmission lines using Adaptive Network-Based Fuzzy Inference System:

2.7. Briefly Study of Research Papers

In order to find out the fault location based upon the voltage synchronization, the study of several research papers is shown below:

Galijasevic et al [10] suggested a novel method for locating short-circuit faults in electric power systems. The origins of the method are in the concept of vulnerability contours which is used in assessing the likelihood of voltage sags effecting a given network area. The method is applied in an off-line step and an on-line step. On-line step consists of measuring voltage sags at selected system buses. Off-line step consists of estimating the most likely fault location by matching measured voltage sags with the ones calculated through the fault simulations. In the process, the fault resistance is estimated as well. To cope with the inherent uncertainty in the problem, the fuzzy logic reasoning is applied.

Morais Pereira et al [11] suggested a new algorithm for fault location in transmission lines, with fault distance calculation based on steady-state measured phasors in local terminal is presented. For the postfault, only voltage phasors are required, avoiding possible errors due to current transformer saturation; the current phasors are required only in prefault time, when saturation does not occur. The algorithm does not use simplifying hypothesis but requires system equivalent data at both line terminals and the fault classification, considering fault resistance purely resistive. In order to verify the algorithm performance, a parametric analysis of variables that influences short-circuit conditions is developed, including an analysis of remote equivalent setting. The results show that the algorithm is very accurate, even in cases when the remote equivalent is not well fitted.

Xia et al [12] suggested voltage data according to two phase-to-ground faults between Ge-Gang transmission line is processed using wavelet transformation, by which the exact inceptive traveling-waves can be obtained as well as the GPS time stamps and the fault distances by means of those GPS time stamps of two ends. The maximum error of fault location is less than 300m. Also, Equivalent circuit considering stray capacitance between primary and secondary windings is presented and discussed that the CVT voltage can be used in traveling-wave fault location.

Yongli et al [13] suggested method of fault location based on one-terminal transient voltage traveling waves is put forward. The transient process caused by breaker tripping contains the information about the fault distance. By measuring the period of voltage traveling waves induced by breaker tripping, fault distance can be obtained. Before giving the fault location principle, the model of breaker tripping is analyzed. The method was verified by EMTDC simulations

Bastard et al [14] suggested a conventional method to locate a fault in a radial network consists in placing current detectors along each feeder. The measured currents indicate if the fault is above or below each sensor. The fault section [l-51 can then be determined, manually or automatically, This method is efficient, at least for phase-to-earth or phase-to-phase faults, but it requires a significant number of sensors. The method proposed in this paper is not based on current measures, but on voltages measures located in MV/LV stations. This method may be particularly interesting if LV potential transformers are already available.

The method is divided into two steps.

1. The first one consists in determining whether each sensor is above or below the fault.
2. The second one consists in determining the fault section, from a purely topological method.

S.M. Brahma [15] suggested the method based upon the synchronized voltage measurements at both ends of lines., eliminating the inherent error due to CT. Accuracy of current measurement is limited by accuracy of the current transformers (CT) used. The method can be applied to transpose and untransposed lines. The method is tested using results from a steady state fault –analysis program and EMTP.

S.M. Brahma [16] again suggested a methodology which describes a new scheme to locate a fault on a multi-terminal transmission line. It describes a simple new algorithm to identify the faulted section first. Then, to exactly locate the fault on this section, a method is described that uses the synchronized voltage measurements at all terminals. The main advantage of this method is that the current-transformer errors in the current measurements can be avoided. Since these errors can be as high as 10%, the fault location is extremely accurate with this method. The scheme can work for transposed as well as untransposed lines and is free of pre fault conditions.

CHAPTER 3

INTRODUCTION ABOUT PSCAD AND MATLAB

3.1. PSCAD

3.1.1. Introduction [17]

PSCAD (Power Systems Computer Aided Design) is a powerful and flexible graphical user interface to the world-renowned, EMTDC solution engine. PSCAD enables the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment. Online plotting functions, controls and meters are also included, so that the user can alter system parameters during a simulation run, and view the results directly. PSCAD comes complete with a library of pre-programmed and tested models, ranging from simple passive elements and control functions, to more complex models, such as electric machines, FACTS devices, transmission lines and cables. If a particular model does not exist, PSCAD provides the flexibility of building custom models, either by assembling those graphically using existing models, or by utilizing an intuitively designed Design Editor.

The following are some common models found in systems studied using PSCAD:

- Resistors, inductors, capacitors
- Mutually coupled windings, such as transformers
- Frequency dependent transmission lines and cables (including the most accurate time domain line model in the world)
- Current and voltage sources
- Switches and breakers
- Protection and relaying
- Diodes, thyristors and GTOs
- Analog and digital control functions
- AC and DC machines, exciters, governors, stabilizers and inertial models
- Meters and measuring functions
- Generic DC and AC controls

- HVDC, SVC, and other FACTS controllers
- Wind source, turbines and governors

PSCAD, and its simulation engine EMTDC, have enjoyed close to 30 years of development, inspired by ideas and suggestions by its ever strengthening, worldwide user base. This development philosophy has helped to establish PSCAD as one of the most powerful and intuitive CAD software packages available.

3.1.2. Typical PSCAD Studied

The PSCAD user's spectrum includes engineers and scientists from utilities, manufacturers, consultants, and research and academic institutions. It is used in planning, operation, design, commissioning, preparing of tender specifications, teaching and research. The following are examples of types of studies routinely conducted using PSCAD:

Contingency studies of AC networks consisting of

- Rotating machines, exciters, governors, turbines, transformers, transmission lines, cables, and loads.
- Relay coordination.
- Transformer saturation effects.
- Insulation coordination of transformers, breakers and arrestors.
- Impulse testing of transformers.
- Sub-synchronous resonance (SSR) studies of networks with machines, transmission lines and HVDC systems.
- Evaluation of filter design and harmonic analysis.
- Control system design and coordination of FACTS and HVDC; including STATCOM, VSC, and cycloconverters.
- Optimal design of controller parameters.
- Investigation of new circuit and control concepts.
- Lightning strikes, faults or breaker operations.
- Investigate the pulsing effects of diesel engines and wind turbines on electric networks.

3.2. MATLAB

3.2.1. Introduction [18]

MATLAB is an interactive computer program that serves as a convenient "laboratory" for computations involving matrices. It provides easy access to matrix software developed by the LINPACK and EISPACK projects **[19-21]**. The capabilities range from standard tasks such as solving simultaneous linear equations and inverting matrices, through symmetric and non symmetric eigen value problems, to fairly sophisticated matrix tools such as the singular value decomposition. It is expected that one of MATLAB's primary uses will be in the classroom. It should be useful in introductory courses in applied linear algebra, as well as more advanced courses in numerical analysis, matrix theory, statistics and applications of matrices to other disciplines. In nonacademic settings, MATLAB can serve as a "desk calculator" for the quick solution of small problem involving matrices. The program is written in FORTRAN and is designed to be readily installed under any operating system which permits interactive execution of FORTRAN programs. The resources required are fairly modest. There are less than 7000 lines of FORTRAN source code, including the LINPACK and EISPACK subroutines used. With proper use of overlays, it is possible run the system on a minicomputer with only 32K bytes of memory. The size of the matrices that can be handled in MATLAB depends upon the amount of storage that is set aside when the system is compiled on a particular machine. We have found that an allocation of 5000 words for matrix elements is usually quite satisfactory. This provides room for several 20 by 20 matrices, for example. One implementation on a virtual memory system provides 100,000 elements. Since most of the algorithms used access memory in a sequential fashion, the large amount of allocated storage causes no difficulties.

In some ways, MATLAB resembles SPEAKEASY and, to a lesser extent, APL. All are interactive terminal languages that ordinarily accept single-line commands or statements, process them immediately, and print the results. All have arrays or matrices as principal data types. But for MATLAB, the matrix is the only data type (although scalars, vectors and text are special cases), the underlying system is portable and requires fewer resources, and the supporting subroutines are more powerful and, in some cases, have better numerical properties.

Together, LINPACK and EISPACK represent the state of the art in software for matrix computation. EISPACK is a package of over 70 FORTRAN subroutines for various matrix eigenvalue computations that are based for the most part on Algol procedures published by Wilkinson, Reinsch and their colleagues. LINPACK is a package of 40 FORTRAN subroutines (in each of four data types) for solving and analyzing simultaneous linear equations and related matrix problems. Since MATLAB is not primarily concerned with either execution time efficiency or storage savings, it ignores most of the special matrix properties that LINPACK and EISPACK subroutines use to advantage. Consequently, only 8 subroutines from LINPACK and 5 from EISPACK are actually involved.

In more advanced applications, MATLAB can be used in conjunction with other programs in several ways. It is possible to define new MATLAB functions and add them to the system. With most operating systems, it is possible to use the local _le system to pass matrices between MATLAB and other programs. MATLAB command and statement input can be obtained from a local instead of from the terminal. The most power and edibility is obtained by using MATLAB as a subroutine which is called by other programs. This study gives an overview of MATLAB from the user's point of view. Several extended examples involving data fitting, partial differential equations, eigenvalue sensitivity and 3
Other topics are included. A formal definition of the MATLAB language and an brief description of the parser and interpreter are given. The system was designed and programmed using techniques described by Wirth, implemented in non recursive, portable FORTRAN.

3.2.2. The MATLAB System

The MATLAB system consists of five main parts:

3.2.2.1. Development Environment

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files, and the search path.

3.2.2.2. The MATLAB Mathematical Function Library

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse [22], matrix eigenvalues, Bessel functions, and fast Fourier transforms.

3.2.2.3. The MATLAB Language

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create large and complex application programs.

3.2.2.4. Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

3.2.2.5. The MATLAB External Interfaces (API)

This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

CHAPTER 4

CURRENT TRANSFORMER SATURATION

4.1. Current Transformer

In electrical engineering, a current transformer (CT) is used for measurement of electric currents. Current transformers, together with voltage transformers (VT) (potential transformers (PT), are known as instrument transformers. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit. Current transformers are commonly used in metering and protective relays in the electrical power industry.

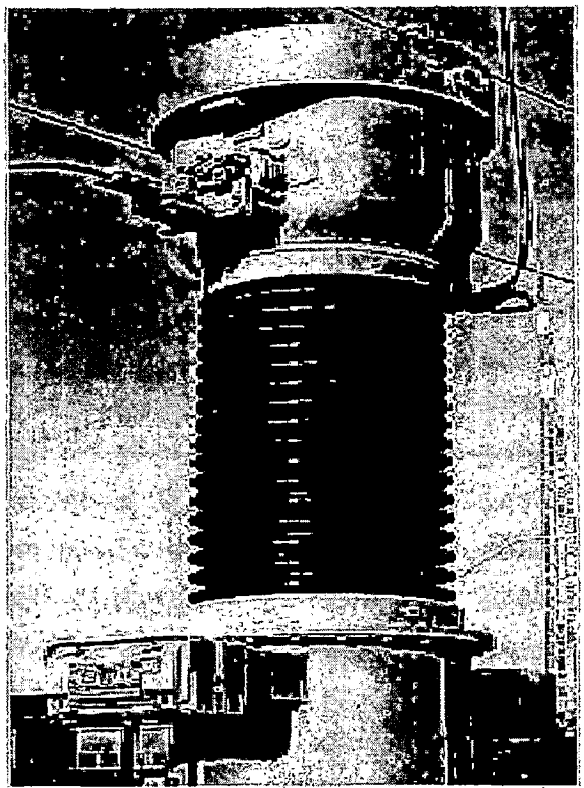

Fig.4.1 current transformer

4.2. Current Transformation Saturation

Power system has grown both in complexity and size, presenting increased levels of fault currents. Power system protective relays are playing an increasingly important role in the new power systems. They should clear system faults with a high degree of reliability and as fast as possible.

To be able to perform properly, they require reasonably accurate reproduction of the primary current and voltage signals during system faults. In this respect, current transformers (CTs) are employed to provide a reduced version of the primary current. Most CTs use iron core to maximize the flux linkage between primary and secondary windings. Iron-cored CTs, however, are not ideal because of the nonlinearity of their excitation characteristics and their ability to retain large flux levels in their cores known as remnant flux.

As a result, they are prone to saturation. Many studies on the analysis of steady-state and transient behavior of iron-cored CTs have been reported in following references [23]–[25]. It is well known that the exciting current drawn by the core increases far more rapidly for the points above the CT magnetization curve knee-point. If the CT flux increases beyond the knee-point, then the CT saturates. In this case, CT secondary current does not represent its primary current and the CT ratio error increases considerably. This could lead to the malfunction of the system protective relays.

4.2.1. Reviewing of Problems Occurs Due To C.T Saturation in Different Protection Schemes [26]

Regardless of the installed protection, differential protections are designed to respond very accurately in two extreme situations, namely:

- To provide a safe and fast operation for all faults in the protection area, which situation is characterized by a sensitivity index;
- To not operate upon faults or over currents outside the protected area, which situation is characterized by a steady-state (safety) index;

There are two generations of equipment in operation utilized to achieve the bus bar differential protection- the conventional equipment with electromagnetic braking and the modern one, manufactured using digital techniques.

The main characteristic features of differential protections, regardless of their manufacturing technology, are as follows:

The basic principle, which consists in calculating the sum of currents from the transformer secondaries in the protected area- which is the working current, as well as the sum of the modules of such values- which is the damped current;

Measures preventing the faulty operations resulting from the saturation of current transformers;

Measures to achieve the shortest release time possible;

Differential protections have to provide a higher adaptability, taking into account they can be under operational conditions very different from one case to another as regards:

- values of short circuit currents;
- technical characteristics of current transformers within the protection;
- characteristic features of the area to be protected;
- neutral treatment;

All types of protections meet such requirements without any problems, except for the bus bar differential protection that, in certain circumstances, cannot provide the steady-state coefficient for external short-circuits. The faulty situation is usually triggered by the saturation of current transformers during the transient short-circuit regime if they do not meet certain requirements. Thus, if the value of the short-circuit current is very high (short-circuit near the protected area), certain current transformers can saturate and the value shown in the secondary does not represent the accurate conversion of the value in the primary and therefore the differential protection can operate erroneously.

4.2.2. A Method Reviewing the Behaviour of the Current Transformer in a Transient Regime

The behaviour of the current transformer in a transient regime can be analyzed also using the simulation and the software methods, taking into account the aspects of the transformer operation. Mathematical modeling presupposes modeling the component parts if the characteristics of components are known.

The items that have to be very well known initially are as follows:

- value of the short-circuit current, time constant of the system, T1, conditioning the a-periodical component (possible to appreciate)
- type of current transformer,
- transformer ratio of the CT
- actual load of the winding;

The magnetising component is introduced in pairs (flow, current) and is a linear characteristic shown with saturation (first cases given further) and without it (last cases).

To illustrate the analysis method, a transformer is taken into consideration with the following rated values:

- nominal transformer ratio: 600/1A
- nominal capacity: 60 VA
- secondary internal strength: 5.35 ohm
- secondary internal reactance: 0.026 ohm

The factors that will be analyzed are as follows:

- Amplitude of the primary short-circuit current (actual value of the primary current under permanent failure regime)
- network constant
- Initial stage of the primary short-circuit current
- Value of the nominal transformer ratio of the current transformer
- Value and nature of the load in the secondary transformer circuit.

Table.4.1 Reviews of the current transformer behaviour under transient regime

Case	Iprim ef [A]	T network [s]	Phase [rad]	n_{TC}	$R_{sarc+TC}$ [ohm]	Magnetising characteristic
1.	3500	0.06	$\pi/2$	60	4	Linear with saturation
2.	3500	0.06	π	60	4	Linear with saturation
3.	7000	0.06	$\pi/2$	60	4	Linear with saturation
4.	7000	0.06	π	60	4	Linear with saturation
5.	3500	0.06	$\pi/2$	60	8	Linear with saturation
6.	3500	0.01	π	60	4	Linear with saturation
7.	3500	0.06	$\pi/2$	60	2	Linear with saturation
8.	3500	0.06	$\pi/2$	60	4	Linear without saturation
9.	3500	0.06	π	60	4	Linear without saturation
10.	7000	0.06	$\pi/2$	60	4	Linear without saturation
11.	7000	0.06	π	60	4	Linear without saturation
12.	3500	0.06	$\pi/2$	60	8	Linear without saturation
13.	3500	0.06	π	60	8	Linear without saturation

The curves obtained for the primary short-circuit current and for the current in the transformer secondary are given in figures shown in below

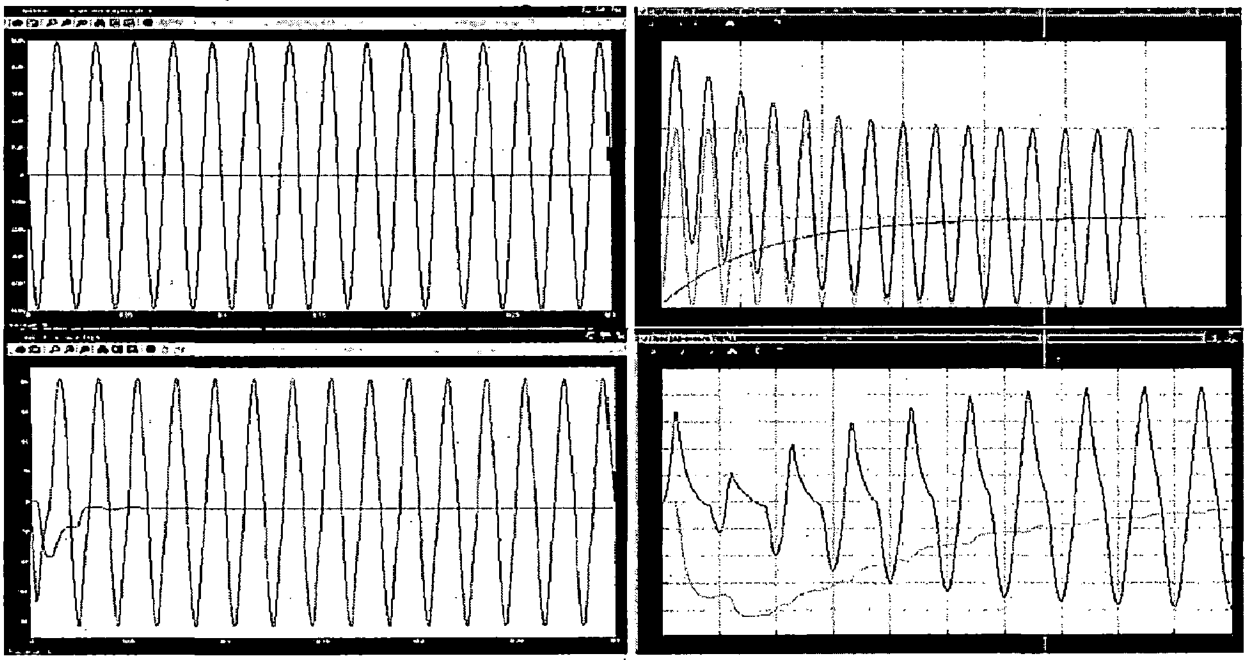

Fig. 4.2(a) and Fig 4.2(b) Analysis on the behaviour of current transformers

4.2.2.1. Conclusion from the Graph

A current transformer can operate with errors below 10% Fig 4.2(a) or over 10% fig 4.2(b) depending on the occurrence time of the short-circuit. In case the short-circuit does not occur in the peaking voltage time ($\Phi=\pi/2$), an important a-periodical component with a maximum value for ($\Phi=\pi$) overlaps on the symmetrical current component, and it is damped with the network time constant T=L/R from the source up to the faulty spot; the a-periodical component leads to the occurrence or enhancement of the current transformer saturation, which generates great errors in its operation.

4.3. Correction of Saturated Current Transformer Secondary Current Using ANNs [27]

Current transformers (CTs) provide instrument-level current signals to meters and protective relays. Protective relays accuracy and performance are directly related to steady-state and transient performance of CTs. CT saturation could lead to protective relay maloperation or even prevent tripping. In this method the use of an artificial neural networks scheme to correct CT secondary waveform distortions. The module uses samples of current signals to achieve the inverse transfer function of CT. Simulation studies are preformed and the influence of changing different parameters is studied. Performance studies results show that the proposed algorithm is accurate and reliable. The algorithm has also been implemented and tested on a digital signal processor board.

CHAPTER 5

VOLTAGE BASED FAULT DETECTION TECHNIQUE

5.1. Fault Analysis by Voltage

Due to the common problem of current transformer in distance protection of power system and as result increasing cost and reduction of protection accuracy ,the voltage based fault detection technique is used this method is independent of current measurement and mainly based on the transmission line terminals voltages measurement. In this method fault voltage, pre fault and post fault voltages at both end of line are measured synchronously and used to calculate fault location.

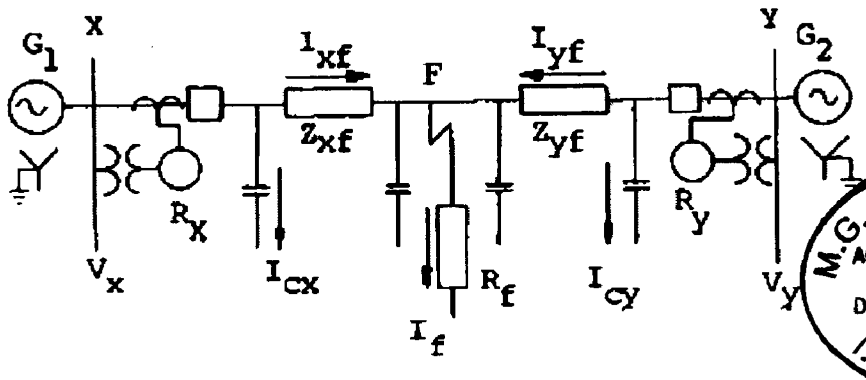

Fig. 5.1Single line diagram of balanced three phase system

5.2. Proposed Calculation

This method based on synchronized voltage measurement technique in order to identify the fault locations in two terminal transmission lines. Transmission lines at any voltage level are subject to faults. We have to analyze the fault voltage, pre fault voltage and post fault voltages data. Further, with the help of proposed equations we eliminate the current finally. The proposed equations are shown further.

5.2.1. Two Terminal Transmission Line

In two terminal transmission line if l_1 be the distance of fault location from sending end, l_2 the distance of fault from receiving end. To study of fault location, the requirement of fault time in needed at which fault is occurred. The time of fault i.e. t=0.2 sec, is find out by the PSCAD.

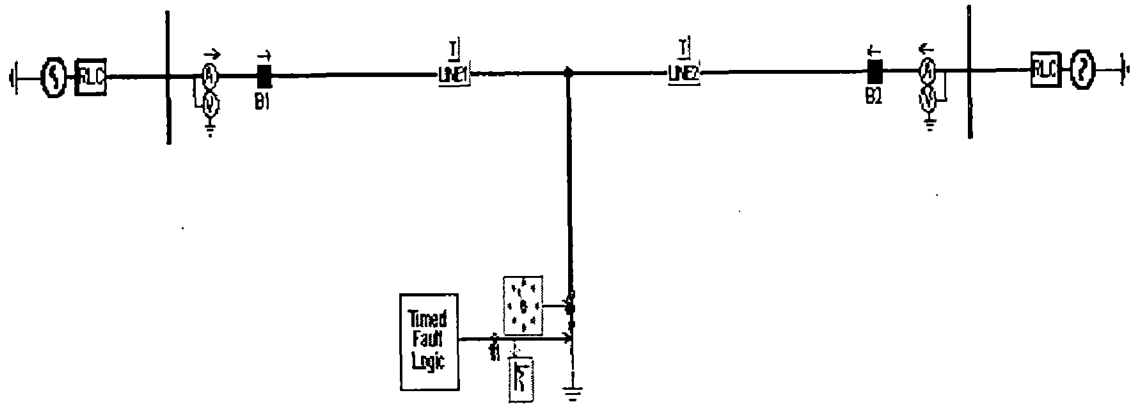

Fig 5.2 Single line diagram of two terminal transmission lines

A fault occurs at the point F. figure shows the faulted model in the terms of pre fault voltage and post fault voltage.

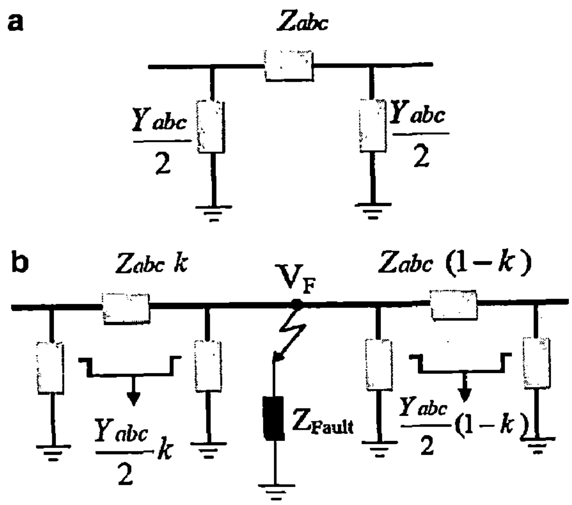

Fig 5.3(a) pre fault voltage and **Fig 5.3(b)** post fault voltage

According to Fig. 5.3(b) the transmission line is separated into two parts with distances of l_1 and l_2.

$$K=\frac{l1}{L} \quad , \quad (1\text{-}k)=\frac{l2}{L} \quad \ldots\ldots\ldots(1)$$

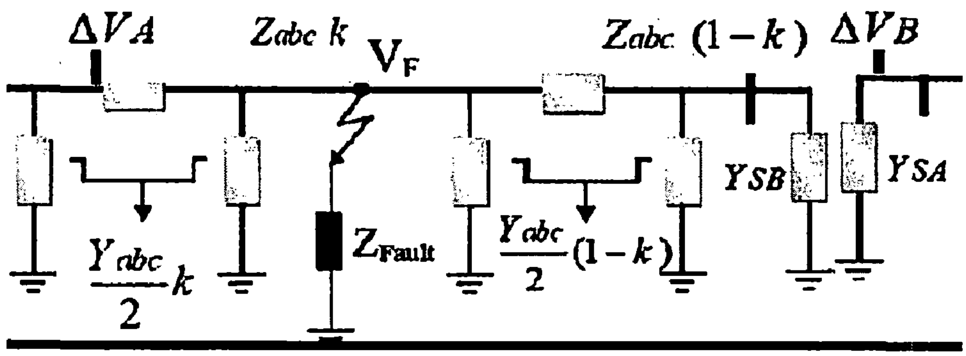

Fig.5.4Thevenin equivalent model

Fig 5.4 shows the Thevenin equivalent model of the faulted system. Bus voltages of the system vary between pre-fault and post-fault voltages. This variation is equal to post-fault voltages minus pre-fault voltages. The current in this network only includes the fault current. All parameters of **Fig 5.4** are in a three-phase form (abc).

PSCAD generates the Fault voltage (V_F), pre fault voltage post fault voltage and current data which are shown in **table.6.1** The implementation of these data also shown in MATLAB in result and analysis chapter the ΔVA and , ΔVB are known parameters data. So the system equations can be written as:

$$\text{IAabc}=\begin{bmatrix} iAa \\ IAb \\ IAc \end{bmatrix}, \qquad \text{IBabc}=\begin{bmatrix} IBa \\ IBb \\ IBc \end{bmatrix} \qquad ...(2)$$

$$\text{IAabc}=\left[YSAabc+\frac{Yabc*(k)}{2} \right]*\Delta VAabc \qquad ...(3.a)$$

$$\text{IBabc}=\left[YSBabc+\frac{Yabc*(1-k)}{2} \right]*\Delta VBabc \qquad ...(3.b)$$

By definition of matrix T as:

$$T=\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix}, \quad \alpha \equiv e^{\frac{2\pi}{3}i}$$

Eq. (3.a) and Eq. (3.b) can be transferred to symmetric components (zero, positive and negative sequences), as follow:

$$IA_{012}=\left[YSA012+\frac{Y012*(k)}{2}\right]*\Delta VA012$$

$$IB_{012}=\left[YSB012+\frac{Y012*(k)}{2}\right]*\Delta VB012\backslash \quad .....(5)$$

And fault–point voltage can be written as:

$VF_{abc}=Z_{abc}*IA_{abc}*k+\Delta VA_{abc}$

$VF_{abc}=Z_{abc}*IB_{abc}*(1\text{-}k)+\Delta VB_{abc}$ ....(6)

Eq. (6) is transformed to symmetric components as:

$VF_{012}=Z_{012}*IA_{012}*k+\Delta VA_{012}$

$VF_{012}=Z_{012}*IB_{012}*(1\text{-}k)+\Delta VB_{012}$ ......(7)

to derive independent equations of current, post fault conditions, substituting IA_{012} and IB_{012} from Eq. (5) into Eq. (7), we have:

$[I_{3x3}+kZ_{012}[YSA_{012}+Y_{012}/2*k]]$ $\Delta VA_{012}=[I_{3x3}+(1\text{-}k)Z_{012}[YSA_{012}+Y_{012}/2*(1\text{-}k)]]$ ΔVB_{012}

......(8

k can be obtained from Eq. (8) to achieve accurate fault-point distance. Eq. (8) can be modified as Eq. (9) and with complex coefficients as Eq. (10):

$Ak^2+bk+c=0$ '.....(9)

According the equation (9) k has two value. for the simplicity of equation we separate the coefficient of equation. (9) Which are shown below.

$[a]_{3x1}=Z_{012}Y_{012}/2[\Delta VA_{012} - \Delta VB_{012}]$ ....(10)

$[b]_{3x1}= Z_{012}[YSA_{012}\Delta VA_{012} + YSB_{012}\Delta YSB_{012}\Delta VB_{012}] + Z_{012}Y_{012}/2\Delta VB_{012}$ ....(11)

$[c]_{3x1}= [\Delta VA_{012} - \Delta VB_{012}] - Z_{012}[YSB_{012} + Y_{012}/2]\ \Delta VB_{012}$ .... (12)

After using the fault voltage, pre fault voltage and post fault voltages data, in to the MATLAB software, these coefficient can be easily calculated. And the results of simulation are shown in result and simulation chapter.

5.2.2. Conclusion

Finally according the equation (9), based upon the value of k the distance from sending end (l_1) is calculated by the equation shown below.

$$K= \frac{l1}{L} \quad , \quad (1\text{-}k)=\frac{l2}{L}$$

CHAPTER 6

RESULT AND SIMULATION

In the previous chapter the proposed technique and problem formulation part is shown. Now the output and implementation of parameters to find out the location of fault is shown below.

6.1. PSCAD/EMTP Based Output

Initially at no fault in the system PSCAD output and snapshots of voltage and current representation is shown below **fig 6.1.**

6.1.1. Initially at No Fault Level

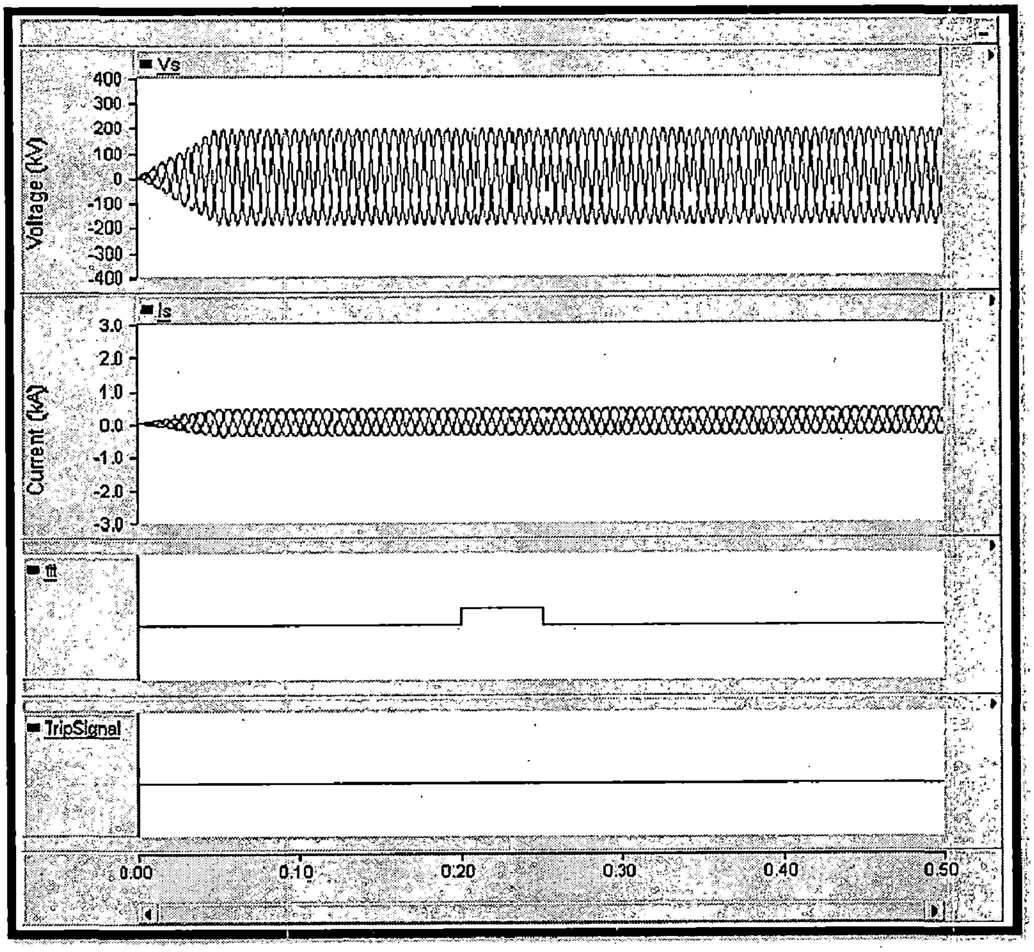

Fig 6.1 voltage and current response at no fault

At the time of fault i.e 0.2 sec, the results and snap shots of output of the Power System Computer Aided Design are shown in **fig 6.2**

Time to apply fault = 0.2 sec

Duration of fault = 0.05 sec

Fault type = external

6.1.2. Line to Ground Fault

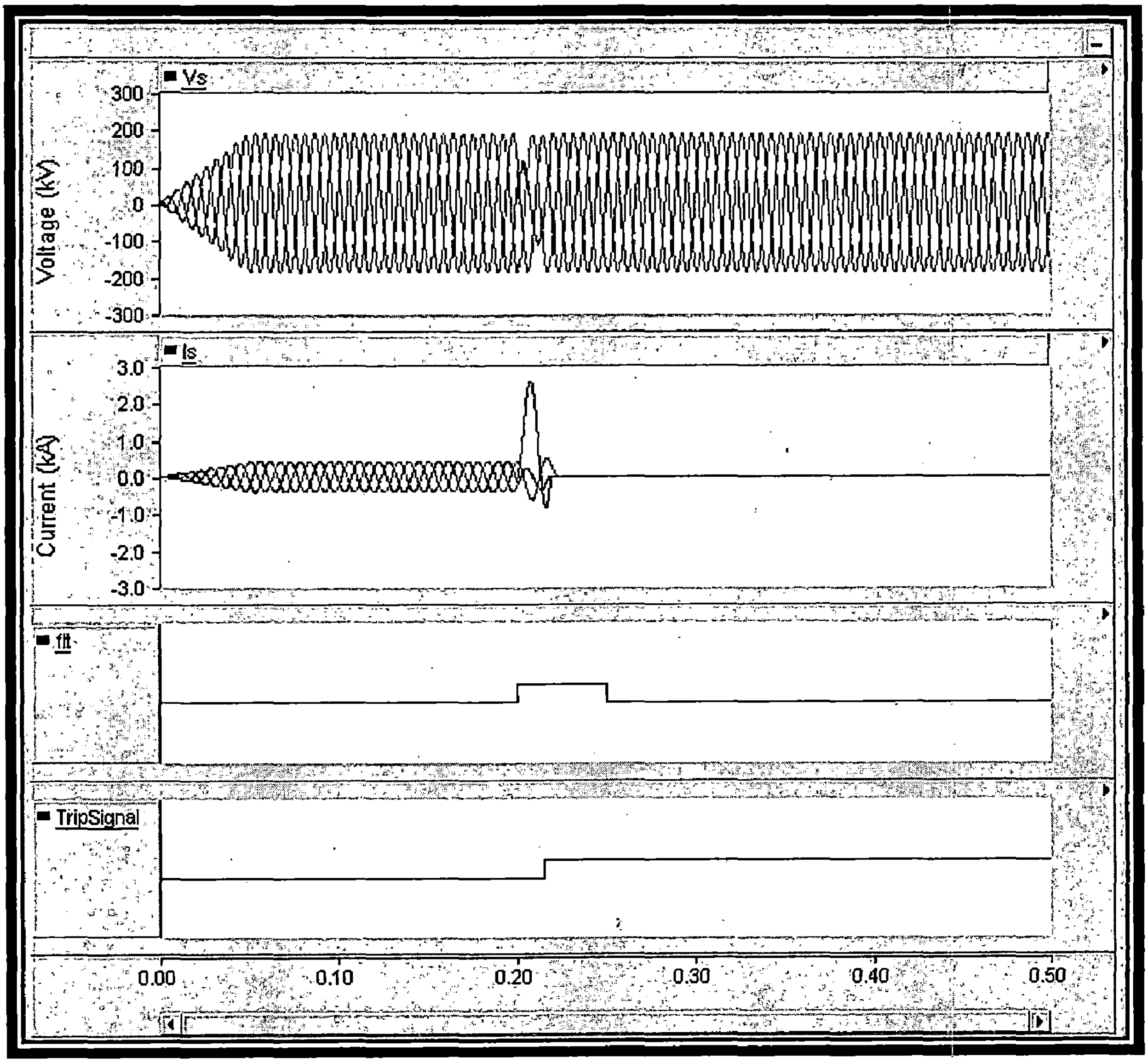

Fig.6.2 voltage and current response after fault (L-G)

6.1.3. Line to Line Fault

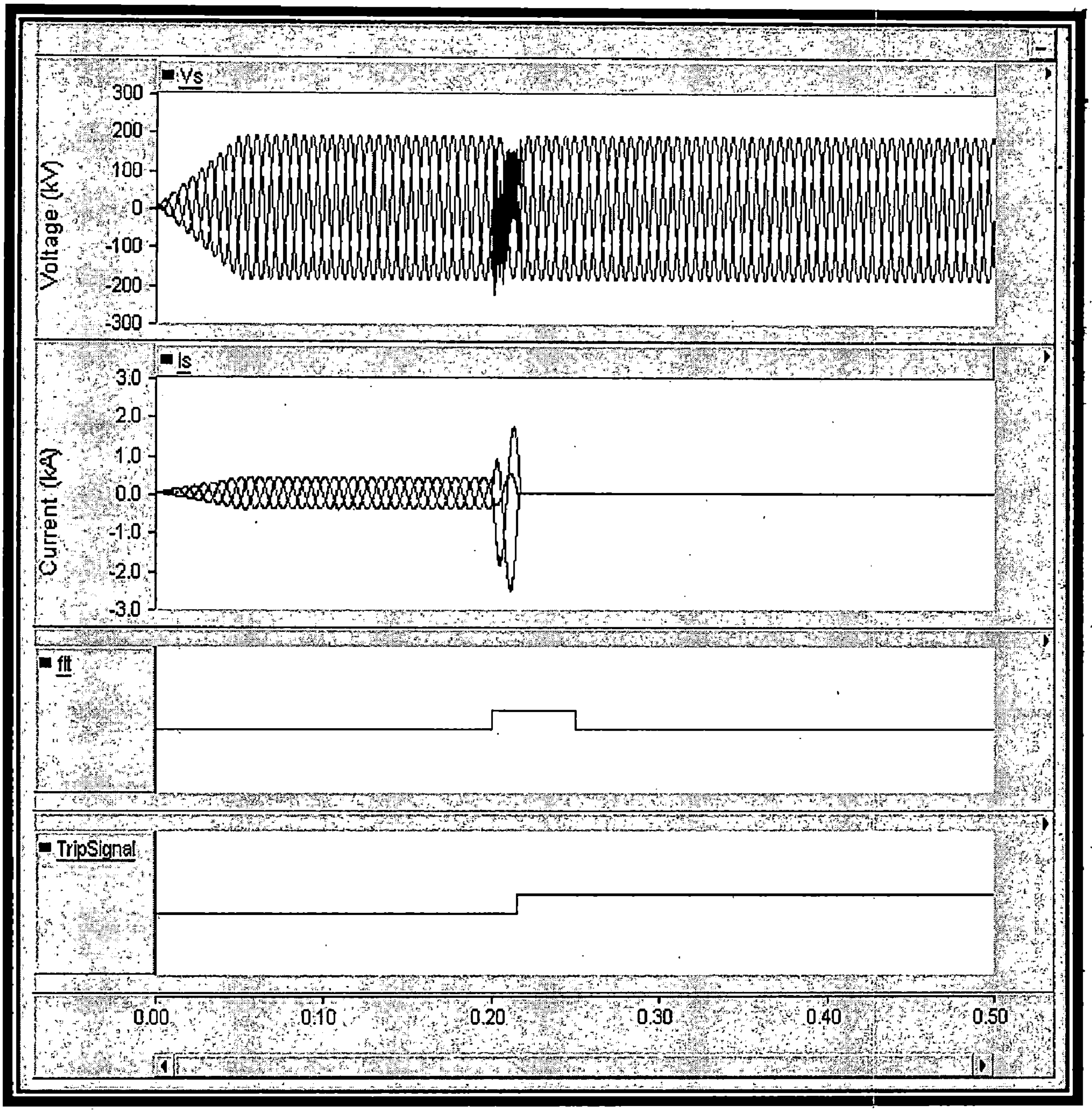

Fig.6.3 voltage and current response after fault (L-L)

6.1.4. Three Phase Fault

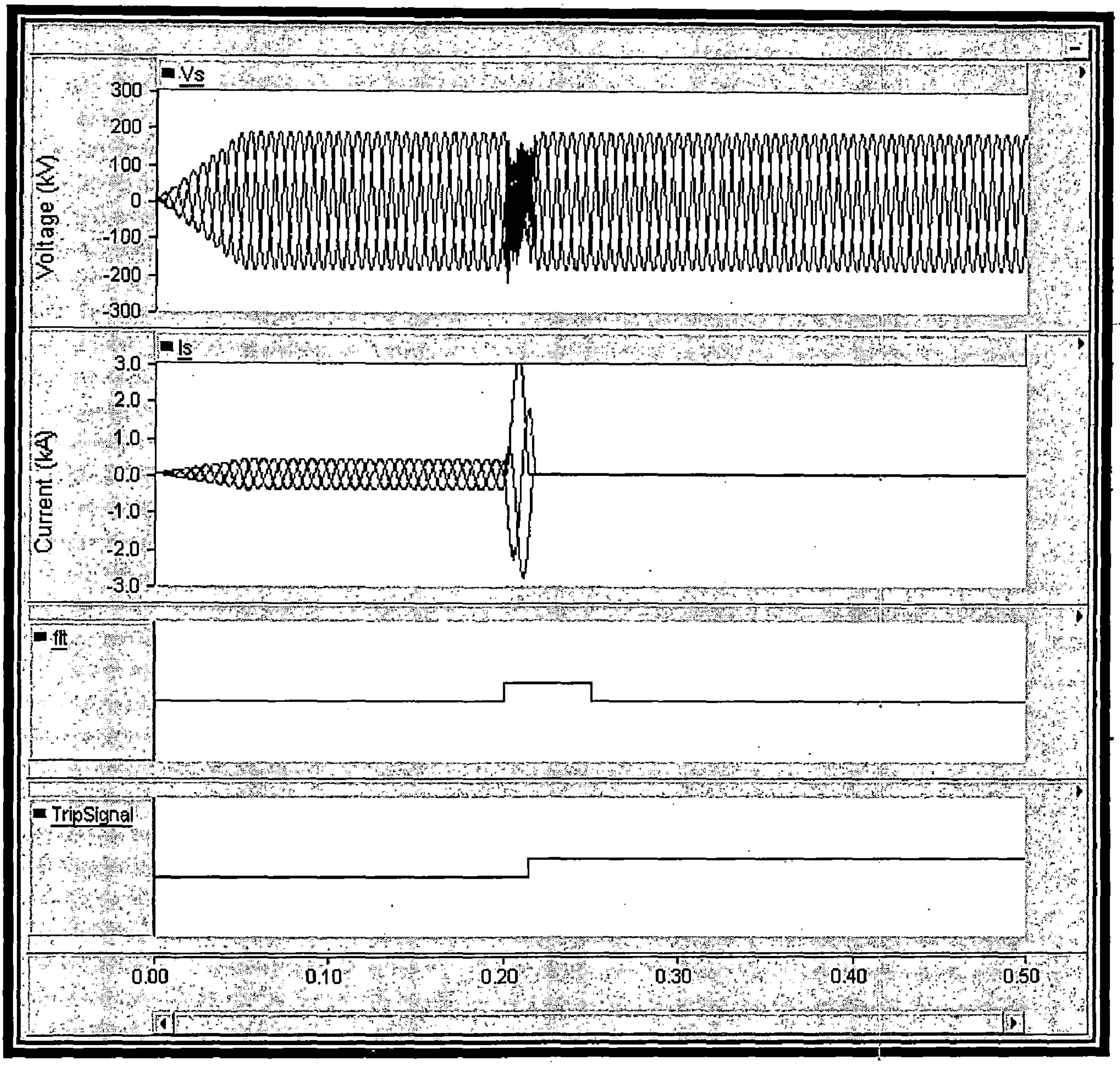

Fig.6.4 voltage and current response after fault (3-phase)

6.1.5. Double Line to Ground Fault

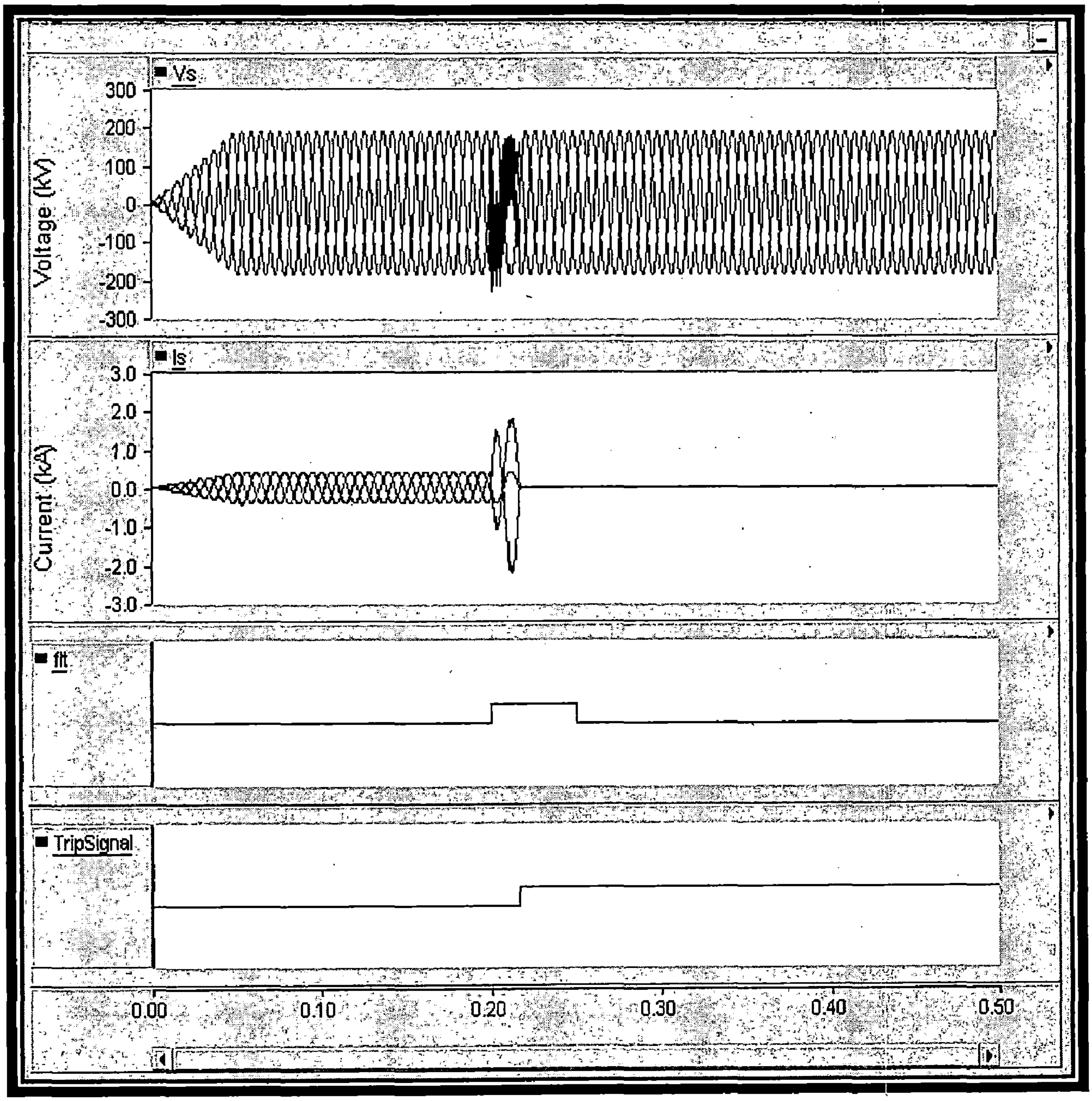

Fig.6.5 voltage and current response after fault (2L-G)

6.1.6. Three Phase to Ground Fault

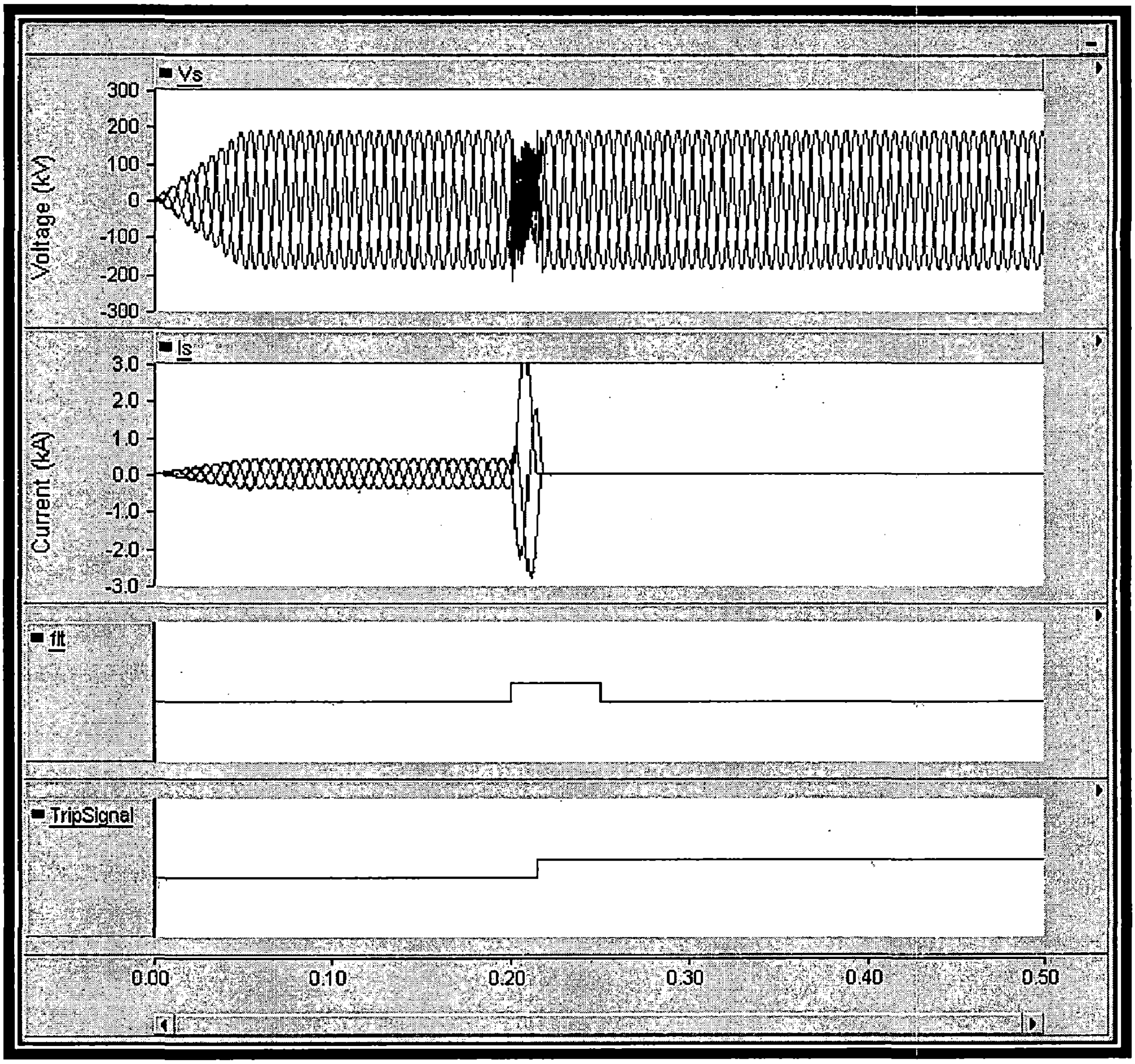

Fig.6.6 Voltage and current response after fault (3-phase to ground)

After that fault at t=0.2 sec the voltages and current data output in **table 6.1** and the MATLAB outputs are shown below :

Table 6.1 Voltage and Current Data

Time	fault	Va	Vb	Vc	Ia	Ib	Ic
0.1873	0.0000	187.6435	-90.5698	-97.0737	-0.4017	0.1508	0.2509
0.1875	0.0000	186.4592	-74.7054	-111.7537	-0.3944	0.1147	0.2798
0.1878	0.0000	183.6201	-58.1743	-125.4459	-0.3837	0.0775	0.3062
0.1880	0.0000	179.1501	-41.1203	-138.0298	-0.3696	0.0397	0.3299
0.1883	0.0000	173.0881	-23.6972	-149.3909	-0.3522	0.0016	0.3506
0.1885	0.0000	165.4888	-6.0652	-159.4236	-0.3317	-0.0366	0.3683
0.1888	0.0000	156.4212	11.6149	-168.0361	-0.3082	-0.0745	0.3827
0.1890	0.0000	145.9669	29.1864	-175.1533	-0.2820	-0.1117	0.3937
0.1893	0.0000	134.2184	46.4978	-180.7162	-0.2533	-0.1480	0.4012
0.1895	0.0000	121.2786	63.4006	-184.6792	-0.2223	-0.1828	0.4051
0.1898	0.0000	107.2611	79.7467	-187.0078	-0.1894	-0.2161	0.4055
0.1900	0.0000	92.2898	95.3883	-187.6781	-0.1548	-0.2475	0.4022
0.1903	0.0000	76.4987	110.1811	-186.6798	-0.1188	-0.2766	0.3954
0.1905	0.0000	60.0293	123.9903	-184.0196	-0.0817	-0.3034	0.3851
0.1908	0.0000	43.0287	136.6941	-179.7228	-0.0440	-0.3274	0.3713
0.1910	0.0000	25.6474	148.1843	-173.8317	-0.0058	-0.3485	0.3543
0.1913	0.0000	8.0383	158.3636	-166.4020	0.0324	-0.3665	0.3341
0.1915	0.0000	-9.6434	167.1430	-157.4995	0.0703	-0.3812	0.3109
0.1918	0.0000	-27.2411	174.4412	-147.2000	0.1076	-0.3926	0.2850
0.1920	0.0000	-44.5975	180.1884	-135.5909	0.1440	-0.4005	0.2566
0.1923	0.0000	-61.5572	184.3308	-122.7737	0.1790	-0.4049	0.2259
0.1925	0.0000	-77.9689	186.8329	-108.8641	0.2125	-0.4056	0.1931
0.1928	0.0000	-93.6875	187.6771	-93.9896	0.2441	-0.4028	0.1587
0.1930	0.0000	-108.5749	186.8600	-78.2852	0.2735	-0.3963	0.1228
0.1933	0.0000	-122.4999	184.3895	-61.8897	0.3005	-0.3864	0.0859
0.1935	0.0000	-135.3389	180.2841	-44.9451	0.3248	-0.3730	0.0482
0.1938	0.0000	-146.9770	174.5754	-27.5984	0.3463	-0.3563	0.0100
0.1940	0.0000	-157.3095	167.3118	-10.0024	0.3646	-0.3365	-0.0282
0.1943	0.0000	-166.2442	158.5598	7.6844	0.3798	-0.3136	-0.0661

0.1945	0.0000	-173.7025	148.4014	25.3012	0.3915	-0.2880	-0.1035
0.1948	0.0000	-179.6195	136.9304	42.6891	0.3998	-0.2598	-0.1400
0.1950	0.0000	-183.9436	124.2486	59.6949	0.4045	-0.2293	-0.1752
0.1953	0.0000	-186.6361	110.4650	76.1711	0.4057	-0.1968	-0.2089
0.1955	0.0000	-187.6721	95.6975	91.9746	0.4032	-0.1626	-0.2407
0.1958	0.0000	-187.0413	80.0757	106.9657	0.3972	-0.1269	-0.2703
0.1960	0.0000	-184.7490	63.7403	121.0087	0.3876	-0.0900	-0.2976
0.1963	0.0000	-180.8161	46.8407	133.9755	0.3746	-0.0524	-0.3223
0.1965	0.0000	-175.2790	29.5300	145.7490	0.3583	-0.0143	-0.3440
0.1968	0.0000	-168.1873	11.9612	156.2262	0.3388	0.0240	-0.3628
0.1970	0.0000	-159.6039	-5.7134	165.3173	0.3163	0.0620	-0.3783
0.1973	0.0000	-149.6037	-23.3409	172.9446	0.2910	0.0994	-0.3904
0.1975	0.0000	-138.2745	-40.7659	179.0404	0.2631	0.1360	-0.3991
0.1978	0.0000	-125.7168	-57.8311	183.5479	0.2328	0.1714	-0.4042
0.1980	0.0000	-112.0427	-74.3810	186.4237	0.2005	0.2052	-0.4058
0.1983	0.0000	-97.3749	-90.2661	187.6410	0.1664	0.2373	-0.4037
0.1985	0.0000	-81.8440	-105.3466	187.1906	0.1309	0.2672	-0.3981
0.1988	0.0000	-65.5875	-119.4922	185.0797	0.0941	0.2947	-0.3889
0.1990	0.0000	-48.7486	-132.5810	181.3296	0.0566	0.3197	-0.3763
0.1993	0.0000	-31.4760	-144.4972	175.9731	0.0185	0.3418	-0.3603
0.1995	0.0000	-13.9228	-155.1323	169.0551	-0.0197	0.3608	-0.3411
0.1998	0.0000	3.7543	-164.3880	160.6338	-0.0578	0.3767	-0.3189
0.2000	**1.0000**	**21.3972**	**-172.1803**	**150.7831**	**-0.0953**	**0.3892**	**-0.2939**
0.2003	1.0000	38.8490	-178.4414	139.5925	-0.1320	0.3983	-0.2663
0.2005	1.0000	55.9552	-183.1194	127.1642	-0.1675	0.4038	-0.2363
0.2008	1.0000	72.5652	-186.1758	113.6107	-0.2016	0.4058	-0.2042
0.2010	1.0000	88.5322	-187.5836	99.0514	-0.2338	0.4041	-0.1703
0.2013	1.0000	103.7143	-187.3272	83.6129	-0.2640	0.3989	-0.1349
0.2015	1.0000	117.9760	-185.4054	67.4294	-0.2918	0.3901	-0.0983
0.2018	1.0000	131.1897	-181.8338	50.6441	-0.3170	0.3778	-0.0608
0.2020	1.0000	143.2378	-176.6459	33.4081	-0.3395	0.3622	-0.0228
0.2023	1.0000	154.0140	-169.8913	15.8773	-0.3589	0.3434	0.0155
0.2025	1.0000	163.4236	-161.6325	-1.7911	-0.3751	0.3216	0.0536
0.2028	1.0000	171.3837	-151.9424	-19.4413	-0.3880	0.2968	0.0912
0.2030	1.0000	177.8235	-140.9041	-36.9194	-0.3975	0.2695	0.1280
0.2033	1.0000	182.6849	-128.6121	-54.0728	-0.4034	0.2398	0.1636
0.2035	1.0000	185.9238	-115.1748	-70.7491	-0.4057	0.2079	0.1979

0.2038	1.0000	187.5115	-100.7133	-86.7981	-0.4045	0.1742	0.2303
0.2040	1.0000	187.4344	-85.3595	-102.0748	-0.3996	0.1389	0.2607
0.2043	1.0000	185.6942	-69.2518	-116.4424	-0.3912	0.1024	0.2888
0.2045	1.0000	182.3068	-52.5323	-129.7745	-0.3794	0.0650	0.3144
0.2048	1.0000	177.3019	-35.3464	-141.9556	-0.3641	0.0270	0.3371
0.2050	1.0000	170.7232	-17.8437	-152.8795	-0.3457	-0.0112	0.3569
0.2053	1.0000	162.6282	-0.1791	-162.4491	-0.3241	-0.0493	0.3735
0.2055	1.0000	153.0887	17.4884	-170.5771	-0.2997	-0.0870	0.3867
0.2058	1.0000	142.1902	34.9987	-177.1889	-0.2727	-0.1239	0.3966
0.2060	1.0000	130.0302	52.1948	-182.2250	-0.2432	-0.1597	0.4029
0.2063	1.0000	116.7171	68.9251	-185.6423	-0.2115	-0.1941	0.4057
0.2065	1.0000	102.3686	85.0443	-187.4129	-0.1780	-0.2268	0.4048
0.2068	1.0000	87.1112	100.4117	-187.5228	-0.1429	-0.2575	0.4003
0.2070	1.0000	71.0796	114.8910	-185.9706	-0.1065	-0.2858	0.3923
0.2073	1.0000	54.4163	128.3513	-182.7676	-0.0692	-0.3117	0.3809
0.2075	1.0000	37.2699	140.6702	-177.9401	-0.0313	-0.3347	0.3660
0.2078	1.0000	19.7934	151.7371	-171.5305	0.0070	-0.3548	0.3479
0.2080	1.0000	2.1421	161.4552	-163.5973	0.0451	-0.3718	0.3267
0.2083	1.0000	-15.5277	169.7412	-154.2135	0.0829	-0.3854	0.3026
0.2085	1.0000	-33.0601	176.5236	-143.4635	0.1199	-0.3957	0.2758
0.2088	1.0000	-50.2999	181.7419	-131.4421	0.1558	-0.4024	0.2466
0.2090	1.0000	-67.0940	185.3475	-118.2536	0.1904	-0.4055	0.2151
0.2093	1.0000	-83.2925	187.3056	-104.0131	0.2233	-0.4051	0.1818
0.2095	1.0000	-98.7510	187.5980	-88.8470	0.2542	-0.4010	0.1469
0.2098	1.0000	-113.3321	186.2237	-72.8916	0.2828	-0.3934	0.1106
0.2100	1.0000	-126.9070	183.1977	-56.2908	0.3089	-0.3823	0.0734
0.2103	1.0000	-139.3558	178.5487	-39.1929	0.3323	-0.3678	0.0355
0.2105	1.0000	-150.5686	172.3174	-21.7487	0.3527	-0.3500	-0.0027
0.2108	1.0000	-160.4456	164.5564	-4.1109	0.3701	-0.3292	-0.0409
0.2110	1.0000	-168.8983	155.3324	13.5658	0.3841	-0.3054	-0.0787
0.2113	1.0000	-175.8510	144.7268	31.1243	0.3947	-0.2789	-0.1158
0.2115	1.0000	-181.2422	132.8354	48.4068	0.4018	-0.2499	-0.1519
0.2118	1.0000	-185.0244	119.7665	65.2579	0.4053	-0.2187	-0.1866
0.2120	1.0000	-187.1649	105.6375	81.5274	0.4053	-0.1856	-0.2197
0.2123	1.0000	-187.6449	90.5729	97.0720	0.4016	-0.1508	-0.2508
0.2125	1.0000	-186.4598	74.7039	111.7559	0.3944	-0.1147	-0.2797
0.2128	1.0000	-183.6195	58.1693	125.4501	0.3837	-0.0775	-0.3061

0.2130	1.0000	-179.1486	41.1158	138.0328	0.3696	-0.0397	-0.3298
0.2133	1.0000	-173.0869	23.6967	149.3902	0.3522	-0.0015	-0.3506
0.2135	1.0000	-165.4887	6.0689	159.4198	0.3316	0.0367	-0.3683
0.2138	1.0000	-156.4223	-11.6099	168.0322	0.3082	0.0745	-0.3827
0.2140	1.0000	-145.9682	-29.1840	175.1522	0.2820	0.1117	-0.3937
0.2143	1.0000	-134.2188	-46.4998	180.7186	0.2532	0.1479	-0.4012
0.2145	1.0000	-121.2778	-63.4054	184.6832	0.2223	0.1828	-0.4051
0.2148	1.0000	-107.2596	-79.7506	187.0102	0.1893	0.2161	-0.4055
0.2150	1.0000	-92.2888	-95.3882	187.6769	0.1547	0.2475	-0.4022
0.2153	1.0000	-76.4988	-110.1772	186.6760	0.1187	0.2766	-0.3954
0.2155	1.0000	-60.0304	-123.9857	184.0161	0.0817	0.3034	-0.3851
0.2158	1.0000	-43.0298	-136.6924	179.7222	0.0439	0.3274	-0.3713
0.2160	1.0000	-25.6476	-148.1868	173.8344	0.0058	0.3485	-0.3543
0.2163	1.0000	-8.0374	-158.3683	166.4057	-0.0324	0.3665	-0.3341
0.2165	1.0000	9.6448	-167.1462	157.5014	-0.0703	0.3812	-0.3109
0.2168	1.0000	27.2420	-174.4405	147.1985	-0.1076	0.3926	-0.2850
0.2170	1.0000	44.5972	-180.1844	135.5872	-0.1440	0.4005	-0.2566
0.2173	1.0000	61.5560	-184.3267	122.7706	-0.1790	0.4049	-0.2258
0.2175	1.0000	77.9678	-186.8318	108.8640	-0.2125	0.4056	-0.1931
0.2178	1.0000	93.6874	-187.6799	93.9925	-0.2441	0.4028	-0.1587
0.2180	1.0000	108.5758	-186.8645	78.2887	-0.2735	0.3963	-0.1228
0.2183	1.0000	122.5012	-184.3922	61.8910	-0.3005	0.3864	-0.0859
0.2185	1.0000	135.3396	-180.2829	44.9433	-0.3248	0.3730	-0.0482
0.2188	1.0000	146.9766	-174.5714	27.5948	-0.3463	0.3563	-0.0100
0.2190	1.0000	157.3084	-167.3081	9.9998	-0.3647	0.3365	0.0282
0.2193	1.0000	166.2433	-158.5593	-7.6841	-0.3798	0.3136	0.0662
0.2195	1.0000	173.7026	-148.4044	-25.2982	-0.3915	0.2880	0.1035
0.2198	1.0000	179.6205	-136.9346	-42.6860	-0.3998	0.2598	0.1400
0.2200	1.0000	183.9448	-124.2507	-59.6941	-0.4046	0.2293	0.1752
0.2203	1.0000	186.6366	-110.4634	-76.1732	-0.4057	0.1968	0.2089
0.2205	1.0000	187.6716	-95.6936	-91.9780	-0.4033	0.1626	0.2407
0.2208	1.0000	187.0403	-80.0725	-106.9678	-0.3972	0.1269	0.2704
0.2210	1.0000	184.7482	-63.7403	-121.0079	-0.3877	0.0900	0.2976
0.2213	1.0000	180.8163	-46.8439	-133.9725	-0.3747	0.0524	0.3223
0.2215	1.0000	175.2800	-29.5338	-145.7462	-0.3583	0.0143	0.3441
0.2218	1.0000	168.1884	-11.9627	-156.2257	-0.3388	-0.0239	0.3628
0.2220	1.0000	159.6042	5.7154	-165.3196	-0.3163	-0.0620	0.3783

0.2223	1.0000	149.6031	23.3447	-172.9479	-0.2910	-0.0994	0.3904
0.2225	1.0000	138.2735	40.7686	-179.0421	-0.2631	-0.1360	0.3991
0.2228	1.0000	125.7162	57.8306	-183.5468	-0.2328	-0.1714	0.4042
0.2230	1.0000	112.0430	74.3777	-186.4208	-0.2005	-0.2052	0.4058
0.2233	1.0000	97.3759	90.2627	-187.6385	-0.1664	-0.2373	0.4037
0.2235	1.0000	81.8449	105.3456	-187.1905	-0.1309	-0.2672	0.3981
0.2238	1.0000	65.5877	119.4944	-185.0821	-0.0942	-0.2947	0.3889
0.2240	1.0000	48.7480	132.5846	-181.3326	-0.0566	-0.3197	0.3763
0.2243	1.0000	31.4750	144.4994	-175.9744	-0.0185	-0.3418	0.3603
0.2245	1.0000	13.9223	155.1314	-169.0537	0.0197	-0.3608	0.3411
0.2248	1.0000	-3.7538	164.3848	-160.6309	0.0577	-0.3767	0.3190
0.2250	1.0000	-21.3962	172.1772	-150.7811	0.0953	-0.3892	0.2939
0.2253	1.0000	-38.8481	178.4409	-139.5928	0.1320	-0.3983	0.2663
0.2255	1.0000	-55.9552	183.1218	-127.1667	0.1675	-0.4038	0.2363
0.2258	1.0000	-72.5659	186.1793	-113.6134	0.2015	-0.4058	0.2042
0.2260	1.0000	-88.5331	187.5853	-99.0523	0.2338	-0.4041	0.1703
0.2263	1.0000	-103.7147	187.3259	-83.6113	0.2640	-0.3989	0.1349
0.2265	1.0000	-117.9755	185.4021	-67.4266	0.2918	-0.3901	0.0983
0.2268	1.0000	-131.1887	181.8311	-50.6424	0.3170	-0.3778	0.0608
0.2270	1.0000	-143.2371	176.6458	-33.4088	0.3395	-0.3622	0.0228
0.2273	1.0000	-154.0140	169.8939	-15.8798	0.3589	-0.3434	-0.0155
0.2275	1.0000	-163.4243	161.6357	1.7886	0.3751	-0.3216	-0.0535
0.2278	1.0000	-171.3845	151.9437	19.4408	0.3880	-0.2968	-0.0912
0.2280	1.0000	-177.8237	140.9025	36.9212	0.3975	-0.2695	-0.1280
0.2283	1.0000	-182.6843	128.6090	54.0753	0.4034	-0.2397	-0.1636
0.2285	1.0000	-185.9229	115.1725	70.7504	0.4057	-0.2079	-0.1978
0.2288	1.0000	-187.5109	100.7136	86.7972	0.4045	-0.1742	-0.2303
0.2290	1.0000	-187.4345	85.3622	102.0724	0.3996	-0.1389	-0.2607
0.2293	1.0000	-185.6949	69.2547	116.4402	0.3912	-0.1024	-0.2888
0.2295	1.0000	-182.3075	52.5331	129.7743	0.3794	-0.0650	-0.3144
0.2298	1.0000	-177.3020	35.3446	141.9574	0.3641	-0.0270	-0.3371
0.2300	1.0000	-170.7225	17.8407	152.8819	0.3457	0.0112	-0.3569
0.2303	1.0000	-162.6273	0.1772	162.4501	0.3241	0.0493	-0.3735
0.2305	1.0000	-153.0882	-17.4877	170.5759	0.2997	0.0870	-0.3867
0.2308	1.0000	-142.1904	-34.9960	177.1865	0.2727	0.1239	-0.3966
0.2310	1.0000	-130.0310	-52.1922	182.2232	0.2432	0.1597	-0.4029
0.2313	1.0000	-116.7177	-68.9247	185.6424	0.2115	0.1941	-0.4056

0.2315	1.0000	-102.3686	-85.0463	187.4148	0.1780	0.2268	-0.4048
0.2318	1.0000	-87.1105	-100.4145	187.5250	0.1429	0.2575	-0.4003
0.2320	1.0000	-71.0788	-114.8925	185.9713	0.1065	0.2858	-0.3923
0.2323	1.0000	-54.4159	-128.3503	182.7663	0.0692	0.3117	-0.3808
0.2325	1.0000	-37.2702	-140.6676	177.9378	0.0312	0.3347	-0.3660
0.2328	1.0000	-19.7941	-151.7349	171.5290	-0.0070	0.3548	-0.3479
0.2330	1.0000	-2.1427	-161.4551	163.5978	-0.0451	0.3718	-0.3267
0.2333	1.0000	15.5278	-169.7432	154.2154	-0.0829	0.3854	-0.3026
0.2335	1.0000	33.0607	-176.5262	143.4654	-0.1199	0.3957	-0.2758
0.2338	1.0000	50.3006	-181.7431	131.4424	-0.1558	0.4024	-0.2465
0.2340	1.0000	67.0942	-185.3463	118.2521	-0.1904	0.4055	-0.2151
0.2343	1.0000	83.2921	-187.3030	104.0109	-0.2233	0.4051	-0.1818
0.2345	1.0000	98.7503	-187.5961	88.8458	-0.2542	0.4010	-0.1469
0.2348	1.0000	113.3317	-186.2239	72.8922	-0.2828	0.3934	-0.1106
0.2350	1.0000	126.9072	-183.1999	56.2927	-0.3089	0.3823	-0.0734
0.2353	1.0000	139.3565	-178.5511	39.1946	-0.3323	0.3678	-0.0355
0.2355	1.0000	150.5693	-172.3181	21.7488	-0.3528	0.3500	0.0027
0.2358	1.0000	160.4457	-164.5550	4.1093	-0.3701	0.3292	0.0409
0.2360	1.0000	168.8978	-155.3300	-13.5679	-0.3841	0.3054	0.0787
0.2363	1.0000	175.8504	-144.7252	-31.1252	-0.3947	0.2789	0.1158
0.2365	1.0000	181.2419	-132.8359	-48.4060	-0.4018	0.2499	0.1519
0.2368	1.0000	185.0247	-119.7687	-65.2560	-0.4053	0.2187	0.1866
0.2370	1.0000	187.1656	-105.6396	-81.5260	-0.4053	0.1856	0.2197
0.2373	1.0000	187.6455	-90.5733	-97.0722	-0.4016	0.1508	0.2508
0.2375	1.0000	186.4599	-74.7023	-111.7575	-0.3944	0.1147	0.2797
0.2378	1.0000	183.6190	-58.1670	-125.4520	-0.3837	0.0775	0.3062
0.2380	1.0000	179.1480	-41.1146	-138.0334	-0.3696	0.0397	0.3299
0.2383	1.0000	173.0866	-23.6974	-149.3892	-0.3522	0.0015	0.3506
0.2385	1.0000	165.4891	-6.0711	-159.4180	-0.3316	-0.0367	0.3683
0.2388	1.0000	156.4229	11.6081	-168.0310	-0.3082	-0.0745	0.3827
0.2390	1.0000	145.9687	29.1839	-175.1526	-0.2820	-0.1117	0.3937
0.2393	1.0000	134.2188	46.5015	-180.7203	-0.2532	-0.1479	0.4012
0.2395	1.0000	121.2773	63.4076	-184.6849	-0.2223	-0.1828	0.4051
0.2398	1.0000	107.2591	79.7515	-187.0106	-0.1894	-0.2161	0.4055
0.2400	1.0000	92.2886	95.3872	-187.6758	-0.1547	-0.2475	0.4022
0.2403	1.0000	76.4992	110.1751	-186.6743	-0.1188	-0.2766	0.3954
0.2405	1.0000	60.0310	123.9841	-184.0151	-0.0817	-0.3034	0.3851

0.2408	1.0000	43.0303	136.6925	-179.7228	-0.0439	-0.3274	0.3713
0.2410	1.0000	25.6476	148.1885	-173.8361	-0.0058	-0.3485	0.3543
0.2413	1.0000	8.0369	158.3703	-166.4072	0.0324	-0.3665	0.3341
0.2415	1.0000	-9.6453	167.1468	-157.5015	0.0703	-0.3813	0.3109
0.2418	1.0000	-27.2420	174.4393	-147.1973	0.1076	-0.3926	0.2850
0.2420	1.0000	-44.5968	180.1824	-135.5856	0.1440	-0.4005	0.2566
0.2423	1.0000	-61.5554	184.3253	-122.7699	0.1790	-0.4049	0.2258
0.2425	1.0000	-77.9675	186.8322	-108.8647	0.2125	-0.4056	0.1931
0.2428	1.0000	-93.6875	187.6816	-93.9941	0.2441	-0.4028	0.1587
0.2430	1.0000	-108.5763	186.8662	-78.2899	0.2735	-0.3963	0.1228
0.2433	1.0000	-122.5016	184.3925	-61.8910	0.3005	-0.3864	0.0859
0.2435	1.0000	-135.3396	180.2816	-44.9420	0.3248	-0.3730	0.0482
0.2438	1.0000	-146.9761	174.5694	-27.5933	0.3463	-0.3563	0.0100
0.2440	1.0000	-157.3078	167.3071	-9.9993	0.3646	-0.3365	-0.0282
0.2443	1.0000	-166.2431	158.5598	7.6832	0.3798	-0.3136	-0.0661
0.2445	1.0000	-173.7028	148.4061	25.2966	0.3915	-0.2880	-0.1035
0.2448	1.0000	-179.6210	136.9361	42.6849	0.3998	-0.2598	-0.1400
0.2450	1.0000	-183.9451	124.2508	59.6943	0.4046	-0.2293	-0.1752
0.2453	1.0000	-186.6365	110.4621	76.1745	0.4057	-0.1968	-0.2089
0.2455	1.0000	-187.6712	95.6918	91.9794	0.4033	-0.1626	-0.2407
0.2458	1.0000	-187.0398	80.0717	106.9681	0.3972	-0.1269	-0.2704
0.2460	1.0000	-184.7480	63.7410	121.0070	0.3877	-0.0900	-0.2976
0.2463	1.0000	-180.8166	46.8456	133.9710	0.3747	-0.0524	-0.3223
0.2465	1.0000	-175.2804	29.5351	145.7453	0.3583	-0.0143	-0.3440
0.2468	1.0000	-168.1887	11.9626	156.2261	0.3388	0.0239	-0.3628
0.2470	1.0000	-159.6041	-5.7168	165.3209	0.3163	0.0620	-0.3783
0.2473	1.0000	-149.6027	-23.3464	172.9490	0.2910	0.0994	-0.3904
0.2475	1.0000	-138.2731	-40.7692	179.0422	0.2631	0.1360	-0.3991
0.2478	1.0000	-125.7160	-57.8297	183.5458	0.2328	0.1714	-0.4042

6.2. MATLAB Outputs

6.2.1. Fault Voltage Data Output

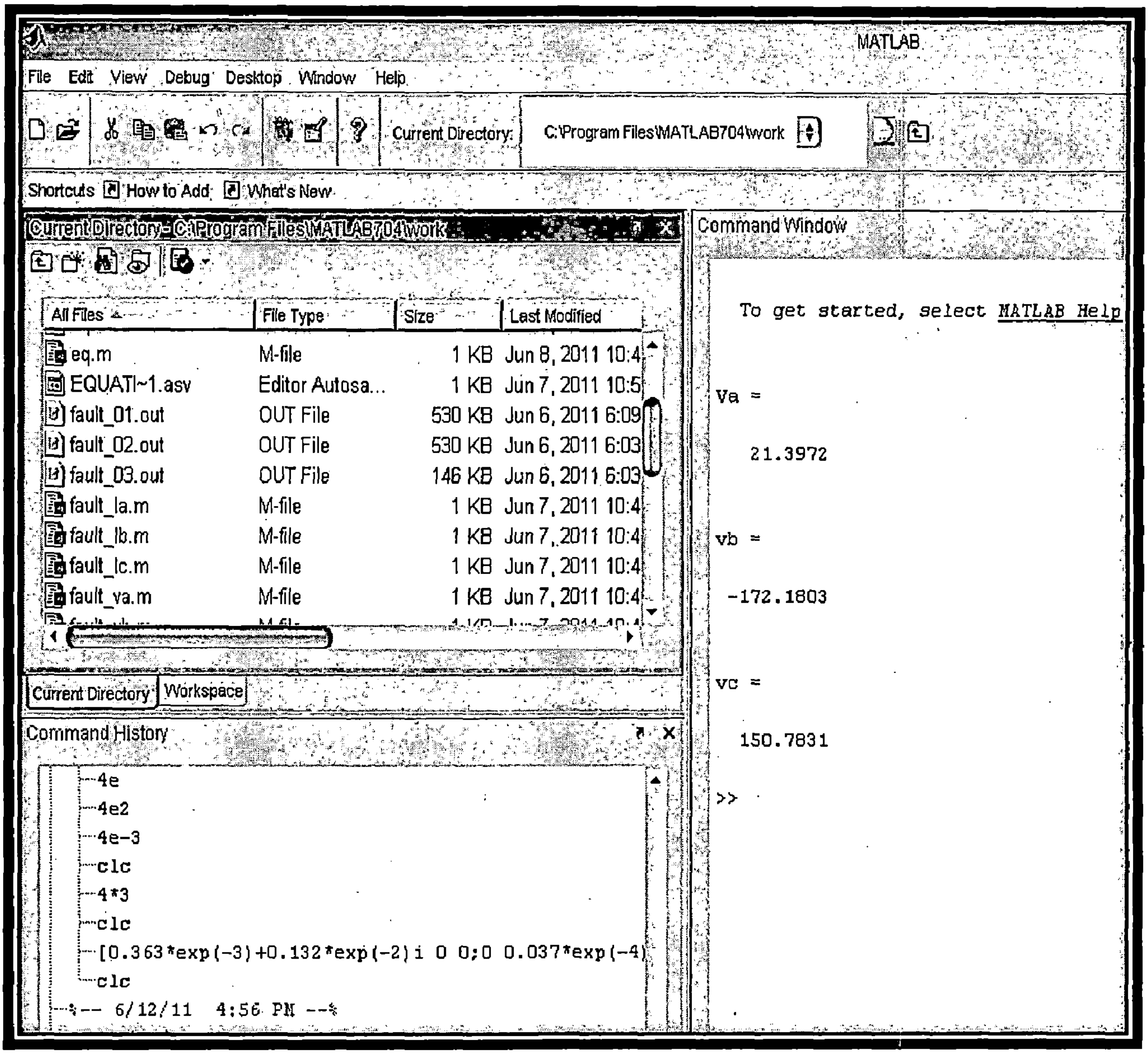

Fig.6.7 Fault Voltage Data Output

6.2.2. Fault Current Data Output

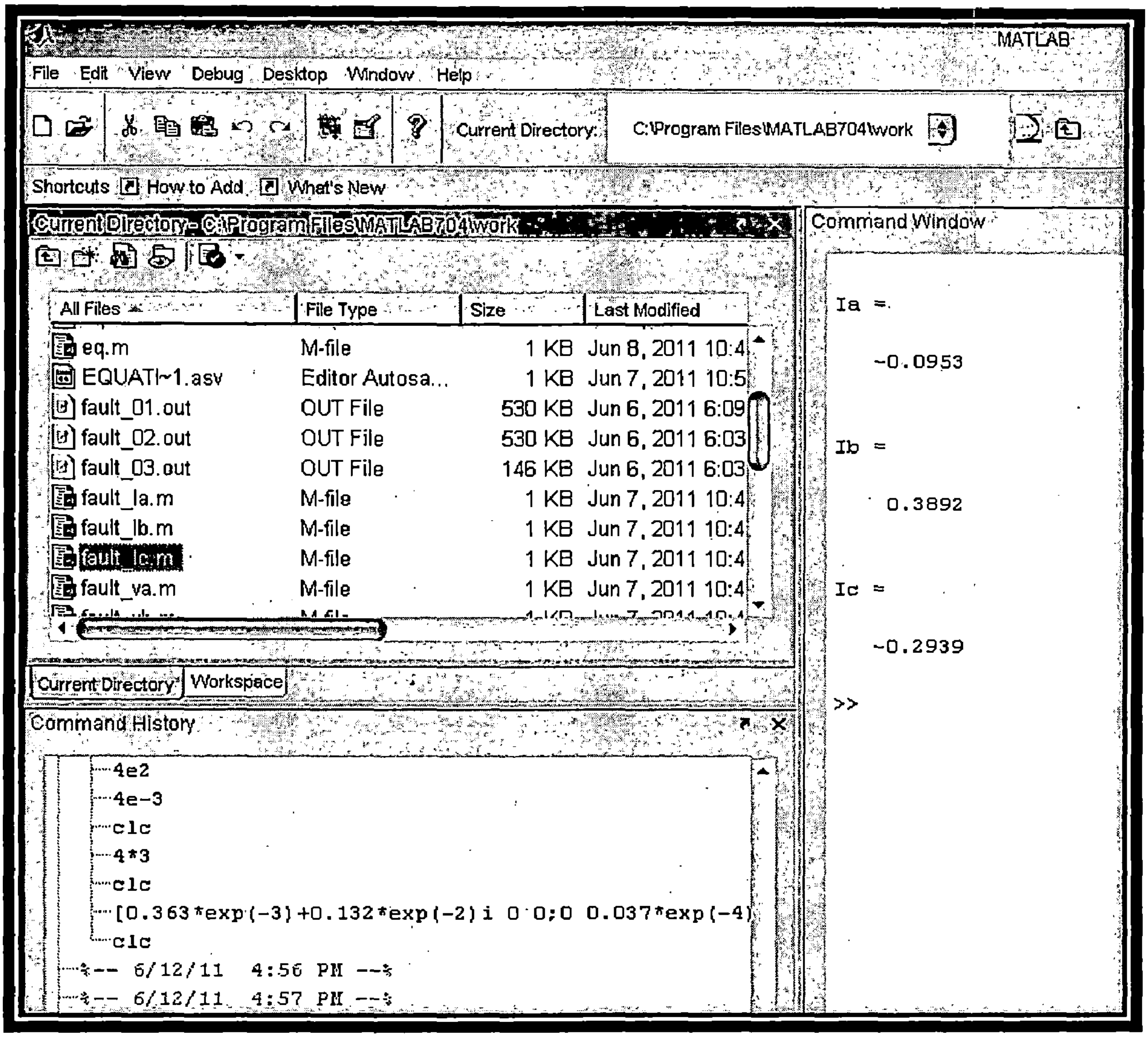

Fig.6.8 Fault Current Data Output

Based upon these value if total length of line L be the 100 km, the distance from sending end l_1 can be calculated i.e $l_1 = 31.67$ km. the snapshots of output in MATLAB are shown in next page.

6.2.3. Sequences Impedance & Admittance Matrix

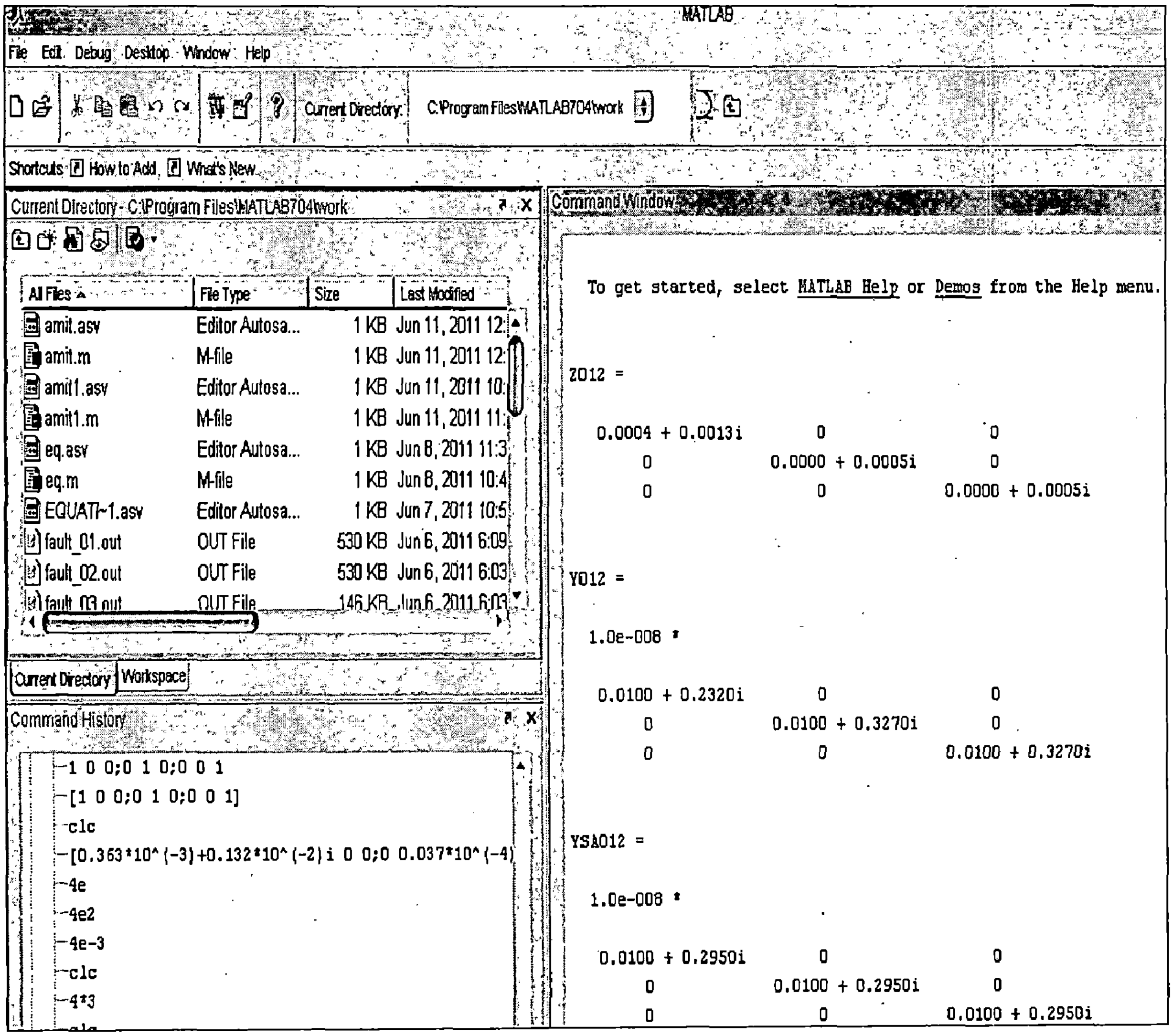

Fig.6.9 Sequences Impedance & Admittance Matrix Output

6.2.4. Sequences Admittance Matrix & Variation in Fault Voltage Output

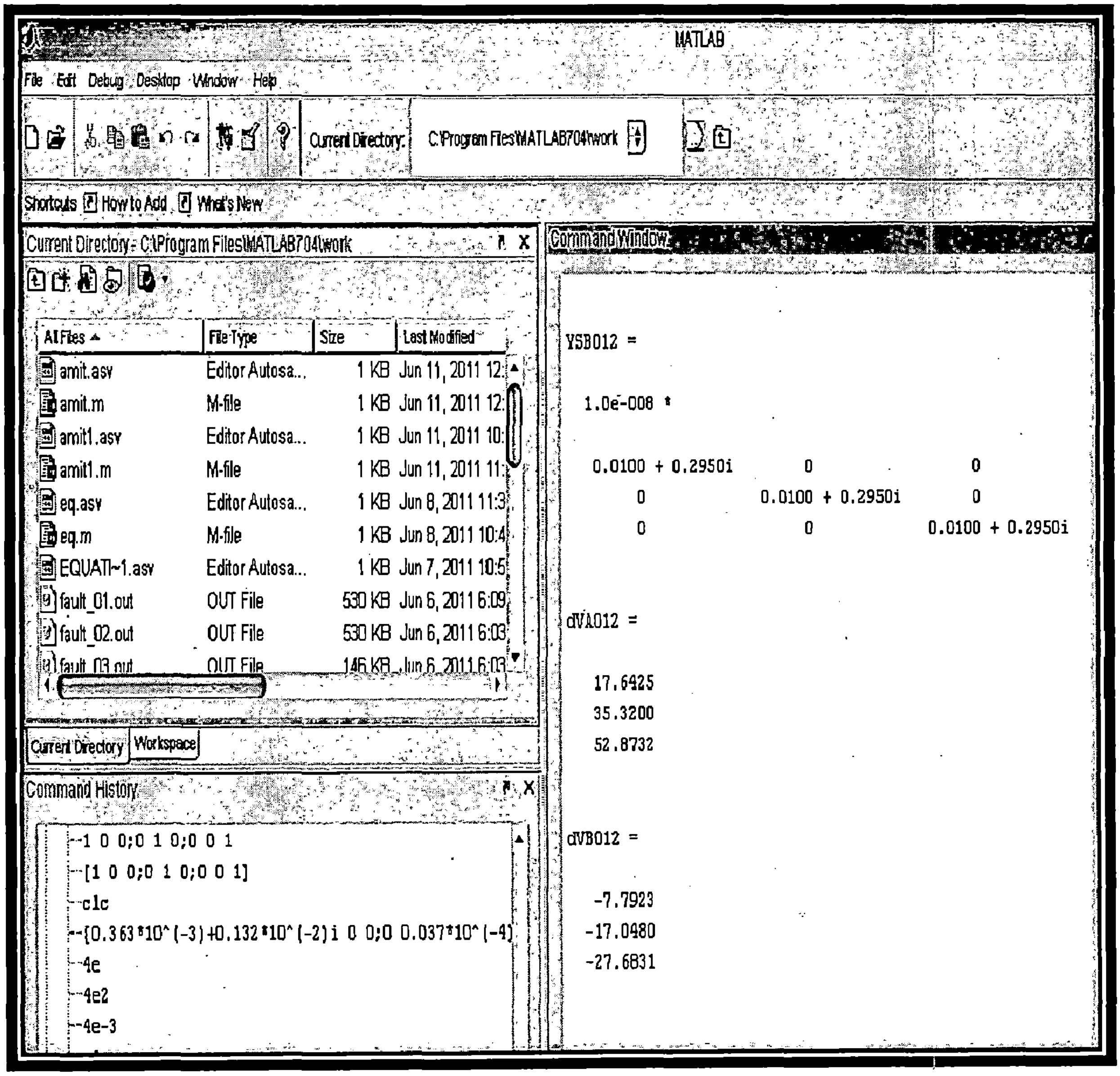

Fig.6.10 Sequences Admittance Matrix & Variation In Fault Voltage Output

6.2.5. Constant Parameters

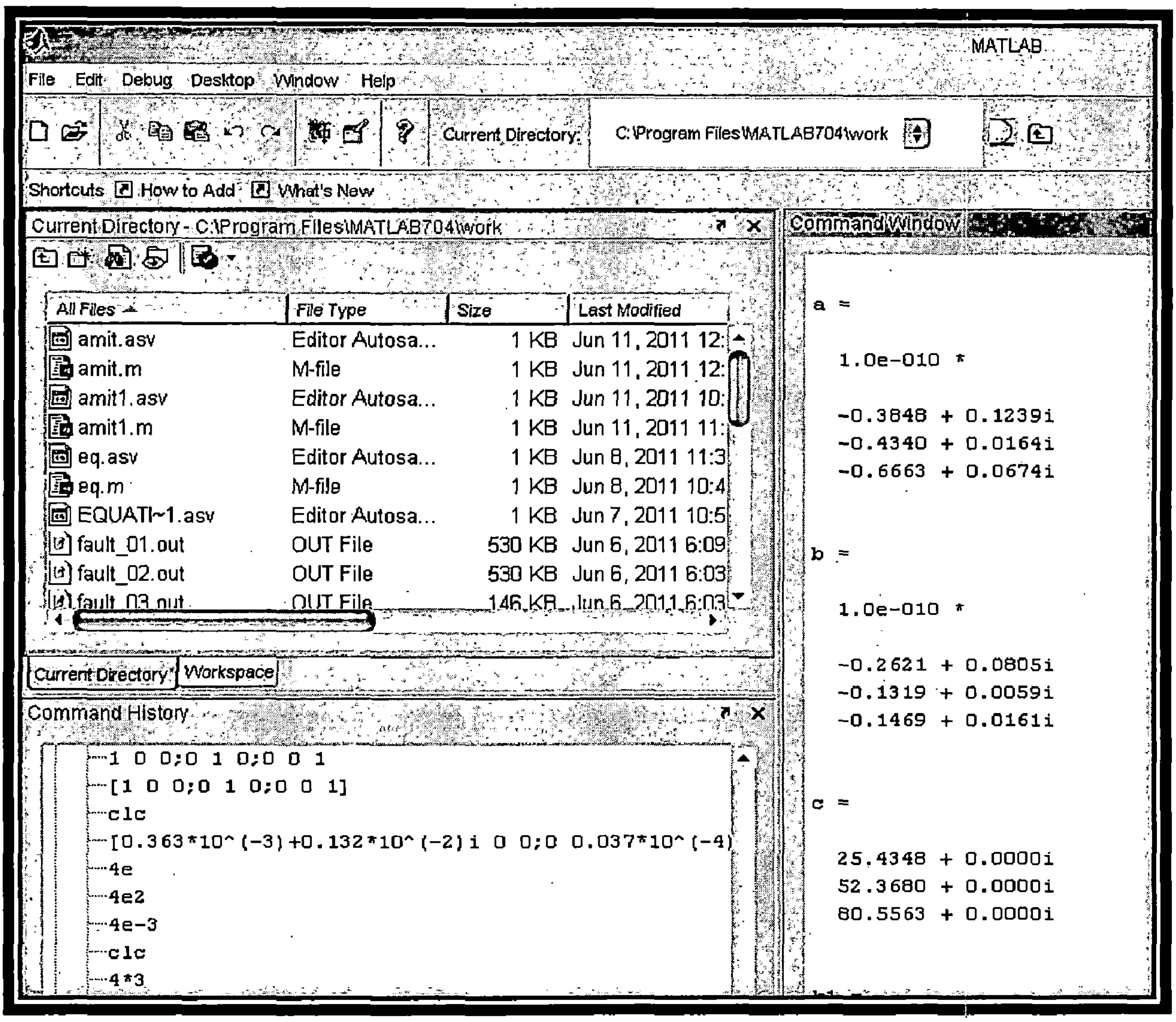

Fig.6.11 Constant Parameters Output

6.2.6. Constant Parameters and Distance

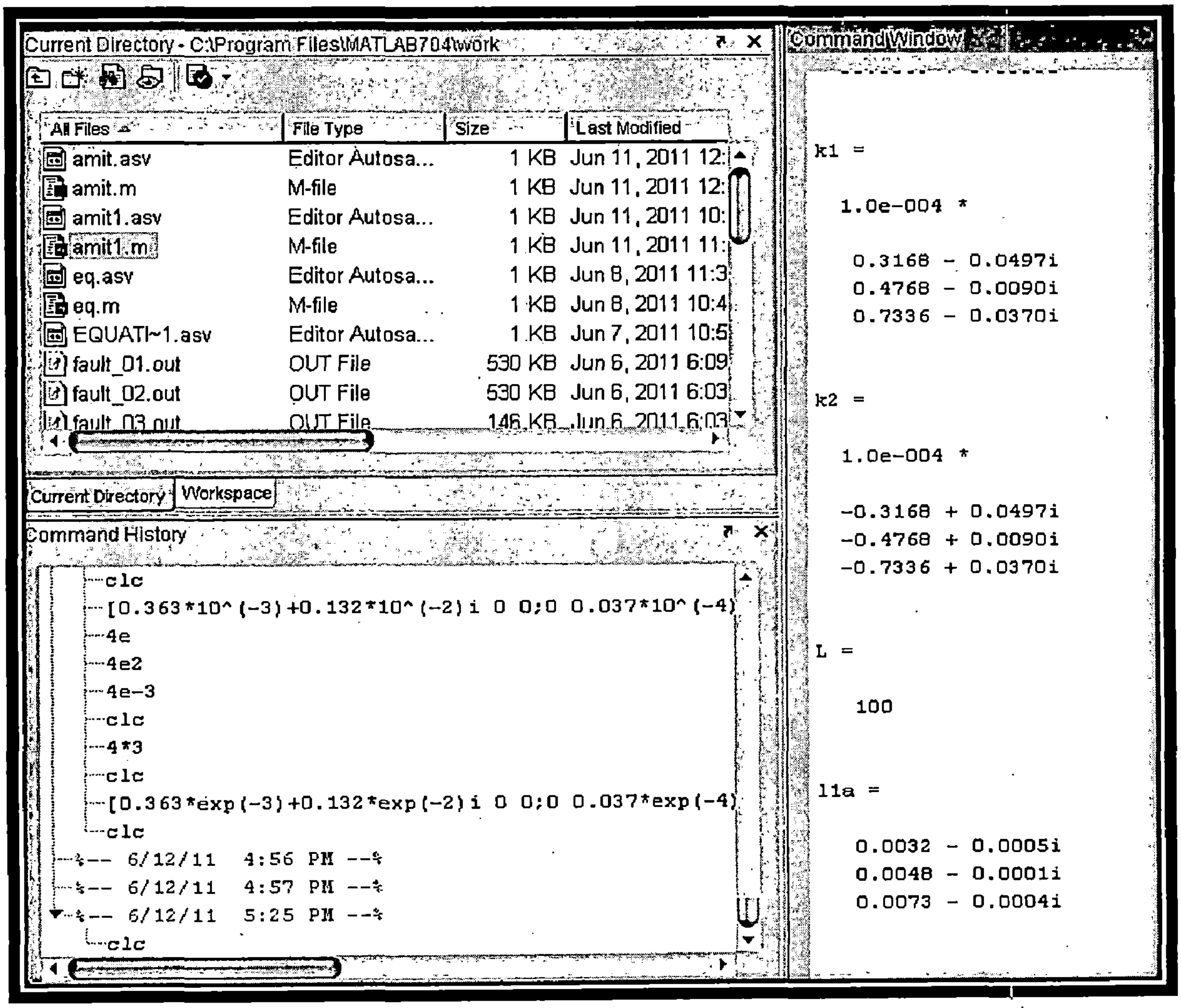

Fig.6.12 Constant parameters and distance output

6.2.7. Distance Parameters

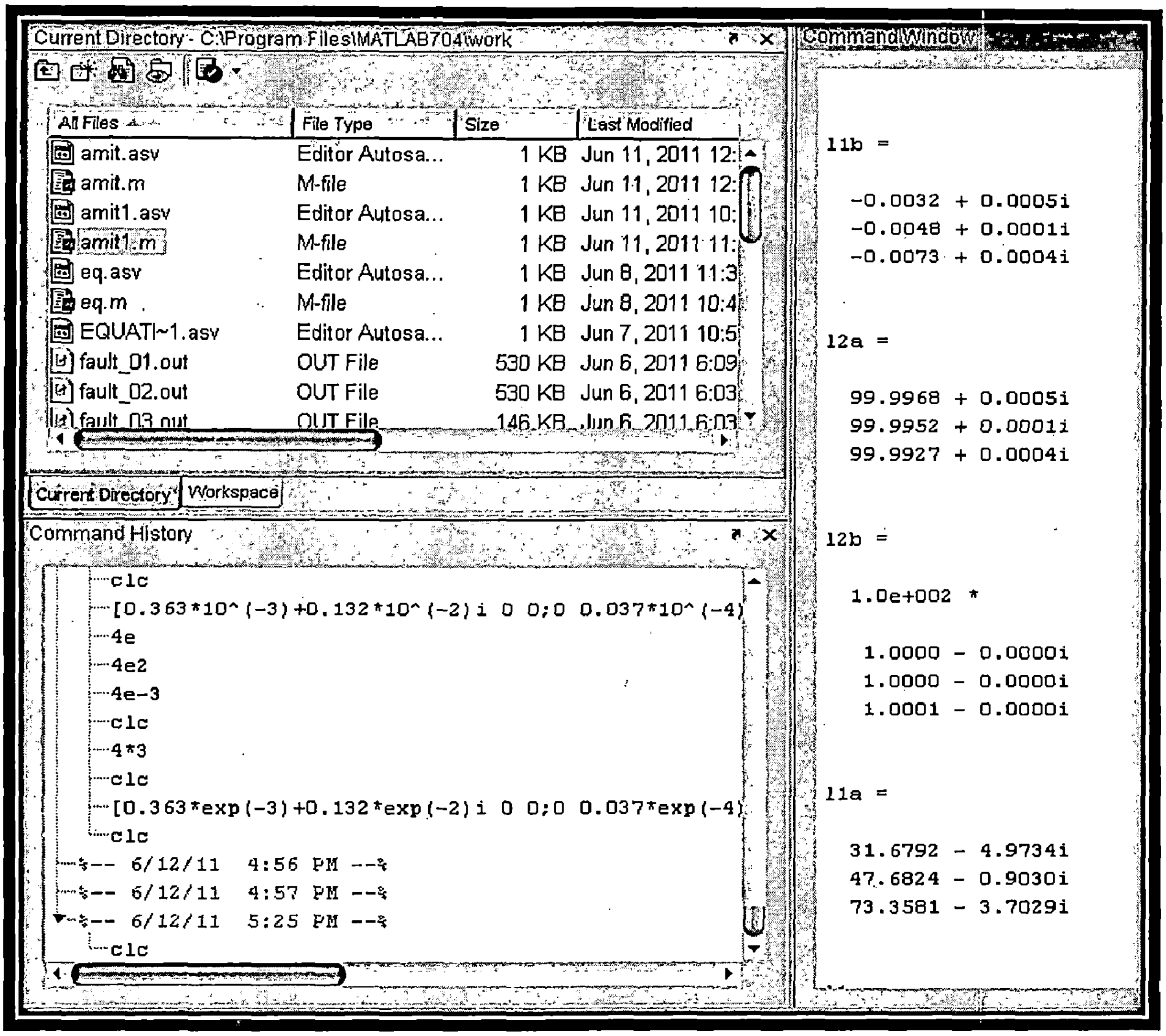

Fig.6.13 Distance Parameters

6.2.8. Distance from Sending End Output

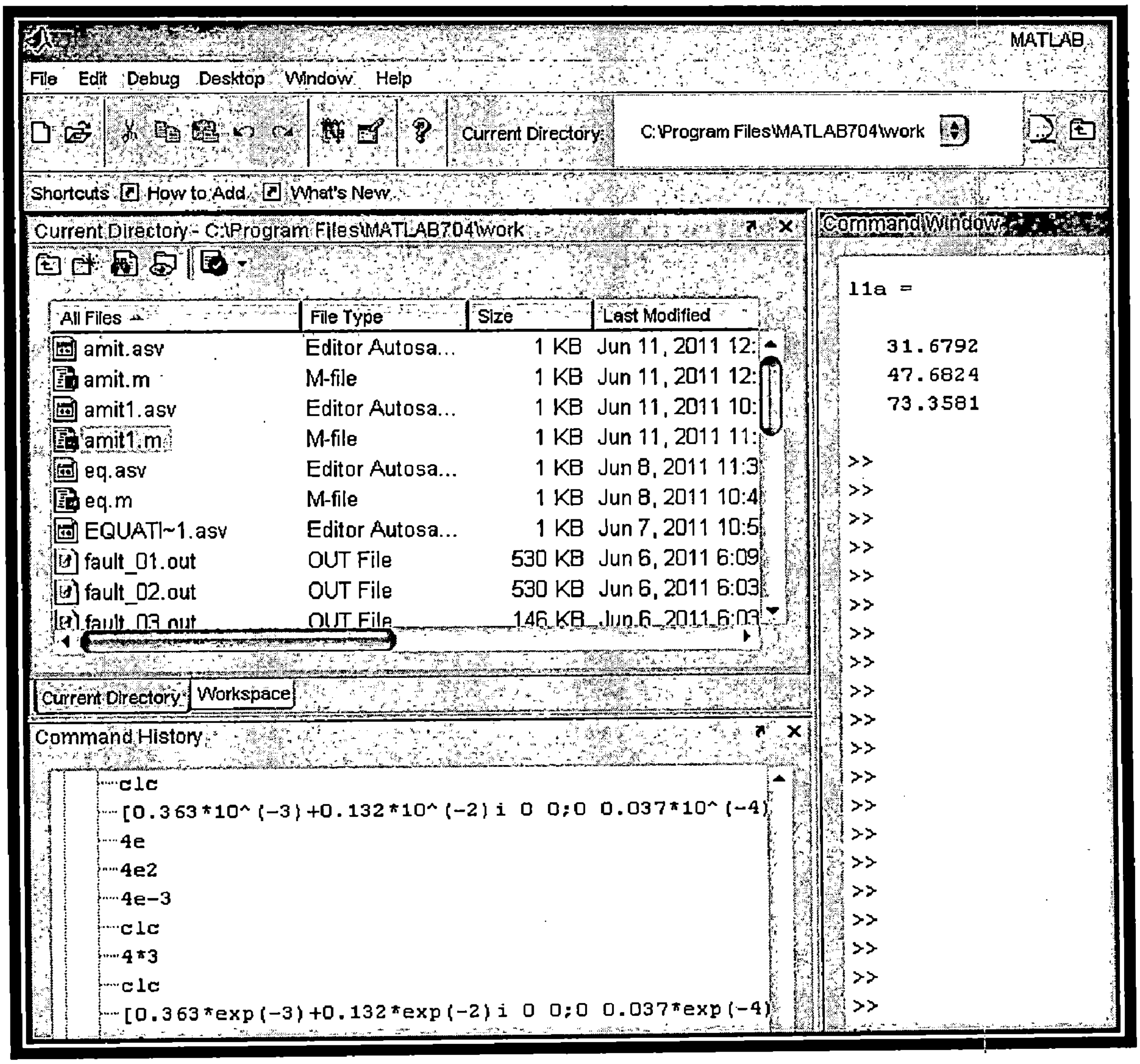

Fig.6.14 Distance from Sending End Output

CHAPTER 7

CONCLUSION

In this dissertation a fault location technique, based upon voltage is presented. The current is eliminated in the problem formulation. The advantage of this technique is non requirement of current transformer. There by eliminating the attendant issue of saturation of current transformer. The overall response of voltage and current during symmetrical and unsymmetrical faults is shown and finally the location of fault from sending end of transmission is detected. The output is executed using PSCAD and MATLAB softwares.

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APPENDIX 1

Nomenclature

T = symmetric components transformation matrix

a = complex scalar

I = unit matrix

I = sequence number: i = 0, 1, 2

Z_{012} = sequence impedance matrix of line (0 for zero, 1 for positive and 2 for negative sequences)

Y_{012} = sequence admittance matrix of line (0 for zero, 1 for positive and 2 for negative sequences)

YSA = Thevenin admittance of bus A

YSB = Thevenin admittance of bus B

YSC = Thevenin admittance of bus C

L = total length of line

LA = total length of line (section A)

LB = total length of line (section B)

LC = total length of line (section C)

R0 = zero sequence of line resistance in (X/km)

R1 = positive sequence of line resistance in (X/km)

R2 = negative sequence of line resistance that is equal to positive sequence

L0 = zero sequence of line inductance in (H/km)

L1 = positive sequence of line inductance in (H/km)

L2 = negative sequence of line inductance that is equal to positive sequence

C0 = zero sequence of line capacitance in (F/km)

C1 = positive sequence of line capacitance in (F/km)

C2 = negative sequence of line capacitance that is equal to positive sequence

l1 = fault point distance from sending side

l2 = fault point distance from receiving side

k = ratio of the fault distance to total line length

RFault = fault impedance

VF = voltage at fault location

E1 = source voltage (bus A)

E2 = source voltage (bus B)

ZSA_0 = zero sequence of Thevenin impedance (bus A)

ZSA_1 = positive sequence of Thevenin impedance (bus A)

ZSA_2 = negative sequence of Thevenin impedance (bus A) (equal to positive s equence

ZSB_0 = zero sequence of Thevenin impedance (bus B)

ZSB_1 = positive sequence of Thevenin impedance (Bus B)

ZSB_2 = negative sequence of Thevenin impedance (bus B) (equal to positive sequence)

ΔVA = variation of during-fault voltage minus pre-fault voltage (bus A)

ΔVB = variation of during-fault voltage minus pre-fault voltage (bus B)

δ = loading angle of the transmission line (degree)

APPENDIX 2

Input Sources 1and 2

Source Impedance type	=	RLC
Magnitude (AC:L-L Rms)	=	230 kv
Frequency	=	50 Hz

Breaker 1 and 2

Breaker open resistance	=	1.06 ohm
Breaker closed resistance	=	0.1 ohm

Transmission line 1

Segment length	=	90 km
Steady state frequency	=	50 hz

Transmission line 2

Segment length	=	10 km
Steady state frequency	=	50 hz

Multi meter

Time constant	=	0.02 sec
Base voltage for per unitizing	=	1.0 kv

Time fault logic

Time to apply fault	=	0.2 sec
Duration of fault	=	0.05 sec

APPENDIX 3

Sequence admittance matrix

$$\begin{bmatrix} 0.1E-09+i0.232E-08 & 0 & 0 \\ 0 & 0.1E-09+i0.327E-08 & 0 \\ 0 & 0 & 0.1E-09+i0.327E-08 \end{bmatrix}$$

Thevenin admittance matrix of bus A

$$\begin{bmatrix} 0.1E-09+i0.295E-08 & 0 & 0 \\ 0 & 0.1E-09+i0.295E-08 & 0 \\ 0 & 0 & 0.1E-09+i0.295E-08 \end{bmatrix}$$

Sequence voltage matrix of bus A

$$\begin{bmatrix} 17.6425 \\ 35.3128 \\ 52.8732 \end{bmatrix}$$

Sequence voltage matrix of bus B

$$\begin{bmatrix} -7.7923 \\ -17.048 \\ -27.6831 \end{bmatrix}$$

Sequence impedance matrix

$$\begin{bmatrix} 0.363E-03+i0.132E-02 & 0 & 0 \\ 0 & 0.357E-04+i0.507E-03 & 0 \\ 0 & 0 & 0.357E-04+i0.507E-03 \end{bmatrix}$$

Thevenin admittance matrix of bus b

$$\begin{bmatrix} 0.1E-09+i0.295E-08 & 0 & 0 \\ 0 & 0.1E-09+i0.295E-08 & 0 \\ 0 & 0 & 0.1E-09+i0.295E-08 \end{bmatrix}$$

APPENDIX 4

```
load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
Va=fault_01(p,3)
end
end
display(Va)
```

```
load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
vb=fault_01(p,4)
end
end
display(vb)
```

```
load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
vc=fault_01(p,5)
end
end
display(vc)
```

APPENDIX 5

```
load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
Ia=fault_01(p,6)
end
end
display(Ia)


load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
Ib=fault_01(p,7)
end
end
display(Ib)


load fault_01.out
[a,b]=size(fault_01)
for p=1:1:a
if fault_01(p,1)==0.2
Ic=fault_01(p,8)
end
end
display(Ic)
```

APPENDIX 6

```
Z012=[(0.363e-3)+(0.132e-2)*i 0  0 ; 0 (0.037e-4)+(0.507e-3)*I 0; 0 0 (0.357e-4)+(0.507e-3)*i]

Y012=[(0.1e-9)+(0.232e-8)*i 0 0 ; 0 (0.1e-9)+(0.327e-8)*i 0 ; 0  0  (0.1e-9)+(0.327e-8)*i]

YSA012=[(0.1e-9)+(0.295e-8)*i 0 0 ; 0 (0.1e-9)+(0.295e-8)*i 0 ; 0 0(0.1e-9)+(0.295e-8)*i]

YSB012=[(0.1e-9)+(0.295e-8)*i 0 0 ; 0  (0.1e-09)+(0.295e-8)*i 0 ; 0 0 (0.1e-09)+(0.295e-8)*i]

dVA012=[ 17.6425 ; 35.32 ; 52.8732]

dVB012=[-7.7923 ; -17.048 ; -27.6831]

a=Z012*(Y012/2)*(dVA012-dVB012)

b=Z012*[YSA012*dVA012+YSB012*dVB012]+Z012*(Y012/2)*dVB012

c=[dVA012-dVB012]-Z012*[YSB012+(Y012/2)]*dVB012

k1=(-b+sqrt(b.^2-4*a.*c))/2

k2=(-b-sqrt(b.^2-4*a.*c))/2

L=100 %km

l1a=L*k1

l1b=L*k2

l2a=L*(1-k1)

l2b=L*(1-k2)
```