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Multi Agent System Based Fault Location in a Smart MicroGrid System

Seetaram Alwala
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Multi Agent System Based Fault Location in a Smart MicroGrid System

Seetaram Alwala

Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Electrical Engineering

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Morgantown, West Virginia
2011

Keywords: Fault Location, MicroGrid, Multi Agent technology, OpenDSS,
JADE

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ABSTRACT

Multi Agent System Based Fault Location in a Smart MicroGrid System

Seetaram Alwala

The electric power grid is inherently a huge network that has been going through a lot of transformation because of its restructuring and increase in the deployment of Distributed Generation. The steep increase in electricity demand and the large financial losses caused by the blackouts has initiated research towards increasing the security and robustness of the electric grid and making it a Smart Grid. Smart Grids might incorporate MicroGrids, which can be defined as low to medium voltage networks that contain aggregation of certain loads and Distribution Generation units that can operate in either grid-connected or islanded mode. One of the leading technologies to deploy intelligence in the electric grid is the agent technology. Multi Agent systems are basically a congregation of individual agents that can sense changes in their environment and autonomously make decisions to meet their design objectives. The technological advancement in the agent technology can provide solutions for a wide range of Smart Grid activities.

In a MicroGrid, a single fault can lead to catastrophic, cascading events that could result in a blackout. This makes fault location an important problem to solve. The penetration of Distributed Generation units causes a two way power flow in the traditional radial distribution system. This, coupled with the inherent unbalanced nature of the distribution system, makes the fault location a difficult problem to solve.

In this thesis, a Multi Agent system has been formulated to determine the precise fault location and identify faulty zones. The algorithm for the fault detection is based on the magnitude of the sequence components of currents and current directions during a fault in the system.

The agent model for the fault detection has been implemented in the software named Java Agent Development Framework. The distribution test system used for this work is the IEEE 37 bus system. In order to simulate the MicroGrid, Distributed Generation units are added at various nodes in the test system. This circuit has been simulated in a distribution system simulation software, OpenDSS. All the possible fault cases for different penetration levels of Distributed Generation are considered and tested. Some of these fault cases have been presented in this thesis.

DEDICATION

I would like to dedicate this thesis to my parents and sister,

For their unhindered support, encouragement and love

&

To Mamaji, Sri Prabhakar Rao Garu,

Without whom my journey to USA would not have been possible.

Grand pa, you are deeply missed!

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NOMENCLATURE

ACL	Agent Communication Language
DSS	Distribution System Simulator
DG	Distributed Generation
FIPA	Foundation for Intelligent Physical Agents
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
JADE	Java Agent Development Framework
KQML	Knowledge Query and Manipulation Language
MAS	Multi-Agent System
OOP	Object Oriented Programming
PV	Photo Voltaic
WVU	West Virginia University

CHAPTER 1

INTRODUCTION

1.1 Background

One of the most expensive and complicated system ever developed is the electric power system whose main purpose is to supply electricity to its various consumers. The three main aspects of the electricity supply are generation, transmission and distribution. Initially, all these aspects were integrated and were centrally monitored and controlled. But, with the steep increase in demand for electricity all the resources in these processes are being utilized to the maximum extent possible. So, from the past decade restructuring of the power system, to separately manage the transmission, generation and distribution has been taking place [1].

Apart from restructuring, another aspect that has changed the dynamics of the power system is the introduction of the Distributed Generation at the distribution level. Distributed Generation can be basically defined as a local generation unit at customer level that can be used during a shortage of electricity supply. The power congestion caused due to power system deregulation has been addressed through the installation of Distributed Generation units. The interconnection of Distributed Generation has further complicated the power system. Thus, there is a need to maintain stability, voltage profile and introduction of new protection schemes with Distributed Generation in the system [2].

Though the electric power grid is a huge network, it is highly sensitive to the faults occurring in it. These faults can shut down the power supply to a large area. The main reason for this is the cascading effect that can essentially shut down the whole system. One of the greatest examples is the 2003 northeast blackout that affected nearly 50 million people and caused 6 billion dollars of financial losses [3]. This has triggered research towards increasing the security and robustness of grid and achieving a Smart Grid. Some of the features of the smart grid are self healing, asset optimization, security,

reliability, demand response etc [4]. One of the initiatives taken in order to improve robustness and security of the grid is the evolution of a Smart MicroGrid, which can supply some critical facilities independently of the main grid. One of the leading technologies to deploy intelligence in the electric grid is the agent technology. The main advantages offered by the agent technology are autonomy and decentralization.

1.2 Multi Agent Systems

Agent based system technology has generated lots of excitement in recent years because of its promise as a new paradigm for conceptualizing, designing, and implementing a wide range of applications. These applications range from small scale ones to large industrial applications. This technology has been deployed in the form of Multi Agent systems in a gamut of fields like transportation, logistics, graphics, GIS networking and mobile technologies and now in power system automation as well.

A Multi Agent system can be defined as a congregation of individual intelligent agents that cooperate and coordinate with each other to achieve a common goal. Before dwelling about the important aspects of Multi Agent System it is imperative to understand the basic concept of an agent. Due to the wide range of applications of agent technology, the term ‘agent’ has been defined in numerous ways. The most appropriate definitions of agent with respect to its implementation in this thesis are listed below.

According to Wooldridge et al. [5], agent is a computer system that is situated in some environment, and is capable of autonomous action in this environment in order to meet its design objectives. While Weiss defines it as an autonomous computational entity such as a software program that can be viewed as perceiving its environment through sensors and acting upon this environment through its effectors[6]. The basic characteristics of an agent according to [7-9] are:

- 1) Interaction with its environment (which may include other agents) (Sociality)
- 2) Learning from its environment (Autonomy)

- 3) Reaction to its environment in a timely manner (Reactivity and Pro-activity)
- 4) Taking initiatives to achieve its goals, (Autonomy and Pro-activity)
- 5) Accomplishing tasks on behalf of its user (Sociality and Reactivity)

In this thesis work an agent is considered as a software entity that can sense a change in its environment and can act meticulously with the sole purpose of accomplishing its design objectives. As described earlier a Multi Agent system is a congregation of these kinds of agents which communicate and coordinate to solve a particular problem according to their objectives.

A critical factor which effects the functioning of an agent based system is its environment. This is because the decisions taken by the Multi Agent system to meet its design objectives are dependent on the environment. In [10] description of the various agent environments possible is provided. They are:

- a) Accessible vs. Inaccessible: An accessible environment is one in which the agent can obtain complete, accurate, up-to-date information about the environment's state. Most of the moderately complex systems are in accessible environment
- b) Deterministic vs. Non-Deterministic: A Deterministic environment is one in which there is no uncertainty about the state that will result from performing an action. While Non-Deterministic environment is the converse of deterministic. Most of the physical world is Non- deterministic which provides greater problem to the designers.
- c) Episodic vs. Non-Episodic: In an episodic environment, the performance of an agent is dependent on a number of discrete episodes, with no link between the performance of an agent in different scenarios.
- d) Discrete vs. Continuous: An environment is discrete if it has a fixed, finite number of actions and percepts in it. The best example for a discrete environment is chess game and for a continuous environment is car driving.
- e) Static vs. Dynamic: A static environment is one that can be assumed to be unchanged except for the actions by agents. While dynamic environment has many processes operating on it, changing it at every instant. It is also very difficult to control.

Apart from their environment, another important requirement of Multi Agent system is to successfully perform their designated tasks is the communication between the agents. A brief insight about the communication aspect is provided in section 1.3.

1.3 Agent Communication

The pivotal function of the Multi Agent system design in order to accomplish its design objectives is the ability of the individuals to communicate and negotiate with each other. In order to enable communication certain protocols have been specified. These Communication protocols enable agents to exchange and understand messages. The behavior of a Multi Agent system not only depends on its component agents, but also on how they interact. In a Multi Agent system of sufficient complexity, each agent would not only need to do the tasks that arise locally, but would also need to interact effectively with other agents. The communication protocols can be regarded as the specification of these interactions. Protocols are a nice way of enforcing modularity in the design of a Multi Agent system. The most popular languages followed for the Agent Communication are,

- Agent Communication Language (ACL) by the Foundation for Intelligent Physical Agents (FIPA)
- Knowledge Query and Manipulation Language (KQML)

Both these languages, define a set of performatives and their meaning. The content of the performative varies from system to system.

To make agents understand each other, they have to not only speak the same language, but also have a common ontology. Ontology is a part of the agent's knowledge base that describes what kind of things an agent can deal with and how they are related to each other.

1.3.1 FIPA –ACL

FIPA is a body for developing and setting computer software standards for heterogeneous and interacting agents and agent-based systems. It was founded as a Swiss nonprofit organization in 1996 with the ambitious goal of defining a full set of standards for both implementing systems within which agents could execute (agent platforms) and specifying how agents communicate among themselves [11]

The language developed by FIPA for the agent communication is known as Agent Communication Language (ACL). It is based on speech act theory. Here the messages are intended to perform some action by virtue of being sent, hence they can be considered as actions or communicative acts. A FIPA ACL message contains a set of one or more message parameters. The parameters required for effective agent communication will vary according to the situation; the only parameter that is mandatory in all ACL messages is the performative, although it is expected that most ACL messages will also contain sender, receiver and content parameters. However, for a meaningful message there should be other parameters required depending upon the situation. The full set of pre-defined message parameters is shown in the following table.

Table 1-1: FIPA ACL Message Parameters [12].

Message Parameter	Meaning:
:sender	Denotes the identity of the sender of the message. i.e., the name of the agent of communicative act
:receiver	Denotes the identity of the intended recipients of the message.
:content	Denotes the content of the message; equivalently denotes the object of the action. The meaning of the content of any ACL message is intended to be interpreted by the receiver of the message. This is particularly relevant for instance when referring to referential expressions, whose interpretation might be different for the sender and the receiver.
:reply-with	Introduces an expression that will be used by the responding

	agent to identify this message
:in-reply-to	This parameter indicates that subsequent messages in this conversation thread are to be directed to the agent named in the reply-to parameter, instead of to the agent named in the sender parameter
:encoding	Denotes the specific encoding of the content language expression.
:language	Denotes the language in which the content parameter is expressed
:ontology	Denotes the ontology(s) used to give a meaning to the symbols in the content expression
:reply-by	Denotes a time and/or date expression which indicates the latest time by which the sending agent would like to receive a reply.
:protocol	Denotes the interaction protocol that the sending agent is employing with this ACL message.
:conversation-id	Introduces an expression (a conversation identifier) which is used to identify the ongoing sequence of communicative acts that together form a conversation.

In this thesis work, Multi agent system communication is performed using ACL language. Java Agent Development Framework (JADE) is a Java based agent platform which abides to FIPA standards for agent communication. JADE is recently employed in most of the Multi Agent systems development has been used in this thesis.

1.3.2 Knowledge Query and Manipulation language

The Knowledge Query and Manipulation Language (KQML), is a language and protocol for communication among software agents and knowledge-based systems. It was developed in the early 1990s. While originally conceived of as an interface to knowledge based systems, it soon became an Agent communication language.

The KQML message format and protocol can be used to interact with an intelligent systems, either by an application program, or by another intelligent system. KQML's performatives are operations that agents perform on each other's knowledge and goal stores. The basic protocol is defined by the following structure [13].

(KQML-performative

: Sender <word>
: Receiver <word>
: Language <word>
: Ontology <word>
: content <expression>
...)

FIPA – ACL has superseded the KQML in most of the agent communications.

1.4 MicroGrid

With the tremendous increase in electricity demand in industrialized countries and the increase in frequency of natural hazards all over the world put forth many difficult challenges of securing critical equipment by seamless and continuous provision of electricity. One such problem occurred in August 2003 when 50 million residents of U.S. and Canada were left without electricity services due to a blackout. Historically, to deal with such situations, more power plants and transmission lines were built to fulfill the electricity requirement. This approach, however, has limitations such as, impacts on carbon emission, fuel availability, land use, health effects due to electromagnetic fields, lack of resiliency etc. Instead, electricity needs for critical equipment could be met by the microgrid concept [14].

MicroGrid can be defined as a low to medium voltage network that contains an aggregation of certain responsive loads and Distributed Generation units, which is connected to the main grid through a point of common coupling. It can operate either in the grid-connected or islanded mode. In the grid connected mode it remains connected to the main grid and is seen as a single aggregate load or source, while in the islanded mode it separates from the main grid, due to a major disturbance, becoming self sustained and continues to serve certain loads [15]. A typical MicroGrid system is shown in Figure 1-1.

Figure 1-1: CERTS MicroGrid schematic [16]

However, the implementation of a MicroGrid poses several technical difficulties with regard to its protection. The basic problems that crop up with the introduction of Distributed Generation into the Radial distribution system are two way power flow and change in magnitude of the Fault currents. So, in this thesis agent based design for the fault location in Microgrid system has been proposed.

1.5 Problem Statement

In this thesis, a Multi Agent system has been implemented to determine the fault location in a smart MicroGrid system. The fault location algorithm implemented in the Multi Agent system is based on sequence current magnitude and direction of the current during a fault. The MicroGrid has been implemented by adding Distributed Generation units at the various nodes of the 37-bus IEEE benchmark system and its fault simulation has been done in the software OpenDss.

The test system considered is divided into 3 zones separated by a switch. Each of these zones has a zone agent and at all the switches separating the zones there is a switch agent. Further, a recloser agent is also present which is located at the recloser near the

substation. When a fault occurs in the network, these agents communicate among each other and come with the fault location in the circuit. The switch agent has the fault location algorithm embedded in it.

A few assumptions made in this thesis work are listed below,

- The fault location will be performed only when the recloser completely locks out.
- The switch agent has measurement of all the lines in the zone to which it is associated.
- The switch agent can open any line to isolate the faulty line
- The only Distributed Generation source considered for the implementation of the MicroGrid is the PV solar generation
- The default model for PV solar generation available in OpenDss is used.
- Only low impedance faults are considered.

In order to simulate a more realistic scenario, this thesis also implements Multi Agent system based algorithm for locating the faulty zone in the system by using only the measurements at the switches separating the various zones considered in the test system. The only measurement used is the positive sequence current magnitude.

1.6 Approach

In order to implement a MicroGrid system, the Radial IEEE 37 bus standard benchmark system was modified by adding PV solar Distributed Generation models at various nodes of the system. The default model for PV solar generation available in OpenDss is used. The circuit has been modeled in open source distribution system simulation software called OpenDSS. The power flow results of OpenDss were verified using Distributed Engineering Workstation (DEW) software. The software used to design the Multi Agent System is Java Agent Development (JADE) framework. The fault detection algorithm was implemented in JADE. Details of each of the software are provided in detail in Chapter 3.

Interfacing of these two software platforms involved was not necessary since the fault location algorithm is being implemented only after the recloser locks out. Hence the agent application was implemented offline. Different kinds of faults, mainly three phase to ground, single line to ground and line and line fault were created at various nodes in the test system in order to test the working of the algorithm.

1.7 Thesis Organization

The rest of the thesis is organized as follows. Chapter 2 primarily provides an extensive review of the research work done in the area of Multi Agent system application for fault location and management of MicroGrid. Further, literature related to Multi Agent system application in other related topics like protection co-ordination, voltage control, Demand response etc. is also discussed. Also, a brief overview of Multi Agent system technology and its advantages are also presented. Chapter 3 elucidates the simulation software packages employed in this work, followed by some insights on their advantages and limitations. Details of the test system, fault location algorithm, Multi Agent system architecture developed for the fault location along with a few test cases are presented in Chapter 4. Conclusions and scope for the future work are discussed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

This chapter primarily provides a thorough summary of the research work done in the area of Multi Agent system application for fault location and management of Microgrid. Further, literature related to Multi Agent system application in other related topics like protection co-ordination, voltage control, Demand response etc. is also discussed. Along with literature mentioned above, a brief overview of Multi Agent system technology and its advantages and limitations in comparison with the traditional schemes are also presented.

2.1 Multi Agent System

The Multi Agent system technology has evolved into being one of the most potent tools in developing a complex system capable of solving difficult problems. It is basically a combination of individual agents that coordinate and cooperate with each other in order to accomplish their assigned tasks which in turn results in achieving the overall goal of the system.

The Multi Agent systems make use of the individual agent characteristics of autonomy, sociality, reactivity and pro-activity. Along with having properties of individual agents the Multi Agent system are designed to be highly decentralized and have an infrastructure to enable communication and interaction between individual agents.

Though the Multi Agent systems have some limitations as discussed in [17], their characteristics provide the perfect solution to the current problems of distributed computing, communication and data integration in power system automation. The Multi Agent systems can offer modular, flexible, and integrated approach for many problems which are of distributed nature in the field of electrical power systems.

2.2 Multi Agent System in Automatic Fault Location

One of the key aspects to ensure reliability and continuous operation of the power system is Fault detection. With the addition of Distributed Generation unit into the power system makes the fault location a more complicated problem because of the introduction of two way power flow. This section provides a brief survey of work done in fault location in a radial power system with and without Distributed Generation.

In [18] the authors propose an agent based fault detection based on fault diagnosis and prognosis in an electric war ship. The future conditions of the system are predicted and agents are trained to act accordingly to take decisions. While, in [19] and [20], the authors propose an automatic fault detection and fault diagnosis mechanism based on several symptoms to differentiate normal and fault conditions. These methods can be based on parameter estimation, parity equations or state observers. Finally, the fault is detected by the use of classification or interference methods. Further, [21] and [22] propose the fault detection mechanism using analytical redundancy. In [23] a decentralized agent based scheme for fault detection in ship board system is discussed.

There has been a lot of work done with regard to fault location in the power system with Distributed Generation integrated into the system. In [24] authors propose an agent based fault location algorithm for a smart distribution system. The agents are located at various node locations and have the local feeder information. When a fault occurs, depending upon the direction and amplitude of the zero transient reactive power flow between neighboring nodes in the distribution test system, the fault location is determined. The zero transient reactive power is calculated by using zero transient voltage and current. But this algorithm is limited only to single line to ground faults.

Zeng Xiangjun et al. [25] propose a decentralized agent based protection which has the capability to detect High Impedance faults, fault location and load shedding for a Distributed Generation system. Faults often produce wide band of frequency energies that are quite different from the harmonics in the normal conditions or switching surges. These fault harmonic energies flow from the fault point to all the generation sources.

Based on the principle of differential protection, the line with the same direction of fault harmonic energy flow in its two terminals is the faulted line. The proposed agent based protection scheme is developed with current differential relays. Relays as agents cooperate and communicate with each other to locate the fault section and they also take decisions to shed the loads if necessary.

A Multi Agent system based on current magnitude and direction to identify faults in a looped distribution system is proposed in [26]. The circuit is divided into different zones and each zone is separated through a zone breaker where the current measurements are taken. The simple concept used in this paper is that during a fault all the Distributed Generation units must feed the fault because of which the threshold of current set at the various breakers associated with a particular zone are violated. Agents are located at Distributed Generation units and at the zone breakers, which exchange information and locate the faulted zone. This agent system is applicable only to identify zones but not the precise fault location and this algorithm works best when the current thresholds are set high.

In [27] the authors propose a Multi Agent based scheme for fault diagnosis in power distribution networks with Distributed Generators. In this work, relay agents are located such that the distribution network is divided into several sections and they measure the bus currents at their location. Based on the entropy of wavelet coefficients of the measured bus currents measured at the various locations of relays, the type of fault if it is a three line to ground (3LG), single line to ground (LG), double line to ground (DLG) or a line to line (LL) fault is identified. Finally, the fault location is determined.

In [27] the authors present an agent based protection scheme based on wavelet coefficients of the transient fault currents to detect and isolate the faults in a distribution system with high penetration of Distributed Generation [28]. The two aspects of the algorithm are to determine the direction of the fault current and then measure the distance of the actual fault location. The fault current direction is determined based on the sign of wavelet coefficients, while the distance to the faulted point is calculated based on the

time interval between the travelling waves (and their reflections) arriving from the fault point. Based on the determination of fault direction and location the faulty sections are isolated. In this work relay agents are located such that the distribution network is divided into several sections.

2.3 Multi Agent system Implementation in Microgrid

The control and communication within MicroGrids has been implemented in two ways: Hierarchical and decentralized control. Hierarchical control requires a central controller that manages the entire system. The approach is similar to the one used in SCADA. Work done by CERTS [29] is one of the most important in this regard. Decentralized approach is being implemented using agent technology. The Authors in [30-32] have implemented agent based control and communication strategies for the optimal operation of the Microgrid. In [30] Multi Agent system has been designed to increase security and reliability of distributed power resources. Military camp setting consisting of HQ, barracks, mess and hospital having a generator, one critical ,one non-critical load (operating independently) a communal bus connecting the four generators and the agent system consisting of four agents to operate the microgrid were defined.

Multi Agent system implementation controlling a small MicroGrid in its grid connected state is presented in [31]. The main objective of this work was to minimize MicroGrid operational cost. The bids for buying and selling energy in a MicroGrid market were expressed as a symmetrical assignment problem, in which persons are matched with objects and the profit was maximized.

In [32], a Multi Agent system for fault restoration was implemented. The agent architecture is hierarchical in which lower layer agents sense the absence of energy and inform the higher layer agents and the higher layer agents perform the restoration by communicating and cooperating with their peers. Oyarzabal et al. have formulated [33] generic Multi Agent system architecture to be used for MicroGrid management. The main aim was to perform measurements for obtaining data and performing demand side management functions like load shifting, load curtailment and generation scheduling. The main components of the Multi Agent system architecture are MicroGrid central

controller, MicroGrid source controller (MSC) and load controller (LC, connected to loads). MCC, MSC and LC further consist of several agents performing their specific tasks. Great emphasis of multi agent functionally has given to the secondary regulation system which starts operation when a load change is detected. The change in load makes the batteries modify their power level and the secondary regulation system sets in and assigns the power requirement difference to generator to supply the new load. Further, the authors in [34] present a optimized method to buy energy from the distributed energy resources to meet the demand at lowest possible price. A generic Multi Agent system was presented in [35] as a control framework for Microgrids.

2.4 Multi Agent system for Restoration and Reconfiguration

Pioneering work has been done with regard to Multi Agent system implementation for restoration and reconfiguration in a power system after a fault. Many authors reinforce the advantages of decentralized Multi Agent system schemes over the centralized schemes. Brief description of some of the work done is provided in the subsequent paragraphs.

In [36-38] Multi Agent system for the fault location and reconfiguration has been implemented on the Southern California distribution system known as circuit of future. The author [37] proposes a reconfiguration algorithm which tries to supply all the critical loads in the network. When multiple solutions for reconfiguration are available the solution with good voltage profile and least power loss is chosen. Shunt compensation and priority based load shedding is done for improving voltage profile of the system. While in [36] reconfiguration algorithm tries to supply as much load as possible while maintaining the power balance in the circuit along with line constraints. Further, in [38] an artificial immune based Multi agent system for power system reconfiguration is proposed. The algorithm for reconfiguration after locating the fault, tries to serve affected load by taking into consideration the voltage profile, line losses and line capacity constraints.

In [39] authors propose a highly decentralized Multi agent system architecture for restoration and reconfiguration of a three phase unbalanced distribution system. In this work, all the agents are localized and communicate only to their neighboring agents making the architecture highly decentralized. The restoration is implemented with limits on generation, load priority and transfer capacity of lines. Authors in [40-42], have designed an decentralized Multi Agent system architecture for restoration of bulk power system. Each of these architectures has different layers of agents and each of the agents cooperate and communicate among themselves and also with agents in other layers to come up with the most optimal restoration plan. The results obtained in these works are promising.

2.5 Multi Agent system in Secondary Voltage Control

In this section a brief description of the work done with regard to implementation of the Multi-agent system for secondary voltage control in power distribution system is presented.

H.F wang et al. proposes a highly decentralized Multi-agent system design for the purpose of secondary voltage control during system contingencies [43]. In the electrical power system the secondary voltage control is done by the generator Automatic Voltage Regulators (AVRs) in order to improve voltage stability. Each of the voltage control devices like AVR, SVC and STATCOM is an agent. Each of these agents monitor their area for voltage violation and upon sensing the violation, they implement voltage control by switching in their reactive power resources. If the voltage violation is still persists, then the agent will negotiate with its neighbors for reactive power and the neighbor having sufficient reactive power responds.

In [44] an optimally coordinated Multi Agent system design for secondary voltage control is presented. In this agent based scheme, each of the primary and secondary voltage controllers are represented as a set of execution and coordination agent, respectively, who either work independently or coordinate with each other for system-wide voltage control. Under normal conditions, the agent system works as a conventional secondary voltage control system but during contingencies contract net protocol is

introduced to setup the coordination and cooperation among voltage control agents to eliminate the voltage level violation. The simulation results of the New England 39-bus system show that the proposed control scheme and coordination method are very effective in managing global voltage profile of power system as well as settling local voltage violation problems during system contingencies.

2.6 Multi Agent system other Applications

Apart from the applications discussed in sections 2.2 to 2.5 Multi Agent systems have also been used for other power system applications like protection coordination [45–50], power visualization [51], demand response [52-58]. Apart from power system applications Multi agent systems have also been employed in other engineering fields for highway traffic management control systems [59], air traffic control system and mine detection [60].

CHAPTER 3

SIMULATION SOFTWARE

This chapter briefly discusses about the various software packages that have been used in this thesis to simulate the MicroGrid and develop the Multi Agent System for fault location.

One of the biggest challenges in this thesis was the selection of the appropriate software that could simulate the distribution test system and the Multi Agent system. The distribution system modeling software must not only perform a 3-phase unbalanced power flow, fault analysis of distribution system but must be able support the islanded Microgrid implementation. Some of the commercially and open source distribution system modeling software are DEW, OpenDSS, Cymdist, Milsoft Windmil and RDAP. Keeping in mind all the requirements of the software, OpenDSS was chosen while Distributed Engineering Workstation (DEW) was used to verify the power flow results obtained in OpenDss. Further, Java Agent Development Framework (JADE) software has been used to develop the agent model in this thesis work.

The simulation model for this work consists of two layers a) Agent model layer and b) Power distribution system software layer. Figure 3-1 depicts the interaction between the two layers through an Interface. In this work no interface has been developed but agent layer acts on the values exported from the distribution system software layer to an excel file in a comma separated values (csv) format.

Figure 3-1: Simulation model architecture

3.1 Distributed Engineering Workstation© (DEW)

Distributed Engineering Workstation is a distribution system modeling software which provides multidiscipline, open-architecture environment with integrated data and applications. It was developed by Electrical Distribution Design Inc. It is capable of meeting the analysis, planning, design, and operation needs of today's distribution systems. DEW offers a wide gamut of applications related to power distribution system like power flow, contingency analysis, Load forecasting, fault analysis, protection coordination design, phase balancing and many more [61]. DEW also has provisions for add-ons that can be separately bought from its providers. The open architecture of DEW allows the integration of external applications into the workstation.

The pivotal components of DEW are the GUI, API, Executive, Database and Application module [62]. All these components have been depicted in Figure 3-2.

Figure 3-2: Major functional parts of DEW [62].

Executive unit handles the key operations in the workstation. It serves as an interface between API, GUI, and database modules. The main function of the API is to amalgamate the application modules into the framework smoothly without disturbing other parts of the workstation. Dew GUI provides user interaction and display functions for all of the remaining DEW applications. All the DEW applications have ready accessibility to the data. Each of the applications utilize data from the SCADA system through an interface called Database Access Integration Service (DAIS)

Figure 3-3 shows the GUI of DEW. To build the single line model of the required distribution system the different power system components available on right hand side pane have to be dragged on to the workspace located to the left of the pane. In this thesis work DEW has been used to validate the power flow results obtained from OpenDss by running a base case test system.

Figure 3-3: DEW GUI

3.2 Open Distribution System Simulator (OpenDSS)

OpenDSS is an open source comprehensive electric power Distribution System Simulator (DSS) for supporting distributed resource integration and grid modernization efforts developed by Electric Power Research Institute (EPRI) [63]. The DSS supports all

steady-state mainly frequency domain analyses commonly performed on electric power distribution systems, such as power flow, harmonic analysis and fault studies. Further, DSS provides an adaptable research platform and foundation for special distribution system analysis like Distributed Generation (DG) interconnection analysis and provides features supporting the enhanced study of energy efficiency, stray voltages, and distribution state estimation.

The DSS can be basically implemented in three ways 1) Standalone EXE user Interface 2) COM interface and 3) User written DLL. In the standalone EXE user interface the users are provided with multiple-windows to assist in building customized distribution systems and solving them. The COM interface can be used to drive the simulator from compatible softwares like MATLAB, VBA, C#, Python and so on. Expansion of DSS capabilities is made possible by the incorporation of sophisticated models of distribution system through user written DLL'S. These models can be linked to be DSS engine for implementation purposes. The DSS structure constituting these different implementations is shown in Figure 3-4 [64].

Figure 3-4: OpenDss structure

Figure 3-5: OpenDss standalone EXE user interface

3.2.1 DSS Solution Modes

DSS offers different types of solution modes which depending on requirement can be used. These different modes have been shown in Figure 3-6. As shown in the figure the different modes are:

- Normal Power flow: This is a default mode in DSS which solves a normal distribution power flow in which the bulk power system is the dominant source of energy. It can solve networked (meshed) and radial systems along with the ability to perform transmission type power flow on small to medium size networks. In this mode there are two types 1) Snapshot in which a single power solution is solved for a given load using iterative methods and 2) Direct in which single power flow solution can be obtained without any iterations.
- Dynamic power flow: This is the mode which supports time series distribution analysis in which power flow solution can be obtained for a load shape defined for a year or day. For different types of dynamic power flow load shapes vary. Load shapes can be imported from CSV file or can be written in the script file in the form of multipliers. In the Daily mode power flow solution is done for each hour in a day for a daily load shape. Similarly, in the yearly mode, yearly power flow simulation can also solve for a Yearly load shape.

- **Dynamics:** In this mode DSS can perform basic machine dynamics simulations modeling that can be used to evaluate DG interconnections. Further, fault simulation is mostly done in the dynamics mode. Thus the simulation of the distribution system which involves both DG and fault simulation this mode has been used to run the solution Mode
- **Harmonics:** This is one of the major solution types of OpenDSS which is used for analyzing harmonic effects of wind turbines and inverter based PV on voltage regulators and capacitor switching in distribution system.
- **Fault studies:** A fault in OpenDss is often simulated in dynamics mode. There are three types of fault studies that can be done 1) Conventional fault study in which currents and voltages at all the buses for different kinds of faults are calculated 2) Monte Carlo fault study in which faults predefined by user are randomly applied and 3) A single snapshot fault study in which user places a fault on the system at a particular bus, defining the type of fault and the value of the fault resistance. In this thesis work, this mode of the fault study was used to define different kinds of faults like Single line to ground (SLG), Line to Line (LL) and three phase to ground fault were defined at a single instant.

Figure 3-6: OpenDSS solution modes

3.3 Java Agent Development Framework (JADE)

JADE is a Java based software framework used to develop agent applications in compliance with the FIPA specifications for interoperable intelligent Multi Agent systems [65]. JADE can also be considered an middle-ware that implements an agent platform and a development framework. It primarily provides the agent and behavior abstractions, transparent distribution of agents across a wide range of devices, peer-to-peer communication between agents and publish-subscribe discovery mechanisms that allow agents to find each other. Further, it also has a number of additional features such as agent mobility, ontologies and content language support, fault tolerance and web services integration and a rich suite of graphical tools that facilitate the administration of a JADE based application.

JADE is one of the most widely used agent development frameworks. The R and D wing of Telecom Italia JADE was initially developed in 1998 by the Research and Development department of Telecom Italia s.p.a., but in 2000, it became open source as a community project and was distributed as open source under the LGPL (Library Gnu Public License). JADE can be freely downloaded from Telecom Italia website [65], with documentation, examples and other important information.

3.3.1 JADE Architecture

The two important aspects of the JADE architecture are the libraries of java classes required to develop application agents and the run-time environment that provides the basic services and must be active on the device or the network for agent instantiation and execution. Each instance of the JADE run-time is called container in which all the agents are embedded. Some of the important libraries of JADE are `jade.core`, `jade.lang.acl`, `jade.domain`, `jade.content` etc. The run time environment in JADE is provided by the Main container which is launched first and the other possible containers must join by registering with it. The functions of the Main container are creation and management of container table and global Agent descriptor table which provide registry for agent object references, transport addresses, current status and location. Further, the main container also contains of Agent Management System (AMS) and the Directory Facilitator (DF) agent which are used for agent management and provide white and yellow page service.

Figure 3-7: JADE distributed architecture [65]

Apart from AMS and DF agent there are many agents available in Jade for the development and debugging of agent platforms. These agents are Dummy Agent, Sniffer Agent, and Introspector Agent. The Dummy Agent is used to simulate other agents behavior by sending ACL messages to them and analyzing the received messages. The sniffer agent can be used to visualize the message exchange between agents which is really helpful for debugging purposes. While the Introspector Agent is useful to control and monitor agent sent and received messages, scheduled behaviors of agent, and the agent life cycle. Thus is useful to debug Agents.

Figure3-8 shows the output of JADE run-time environment, when JADE is launched. While Figure 3-9 represents the Jade GUI.


```

C:\> Command Prompt - java jade.Boot -gui Recloser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent...

This is JADE 3.7 - revision 6154 of 2009/07/01 17:34:15
downloaded in Open Source, under LGPL restrictions,
at http://jade.tilab.com/

-----
Nov 11, 2011 1:36:22 PM jade.core.BaseService init
INFO: Service jade.core.management.AgentManagement initialized
Nov 11, 2011 1:36:22 PM jade.core.BaseService init
INFO: Service jade.core.messaging.Messaging initialized
Nov 11, 2011 1:36:22 PM jade.core.BaseService init
INFO: Service jade.core.mobility.AgentMobility initialized
Nov 11, 2011 1:36:22 PM jade.core.BaseService init
INFO: Service jade.core.event.Notification initialized
Nov 11, 2011 1:36:22 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 11, 2011 1:36:22 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParserImpl$JAXPSAXParser
Nov 11, 2011 1:36:22 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 11, 2011 1:36:22 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.
  
```

Figure 3-8: JADE run time environment

Figure 3-9: JADE GUI

3.3.2 JADE Programming

As mentioned in section 3.3 JADE is a java based platform and thus programming in it involves usage of java concepts and syntax. Every agent that is created must extend the agent class defined in the Library `jade.core.agent` and the agent implementation for initialization purposes has to be done in the `setup` method. Another aspect of agent creation is the usage of the appropriate ‘behavior’ which defines the typical operations to be performed by the agent. Some of the behaviors available in JADE are cyclic behavior,

simple behavior and general behavior. In the creation of agents for this work simple behavior has been employed for all the agents.

Every agent that is created is identified by a unique Agent identifier (AID). To retrieve the AID of a particular agent get AID() method of jade.core.AID is used. Agent names are of the form <local-name>@<platform-name> and every agent must have a unique name globally.

The most pivotal aspect of a Multi Agent system is communication which is also a fundamental feature in JADE. All the messages between the agents are asynchronous and are based on ACL language that is FIPA compliant. All the messages received by an agent are stored in its message queue. The send() and receive () methods are used by an agent to send and receive messages. In order to terminate an agent doDelete() method is used.

JADE has been used in this thesis work for developing the Multi agent system for the Modified IEEE 37 bus Microgrid test system.

CHAPTER 4

FAULT LOCATION ALGORITHM AND RESULTS

In this chapter, the fault detection algorithm, test system, agent architecture and test cases are presented. The fault detection algorithm is developed in JADE. For modeling and designing the test system, OpenDSS has been used.

4.1 Multi Agent System Architecture

The proposed Multi Agent system architecture for fault location is illustrated in the Figure 4-1. According to the architecture, there are mainly two categories of agents available:

- Global Agent
- Zonal Agents

Recloser Agent (RA) is a Global Agent that keeps track of the status of the recloser at the substation and informs the Zone Agents in various zones when the recloser locks out. The Zone Agent (ZA) and Switch Agent (SW) fall into the category of Zonal Agents. These agents are responsible for managing each zone in the power distribution system considered in Figure 4-3. Each Zone Agent has an associated Switch Agent which is responsible for implementing the fault location algorithm.

When a permanent fault occurs in the system, the recloser tries multiple times and locks out, upon which the Recloser Agent informs the Zone Agents about the lock out. Then, the Zone Agent informs its corresponding Switch Agent to check for a fault and implement the fault location algorithm, described in section 4.3. The Zonal Agents have local information like power flow, sequence current magnitude and phase angle of all the distribution lines in their respective zones.

In view of the real world deployment of these agents, information regarding sequence current magnitudes and phase angles can be obtained from the real world protective

relays described in [65-68]. Zonal Agents implement fault location in a decentralized manner. So, the proposed Multi Agent architecture is decentralized.

Figure 4-1: Multi Agent architecture

The main responsibility of each agent is described below:

- **Recloser Agent (RA):** This agent keeps track of the status of the recloser at the substation and informs the Zone Agents in various zones when the recloser locks out. After the lock out, the tripping off action of the recloser has been implemented by opening the substation transformer in the test system. So, the Recloser Agent sees negligible current in all phases of the substation transformer that has been opened and informs the Zone Agents about the lock out.
- **Zone Agent (ZA):** This agent informs its corresponding Switch Agent about the recloser lock out and asks it to implement the fault location algorithm. The Zone Agent receives the fault location from the Switch Agent after it locates the fault.
- **Switch Agent (SW):** This agent is the most important entity in this agent architecture, since it implements the fault location algorithm. The Switch Agent has information of the power flows, sequence current magnitudes and phase

angles of all the lines in its zone. The values of sequence current components are obtained directly from the simulation of the test system in OpenDSS software. The fault location algorithm embedded in the Switch Agent is described in section 4.3.

4.2 Test System

The IEEE 37 bus system was selected as the system of choice for this research. It represents an actual underground radial distribution feeder in California operating at 4.8kV under heavy phase imbalances [69]. It is configured as a three-wire delta system and therefore has delta connected loads only. It does, however, have many different line-to-line loads that contribute to its unbalanced conditions. In addition, they are buried underground with a Spacing ID of 515, corresponding to configuration in the following figure:

Figure 4-2: Cable spacing

To achieve the MicroGrid, the standard IEEE 37 bus system was modified by adding Distribution Generation units at various nodes in the circuit. Distributed Generation unit considered here is solar. The default PV model of the solar generation available in OpenDSS was used in the simulation. The capacity of these Distributed Generation units depends on their penetration level in the MicroGrid. The penetration levels considered are 25%, 50%, 75% and 100%. The details of the rating of the generation units for these various penetration levels are provided in Table 4-1.

In order to implement the Multi agent system described in section 4.1, the Modified IEEE 37 bus system has been divided into three zones such that the Distributed Generation units in that zone can supply either a part or the full load in that zone. The Zone1 considered has 15 distribution lines (L1-L15), 9 loads demanding 779 KW and 344 KVar

and 3 Solar Distributed Generation units connected at nodes 718,724 and 742. While, Zone2 has 10 distribution lines (L16-L25), 8 loads demanding 549 KW and 267 KVar and 2 Distributed Generation units of solar at 729 and 731. Then, Zone3 has 9 distribution lines (L26-L34), 7 loads demanding 567 KW and 275 KVar and 2 Distributed Generation units at 736 and 741. The modified IEEE 37 bus system is shown in Figure 4-3.

Table 4-1: Distributed Generation rating

Penetration Level	Zone1Generation	Zone2Generation	Zone3Generation
100%	DG ₇₂₄ 260kw p.f 1.0 DG ₇₁₈ 260kw p.f 1.0 DG ₇₄₂ 262kw p.f 0.9	DG ₇₂₉ 275.0kw p.f 1.0 DG ₇₃₁ 274.0kw p.f 0.9	DG ₇₃₆ 280kw p.f 1.0 DG ₇₄₁ 282kw p.f 0.9
75%	DG ₇₂₄ 196kw p.f 1.0 DG ₇₁₈ 195kw p.f 1.0 DG ₇₄₂ 195kw p.f 0.9	DG ₇₂₉ 207.0kw p.f 1.0 DG ₇₃₁ 206.5kw p.f 0.9	DG ₇₃₆ 210kw p.f 1.0 DG ₇₄₁ 211kw p.f 0.9
50%	DG ₇₂₄ 130kw p.f 1.0 DG ₇₁₈ 130kw p.f 1.0 DG ₇₄₂ 131kw p.f 0.9	DG ₇₂₉ 137.5kw p.f 1.0 DG ₇₃₁ 137.0kw p.f 0.9	DG ₇₃₆ 140kw p.f 1.0 DG ₇₄₁ 141kw p.f 0.9
25%	DG ₇₂₄ 66kw p.f 1.0 DG ₇₁₈ 65kw p.f 1.0 DG ₇₄₂ 64kw p.f 0.9	DG ₇₂₉ 69.0kw p.f 1.0 DG ₇₃₁ 68.25kw p.f 0.9	DG ₇₃₆ 70kw p.f 1.0 DG ₇₄₁ 70.5kw p.f 0.9

Figure 4-3: Modified IEEE test system

The voltage, current and power flow results for the different penetration levels are presented in the following tables. The voltage magnitude and phase angle in each phase are shown at all the buses of the test system. While, the current magnitude and phase angle in each phase for each node of the distribution line are shown. For all the distribution lines, values of current are first shown at the node near the substation and then at the other node of the line. The power flow results show both the real power (kW) and reactive power (kVar) in all the lines and transformers. The power flow in the lines are shown first at the node near the substation and then at the other node of the line.

4.2.1 100% DG penetration case

Table 4-2: 100% DG penetration case voltages

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
Source bus	230	1	132791	0	1.00	2	132791	-120	1.00	3	132791	120	1.00
709	4.8	1	2672.51	-2.6	0.96	2	2710.87	-120	0.98	3	2797.74	118	1.01
775	0.48	1	267.25	-2.6	0.96	2	271.09	-120	0.98	3	279.773	118	1.01
701	4.8	1	2672.62	-2.6	0.96	2	2712.96	-120.1	0.98	3	2790.81	117.9	1.01
702	4.8	1	2673.33	-2.6	0.96	2	2713.23	-120.1	0.98	3	2791.18	118	1.01
705	4.8	1	2674.57	-2.5	0.97	2	2714.44	-120.1	0.98	3	2790.61	118	1.01
713	4.8	1	2673.77	-2.5	0.96	2	2713.31	-120.2	0.98	3	2789.83	118	1.01
703	4.8	1	2673.68	-2.6	0.96	2	2711.8	-120.1	0.98	3	2794.92	118	1.01
704	4.8	1	2676.14	-2.5	0.97	2	2713.43	-120.2	0.98	3	2788.72	118	1.01
720	4.8	1	2677.36	-2.5	0.97	2	2713.88	-120.3	0.98	3	2784.61	118	1.00
706	4.8	1	2677.3	-2.5	0.97	2	2713.38	-120.3	0.98	3	2783.69	118	1.00
725	4.8	1	2677.28	-2.5	0.97	2	2712.85	-120.3	0.98	3	2782.93	118	1.00
707	4.8	1	2685.86	-2.5	0.97	2	2714.67	-120.5	0.98	3	2781.93	118	1.00

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
722	4.8	1	2685.66	-2.5	0.97	2	2713.91	-120.5	0.98	3	2780.74	118	1.00
724	4.8	1	2694.19	-2.5	0.97	2	2720.15	-120.5	0.98	3	2787.24	118.1	1.01
714	4.8	1	2676.54	-2.5	0.97	2	2713.45	-120.2	0.98	3	2789.26	118	1.01
718	4.8	1	2679.58	-2.5	0.97	2	2714.61	-120.1	0.98	3	2793.41	118.1	1.01
712	4.8	1	2673.21	-2.5	0.96	2	2714.44	-120.1	0.98	3	2789.69	118	1.01
742	4.8	1	2677.38	-2.5	0.97	2	2715.41	-120.1	0.98	3	2791.37	118	1.01
727	4.8	1	2674.07	-2.6	0.96	2	2711.8	-120.1	0.98	3	2796.09	118	1.01
730	4.8	1	2672.32	-2.6	0.96	2	2711.1	-120	0.98	3	2796.8	118	1.01
731	4.8	1	2676.75	-2.6	0.97	2	2713.19	-120	0.98	3	2799.32	118	1.01
708	4.8	1	2670.58	-2.7	0.96	2	2709.27	-120	0.98	3	2798.41	118	1.01
732	4.8	1	2669.68	-2.7	0.96	2	2709.27	-120	0.98	3	2797.8	118	1.01
733	4.8	1	2669.16	-2.7	0.96	2	2707.66	-119.9	0.98	3	2799.33	118	1.01
744	4.8	1	2674.97	-2.7	0.97	2	2711.81	-120.1	0.98	3	2797.12	118	1.01
729	4.8	1	2678.07	-2.7	0.97	2	2713.88	-120.1	0.98	3	2800.24	118	1.01
728	4.8	1	2674.02	-2.7	0.96	2	2710.87	-120.1	0.98	3	2796.23	118	1.01
734	4.8	1	2667.53	-2.7	0.96	2	2706.57	-119.9	0.98	3	2800.83	118	1.01
737	4.8	1	2665.13	-2.8	0.96	2	2703.05	-119.8	0.98	3	2802.39	118	1.01
738	4.8	1	2664.61	-2.8	0.96	2	2702.88	-119.8	0.98	3	2803.24	118	1.01
711	4.8	1	2665.02	-2.7	0.96	2	2704.61	-119.8	0.98	3	2803.95	118.1	1.01
741	4.8	1	2666.76	-2.7	0.96	2	2706.34	-119.7	0.98	3	2805.33	118.1	1.01
740	4.8	1	2663.89	-2.7	0.96	2	2704.61	-119.8	0.98	3	2803.19	118	1.01
710	4.8	1	2670.51	-2.6	0.96	2	2710.2	-119.9	0.98	3	2802.32	118.1	1.01
736	4.8	1	2685.08	-2.5	0.97	2	2719.12	-119.8	0.98	3	2810.91	118.3	1.01
735	4.8	1	2669.38	-2.6	0.96	2	2710.2	-119.9	0.98	3	2801.56	118	1.01

Table 4-3: 100% DG Penetration Case Currents

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Vsource.source	4.18E-06	90	4.18E-06	-30	4.18E-06	-150	4.18E-06	-90	4.18E-06	150	4.18E-06	30
Subxf	4.18E-06	-90	4.18E-06	150	4.18E-06	30	2.33E-09	-7.95	2.71E-09	-120.15	2.42E-09	122.91
Xfm1	3.87E-05	-92.64	3.92E-05	149.97	4.05E-05	27.99	4.07E-12	-153.43	2.03E-12	153.43	7.50E-12	-14.04
Line.l1	9.17	164.82	5.14	60.09	9.31	-47.46	9.16	-14.80	5.14	-119.20	9.32	132.92
Line.l2	18.32	-143.38	9.73	36.20	8.60	37.13	18.33	36.65	9.73	-143.73	8.61	-142.89
Line.l3	12.29	-164.72	21.50	-54.04	20.70	92.10	12.29	15.34	21.48	125.95	20.71	-87.93
Line.l4	24.21	42.99	24.15	138.08	32.71	-89.56	24.15	-137.15	24.24	-41.88	32.66	90.58
Line.l5	27.66	166.40	21.48	-54.05	17.99	37.45	27.66	-13.56	21.47	125.93	18.01	-142.56
Line.l6	13.70	-174.22	34.60	-52.28	29.76	104.65	13.71	5.91	34.57	127.70	29.77	-75.41
Line.l7	0.03	87.51	8.77	-90.60	8.73	89.41	0.01	-92.49	8.75	89.27	8.75	-90.73
Line.l8	0.01	87.51	8.75	-90.73	8.75	89.27	0.00	100.62	8.75	89.22	8.75	-90.78
Line.l9	29.86	163.87	28.22	-41.20	12.74	54.16	29.86	-16.08	28.19	138.79	12.77	-125.89
Line.l10	4.37	-32.75	29.17	-90.84	31.70	95.89	4.38	147.21	29.17	89.15	31.70	-84.12
Line.l11	34.07	161.81	24.09	26.09	23.75	-63.13	34.06	-18.15	24.07	-153.87	23.75	116.93
Line.l12	15.41	149.31	13.16	130.64	28.19	-39.26	15.41	-30.68	13.16	-49.36	28.19	140.75
Line.l13	17.47	159.39	16.96	108.64	31.11	-45.56	17.47	-20.56	16.97	-71.33	31.12	134.47
Line.l14	17.92	-32.95	0.01	-30.14	17.93	147.05	17.92	147.03	0.00	0.00	17.92	-32.97
Line.l15	29.77	-177.70	9.72	36.31	22.38	-11.75	29.77	2.32	9.72	-143.64	22.39	168.27
Line.l16	16.32	86.49	1.00	-48.74	15.62	-96.10	16.32	-93.51	0.99	131.12	15.62	83.92
Line.l17	16.70	0.44	25.23	137.85	17.24	-83.37	16.70	-179.64	25.25	-42.14	17.23	96.70
Line.l18	9.88	78.25	25.25	137.86	31.48	-57.96	9.87	-101.75	25.26	-42.14	31.48	122.06
Line.l19	39.78	161.22	24.44	8.09	21.10	-50.33	39.78	-18.74	24.42	-171.88	21.10	129.73
Line.l20	39.80	-4.53	45.00	162.53	10.93	-72.76	39.80	175.46	45.02	-17.47	10.93	107.30
Line.l21	8.84	-33.05	0.01	-29.98	8.85	146.95	8.84	146.89	0.00	101.77	8.84	-33.11

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Line.l22	32.31	2.95	45.03	162.52	18.61	-55.04	32.31	-177.07	45.04	-17.48	18.62	124.99
Line.l23	22.06	106.88	0.994392	-48.88	21.1503	-74.22	22.0494	-73.11	0.984208	130.92	21.148	105.81
Line.l24	34.36	150.14	23.6871	45.14	36.3284	-68.89	34.353	-29.85	23.6849	-134.84	36.3273	111.13
Line.l25	15.40	-1.53	15.4139	-121.59	15.3952	118.4	15.4036	178.44	15.4141	58.38	15.3951	-61.62
Line.l26	18.14	-22.4	35.2454	141.18	18.6159	-55.01	18.1469	157.53	35.2667	-38.82	18.6186	125.06
Line.l27	34.65	17.6	38.6422	177.73	13.2764	-65.11	34.6368	-162.44	38.6639	-2.28	13.2751	115
Line.l28	8.35	-26.08	20.4269	129.94	13.2751	-65	8.35923	153.83	20.4413	-50.05	13.2742	115.07
Line.l29	23.76	-134.25	31.0042	69.31	13.2742	-64.93	23.7727	45.78	31.0066	-110.66	13.2734	115.14
Line.l30	32.37	-167.05	31.0076	69.35	30.0012	-46.6	32.3772	12.98	31.01	-110.62	30.0054	133.43
Line.l31	17.88	-33.16	0.006172	-29.77	17.8865	146.85	17.8834	146.83	2.03E-12	26.57	17.8834	-33.17
Line.l32	26.79	-152	23.3966	61.58	14.8607	-32.69	26.7993	28.03	23.397	-118.38	14.8688	147.37
Line.l33	38.74	-175.79	23.3972	61.64	32.7507	-32.86	38.7464	4.27	23.3982	-118.27	32.7706	147.2
Line.l34	17.88	-33.06	0.006185	-29.85	17.8821	146.94	17.879	146.92	2.45E-12	21.8	17.879	-33.08

Table 4-4: 100% DG Penetration Power Flow

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	-23.93	-5.36	-13.94	0.06	-25.13	6.55	23.93	5.20	13.94	-0.23	25.14	-6.72
Line.l2	-37.98	30.94	-24.19	-10.60	3.83	23.69	38.02	-30.96	24.20	10.57	-3.82	-23.72
Line.l3	-31.28	10.06	23.63	-53.33	52.00	25.20	31.28	-10.09	-23.60	53.30	-51.98	-25.23
Line.l4	45.32	-46.19	-13.38	64.15	-80.96	-42.17	-45.27	46.02	13.43	-64.34	81.05	42.01
Line.l5	-72.59	-14.19	23.60	-53.30	8.28	49.51	72.65	14.18	-23.56	53.27	-8.25	-49.55
Line.l6	-36.29	5.29	35.28	-87.00	80.75	19.13	36.30	-5.36	-35.13	86.99	-80.64	-19.16
Line.l7	0.00	-0.08	20.66	-11.79	21.37	11.63	0.00	0.02	-20.66	11.73	-21.36	-11.69
Line.l8	0.00	-0.02	20.66	-11.73	21.36	11.69	0.00	0.00	-20.65	11.71	-21.35	-11.71
Line.l9	-77.70	-18.86	14.47	-75.20	15.67	31.84	77.94	18.86	-14.25	75.19	-15.62	-31.90
Line.l10	10.14	5.92	68.82	-39.16	81.68	33.23	-10.14	-5.93	-68.79	39.16	-81.65	-33.23
Line.l11	-88.08	-24.78	-54.57	-36.03	-66.07	-1.33	88.35	24.81	54.70	36.00	66.19	1.31
Line.l12	-36.36	-19.47	-11.72	33.73	-72.50	30.41	36.37	19.47	11.72	-33.74	72.52	-30.42
Line.l13	-44.46	-14.53	-30.29	34.65	-83.23	24.56	44.51	14.50	30.34	-34.68	83.38	-24.56
Line.l14	41.32	24.29	0.00	-0.02	43.73	-24.31	-41.30	-24.30	0.00	0.00	-43.70	24.30
Line.l15	-79.34	6.67	-24.20	-10.55	-39.91	48.04	79.42	-6.67	24.21	10.52	39.96	-48.05
Line.l16	0.68	-43.64	0.87	-2.57	-36.17	-24.47	-0.66	43.63	-0.87	2.55	36.19	24.45
Line.l17	44.59	-2.38	-14.29	66.91	-44.89	-17.54	-44.57	2.33	14.35	-66.95	44.92	17.49
Line.l18	4.18	-26.06	-14.35	66.95	-87.82	6.24	-4.18	26.05	14.37	-66.96	87.85	-6.24
Line.l19	-102.13	-29.54	-40.89	-52.13	-57.81	11.95	102.28	29.57	40.94	52.09	57.85	-11.99
Line.l20	106.31	3.50	26.52	119.08	-30.04	-5.71	-106.23	-3.48	-26.42	-119.06	30.05	5.67
Line.l21	20.36	11.94	0.00	-0.03	21.66	-11.99	-20.35	-11.96	0.00	0.00	-21.65	11.96
Line.l22	85.88	-8.45	26.42	119.09	-51.71	6.31	-85.83	8.45	-26.32	-119.07	51.73	-6.34

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l23	-19.72	-55.60	0.87	-2.55	-57.81	-12.48	19.74	55.58	-0.87	2.52	57.83	12.47
Line.l24	-81.74	-42.02	-62.11	-16.37	-100.89	-12.15	81.84	42.03	62.16	16.36	101.00	12.16
Line.l25	41.20	-0.81	41.79	1.09	43.06	-0.32	-41.18	0.80	-41.77	-1.10	-43.05	0.31
Line.l26	45.58	16.34	-14.73	94.29	-51.73	6.34	-45.55	-16.38	14.84	-94.29	51.76	-6.39
Line.l27	86.68	-32.05	48.47	92.68	-37.13	-2.03	-86.57	32.05	-48.32	-92.67	37.15	1.97
Line.l28	20.44	8.81	-19.10	51.81	-37.15	-1.97	-20.44	-8.85	19.13	-51.83	37.16	1.93
Line.l29	-41.94	47.43	-82.75	13.26	-37.16	-1.93	41.98	-47.45	82.81	-13.27	37.17	1.89
Line.l30	-83.07	23.32	-82.81	13.28	-81.12	22.27	83.13	-23.32	82.86	-13.29	81.17	-22.27
Line.l31	41.09	24.14	0.00	-0.02	43.95	-24.16	-41.07	-24.15	0.00	0.00	-43.93	24.15
Line.l32	-61.45	36.48	-63.30	1.61	-36.30	20.36	61.57	-36.49	63.39	-1.63	36.34	-20.39
Line.l33	-102.73	12.31	-63.39	1.65	-80.22	44.60	103.32	-12.22	63.60	-1.69	80.62	-44.56
Line.l34	41.16	24.18	0.00	-0.02	43.88	-24.20	-41.14	-24.19	0.00	0.00	-43.86	24.19

4.2.2 75% DG Penetration Case

Table 4-5: 75% DG penetration case voltages

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
Source bus	230	1	122277	-2.8	0.92	2	123123	-121.6	0.93	3	124925	117.4	0.94
709	4.8	1	2713.87	-3.8	0.98	2	2748.5	-122	0.99	3	2805.28	116.5	1.01
775	0.48	1	271.384	-3.8	0.98	2	274.851	-122	0.99	3	280.529	116.5	1.01
701	4.8	1	2730.21	-3.7	0.99	2	2762.25	-122.1	1.00	3	2811.11	116.6	1.01
702	4.8	1	2724.42	-3.6	0.98	2	2757.74	-122.1	1.00	3	2806.16	116.6	1.01
705	4.8	1	2724.8	-3.6	0.98	2	2758.33	-122.1	1.00	3	2804.9	116.6	1.01
713	4.8	1	2723.43	-3.6	0.98	2	2756.73	-122.1	0.99	3	2803.64	116.6	1.01
703	4.8	1	2719.28	-3.7	0.98	2	2752.39	-122	0.99	3	2805.5	116.6	1.01
704	4.8	1	2723.72	-3.6	0.98	2	2755.28	-122.1	0.99	3	2800.82	116.6	1.01

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
720	4.8	1	2722.79	-3.5	0.98	2	2754.05	-122.2	0.99	3	2794.81	116.6	1.01
706	4.8	1	2722.73	-3.5	0.98	2	2753.56	-122.2	0.99	3	2793.89	116.6	1.01
725	4.8	1	2722.71	-3.5	0.98	2	2753.03	-122.2	0.99	3	2793.15	116.6	1.01
707	4.8	1	2727.58	-3.4	0.98	2	2752.05	-122.3	0.99	3	2788.87	116.7	1.01
722	4.8	1	2727.38	-3.4	0.98	2	2751.29	-122.3	0.99	3	2787.68	116.7	1.01
724	4.8	1	2732.86	-3.4	0.99	2	2755.22	-122.2	0.99	3	2791.47	116.8	1.01
714	4.8	1	2723.95	-3.6	0.98	2	2755.17	-122.1	0.99	3	2801.23	116.6	1.01
718	4.8	1	2725.81	-3.6	0.98	2	2755.51	-122	0.99	3	2804.52	116.7	1.01
712	4.8	1	2723.46	-3.6	0.98	2	2758.33	-122.1	1.00	3	2804	116.6	1.01
742	4.8	1	2726.9	-3.6	0.98	2	2758.81	-122.1	1.00	3	2805.1	116.6	1.01
727	4.8	1	2718.57	-3.7	0.98	2	2751.59	-122	0.99	3	2805.7	116.6	1.01
730	4.8	1	2714.73	-3.7	0.98	2	2749.47	-122	0.99	3	2805.1	116.5	1.01
731	4.8	1	2716.21	-3.7	0.98	2	2749.37	-121.9	0.99	3	2805.19	116.6	1.01
708	4.8	1	2711.24	-3.8	0.98	2	2746.48	-121.9	0.99	3	2805.62	116.5	1.01
732	4.8	1	2710.35	-3.8	0.98	2	2746.48	-121.9	0.99	3	2805.03	116.5	1.01
733	4.8	1	2709.13	-3.8	0.98	2	2744.46	-121.9	0.99	3	2806.21	116.5	1.01
744	4.8	1	2718.59	-3.7	0.98	2	2750.94	-122	0.99	3	2805.97	116.6	1.01
729	4.8	1	2720.38	-3.7	0.98	2	2752.05	-122	0.99	3	2807.94	116.6	1.01
728	4.8	1	2717.65	-3.7	0.98	2	2750.02	-122	0.99	3	2805.09	116.6	1.01
734	4.8	1	2706.3	-3.9	0.98	2	2742.65	-121.9	0.99	3	2807.14	116.5	1.01
737	4.8	1	2702.82	-3.9	0.98	2	2738.43	-121.8	0.99	3	2807.96	116.5	1.01
738	4.8	1	2701.65	-3.9	0.97	2	2737.81	-121.8	0.99	3	2808.34	116.5	1.01
711	4.8	1	2701.39	-3.9	0.97	2	2739.07	-121.7	0.99	3	2808.6	116.5	1.01
741	4.8	1	2702.46	-3.9	0.98	2	2740.33	-121.7	0.99	3	2809.5	116.5	1.01
740	4.8	1	2700.27	-3.9	0.97	2	2739.07	-121.7	0.99	3	2807.84	116.5	1.01
710	4.8	1	2708.44	-3.8	0.98	2	2745.74	-121.9	0.99	3	2808.19	116.5	1.01

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
736	4.8	1	2720.89	-3.8	0.98	2	2753.33	-121.9	0.99	3	2815.6	116.6	1.02
735	4.8	1	2707.32	-3.8	0.98	2	2745.74	-121.9	0.99	3	2807.43	116.5	1.01

Table 4-6: 75% DG Penetration Case Currents

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Vsource	1.74	133.67	1.47	3.99	1.38	-100.87	1.74	-46.33	1.47	-176.01	1.38	79.13
Subxf	1.74	-46.33	1.47	-176.01	1.38	79.13	83.35	133.67	70.24	3.99	66.36	-100.87
Xfm1	0.00	-93.75	0.00	148.05	0.00	26.54	0.00	180.00	0.00	-26.57	0.00	180.00
Line.l1	68.07	-50.13	61.07	-179.89	55.18	71.59	68.12	129.84	61.12	0.08	55.23	-108.46
Line.l2	16.45	-123.17	4.79	46.23	11.79	61.16	16.46	56.85	4.78	-133.62	11.80	-118.88
Line.l3	22.47	-86.98	18.27	-120.80	39.03	77.90	22.48	93.02	18.27	59.15	39.04	-102.12
Line.l4	53.92	-17.38	56.40	167.56	5.32	47.14	53.94	162.53	56.49	-12.47	5.40	-133.19
Line.l5	18.43	-137.19	18.27	-120.85	36.36	50.97	18.45	42.85	18.27	59.09	36.38	-129.05
Line.l6	18.69	-110.97	24.20	-80.98	41.48	85.99	18.72	69.06	24.18	98.97	41.49	-94.05
Line.l7	0.03	86.48	8.71	-92.38	8.68	87.63	0.01	-93.52	8.70	87.49	8.69	-92.51
Line.l8	0.01	86.48	8.70	-92.51	8.69	87.49	0.00	161.57	8.69	87.44	8.69	-92.56
Line.l9	22.76	-160.48	15.73	-74.78	28.64	52.78	22.77	19.59	15.71	105.15	28.67	-127.25
Line.l10	4.37	-33.67	29.17	-92.55	31.65	94.24	4.38	146.29	29.17	87.44	31.65	-85.76
Line.l11	25.63	-168.27	14.98	68.87	21.55	-23.93	25.63	11.78	14.99	-111.04	21.56	156.12
Line.l12	8.42	144.32	15.53	148.03	23.93	-33.25	8.41	-35.66	15.54	-31.97	23.94	146.76
Line.l13	10.51	161.82	17.30	124.69	26.44	-41.41	10.50	-18.10	17.31	-55.29	26.45	138.62
Line.l14	17.74	-33.98	0.01	-32.08	17.75	146.02	17.74	146.00	0.00	132.51	17.74	-34.00
Line.l15	24.03	-170.73	4.78	46.47	20.42	1.17	24.03	9.29	4.78	-133.41	20.43	-178.82
Line.l16	9.60	-16.75	18.26	167.34	8.71	-8.14	9.60	163.21	18.27	-12.67	8.72	171.89

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Line.I17	44.34	-17.62	38.22	167.61	7.14	133.61	44.35	162.35	38.25	-12.40	7.14	-46.57
Line.I18	27.87	-7.29	38.25	167.60	10.80	-25.97	27.87	172.70	38.25	-12.40	10.81	154.06
Line.I19	29.66	-169.87	9.05	53.07	23.85	-4.85	29.67	10.17	9.04	-126.78	23.87	175.18
Line.I20	56.87	1.69	42.81	178.68	14.30	-169.09	56.86	-178.33	42.82	-1.33	14.29	10.90
Line.I21	8.77	-34.15	0.01	-31.93	8.78	145.85	8.78	145.79	0.00	-144.78	8.78	-34.21
Line.I22	50.01	7.57	42.83	178.67	10.20	-131.55	50.01	-172.45	42.84	-1.34	10.19	48.48
Line.I23	2.88	48.00	18.27	167.33	17.04	-21.14	2.87	-132.13	18.28	-12.68	17.05	158.89
Line.I24	21.26	-176.82	20.96	94.33	30.15	-40.84	21.26	3.20	20.96	-85.65	30.15	139.18
Line.I25	15.23	-3.01	15.24	-123.03	15.23	116.96	15.23	176.97	15.24	56.94	15.23	-63.06
Line.I26	33.89	-2.64	28.60	161.36	10.19	-131.52	33.89	177.32	28.62	-18.65	10.17	48.53
Line.I27	41.87	8.06	43.84	-179.21	5.81	-65.76	41.86	-171.97	43.86	0.78	5.81	114.49
Line.I28	17.29	-25.92	22.05	144.49	5.81	-65.51	17.29	154.03	22.07	-35.51	5.81	114.65
Line.I29	21.73	-112.95	25.97	76.51	5.81	-65.35	21.74	67.06	25.97	-103.45	5.81	114.80
Line.I30	25.22	-156.65	25.98	76.56	22.97	-41.79	25.23	23.38	25.98	-103.41	22.97	138.25
Line.I31	17.78	-34.33	0.01	-31.75	17.79	145.67	17.78	145.65	0.00	-33.69	17.78	-34.35
Line.I32	15.07	-170.42	19.36	30.27	7.50	-104.40	15.07	9.64	19.35	-149.69	7.49	75.69
Line.I33	30.48	165.79	19.35	30.33	21.51	-53.36	30.47	-14.13	19.33	-149.56	21.52	126.74
Line.I34	17.77	-34.27	0.01	-31.87	17.77	145.74	17.77	145.72	0.00	-67.38	17.77	-34.28
Line.I35	75.77	-46.33	63.85	-176.01	60.33	79.13	75.88	133.59	63.98	3.90	60.42	-100.99

Table 4-7: 75% DG Penetration Power Flow

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	154.33	146.37	105.13	146.70	135.79	107.21	395.24	0.00	-158.07	-121.11	-114.57	-157.15
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	128.00	134.75	89.90	142.73	109.73	109.66	-127.71	-134.66	-89.71	-142.71	-109.56	-109.62
Line.l2	-22.09	39.00	-12.92	-2.67	18.79	27.24	22.12	-39.02	12.93	2.64	-18.78	-27.27
Line.l3	7.11	60.79	50.37	-1.12	85.52	68.41	-7.08	-60.81	-50.35	1.09	-85.44	-68.40
Line.l4	142.69	34.86	52.26	146.50	5.25	13.97	-142.46	-34.86	-52.04	-146.51	-5.25	-14.22
Line.l5	-34.60	36.38	50.35	-1.09	42.11	92.84	34.63	-36.41	-50.32	1.05	-42.01	-92.83
Line.l6	-15.21	48.59	50.22	-43.85	99.97	59.17	15.26	-48.64	-50.15	43.80	-99.76	-59.13
Line.l7	0.00	-0.09	20.81	-11.92	21.21	11.75	0.00	0.02	-20.81	11.86	-21.21	-11.81
Line.l8	0.00	-0.02	20.81	-11.86	21.21	11.81	0.00	0.00	-20.80	11.83	-21.20	-11.83
Line.l9	-57.02	24.26	29.33	-31.88	35.31	71.85	57.16	-24.29	-29.26	31.82	-35.07	-71.85
Line.l10	10.31	6.01	69.72	-39.78	81.56	33.76	-10.30	-6.02	-69.69	39.78	-81.52	-33.76
Line.l11	-67.46	18.28	-40.46	7.96	-46.48	38.09	67.62	-18.29	40.51	-8.01	46.59	-38.12
Line.l12	-19.42	-12.18	0.10	42.80	-57.97	33.67	19.42	12.17	-0.10	-42.81	57.98	-33.67
Line.l13	-27.70	-7.21	-18.79	43.80	-68.69	27.71	27.72	7.18	18.83	-43.84	68.80	-27.72
Line.l14	41.70	24.44	0.00	-0.02	43.35	-24.47	-41.68	-24.45	0.00	0.00	-43.32	24.45
Line.l15	-63.82	14.58	-12.93	-2.62	-24.57	51.74	63.88	-14.59	12.93	2.59	24.61	-51.75
Line.l16	25.42	5.88	16.67	47.42	-13.91	20.10	-25.41	-5.90	-16.65	-47.44	13.92	-20.12
Line.l17	117.04	28.98	35.36	99.08	19.16	-5.88	-116.86	-28.94	-35.23	-99.08	-19.16	5.82
Line.l18	75.51	4.68	35.23	99.08	-24.04	18.44	-75.49	-4.68	-35.18	-99.08	24.04	-18.46
Line.l19	-78.15	19.31	-24.77	-2.16	-34.85	57.11	78.23	-19.32	24.78	2.10	34.90	-57.14
Line.l20	153.63	-14.63	59.95	101.23	10.81	-38.64	-153.47	14.69	-59.86	-101.22	-10.80	38.62
Line.l21	20.53	12.02	0.00	-0.03	21.49	-12.07	-20.52	-12.05	0.00	0.00	-21.48	12.05
Line.l22	132.94	-26.71	59.86	101.25	-10.69	-26.54	-132.82	26.75	-59.77	-101.23	10.70	26.51

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l23	4.85	-6.15	16.65	47.44	-35.36	32.17	-4.85	6.12	-16.63	-47.46	35.37	-32.20
Line.l24	-57.38	6.94	-46.45	34.15	-78.10	32.48	57.42	-6.96	46.48	-34.16	78.18	-32.48
Line.l25	41.40	-0.52	41.91	0.76	42.73	-0.29	-41.39	0.50	-41.90	-0.77	-42.72	0.27
Line.l26	91.78	-1.91	18.00	76.39	-10.70	-26.51	-91.69	1.91	-17.93	-76.41	10.71	26.45
Line.l27	110.86	-23.42	64.86	101.24	-16.30	-0.64	-110.69	23.45	-64.67	-101.21	16.31	0.57
Line.l28	43.32	17.49	-3.90	60.26	-16.31	-0.57	-43.31	-17.52	3.93	-60.29	16.31	0.53
Line.l29	-19.12	55.50	-67.51	22.31	-16.31	-0.53	19.15	-55.52	67.55	-22.33	16.31	0.48
Line.l30	-60.57	31.20	-67.55	22.35	-59.93	23.86	60.61	-31.22	67.59	-22.37	59.96	-23.89
Line.l31	41.42	24.33	0.00	-0.02	43.62	-24.35	-41.40	-24.34	0.00	0.00	-43.60	24.34
Line.l32	-39.66	9.48	-46.93	-24.82	-15.91	-13.78	39.70	-9.52	46.99	24.79	15.92	13.74
Line.l33	-81.19	-14.85	-46.99	-24.78	-59.47	10.65	81.56	14.86	47.14	24.71	59.64	-10.70
Line.l34	41.49	24.37	0.00	-0.02	43.55	-24.39	-41.48	-24.38	0.00	0.00	-43.53	24.38

4.2.3 50% DG penetration case

Table 4-8: 50% DG penetration case voltages

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
Source bus	230.00	1.00	123771.00	-4.50	0.93	2.00	124689.00	-123.40	0.94	3.00	126299.00	115.70	0.95
Source bus	4.80	1.00	2715.90	-6.70	0.98	2.00	2761.89	-124.80	1.00	3.00	2819.02	113.40	1.02
709	0.48	1.00	271.59	-6.70	0.98	2.00	276.19	-124.80	1.00	3.00	281.90	113.40	1.02
775	4.80	1.00	2743.36	-6.50	0.99	2.00	2783.94	-124.80	1.00	3.00	2833.23	113.70	1.02
701	4.80	1.00	2734.07	-6.60	0.99	2.00	2776.95	-124.90	1.00	3.00	2825.80	113.60	1.02
702	4.80	1.00	2733.73	-6.50	0.99	2.00	2776.89	-124.90	1.00	3.00	2823.91	113.60	1.02
705	4.80	1.00	2732.45	-6.50	0.99	2.00	2775.38	-124.90	1.00	3.00	2822.80	113.50	1.02

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
713	4.80	1.00	2725.39	-6.70	0.98	2.00	2769.09	-124.90	1.00	3.00	2822.52	113.50	1.02
703	4.80	1.00	2731.82	-6.50	0.99	2.00	2773.12	-124.90	1.00	3.00	2819.29	113.60	1.02
704	4.80	1.00	2730.21	-6.50	0.99	2.00	2771.27	-125.00	1.00	3.00	2812.76	113.60	1.02
720	4.80	1.00	2730.16	-6.50	0.99	2.00	2770.77	-125.00	1.00	3.00	2811.85	113.60	1.01
706	4.80	1.00	2730.13	-6.50	0.99	2.00	2770.25	-125.00	1.00	3.00	2811.11	113.60	1.01
725	4.80	1.00	2733.39	-6.40	0.99	2.00	2767.76	-125.10	1.00	3.00	2805.41	113.70	1.01
707	4.80	1.00	2733.18	-6.40	0.99	2.00	2767.00	-125.10	1.00	3.00	2804.22	113.70	1.01
722	4.80	1.00	2737.32	-6.40	0.99	2.00	2769.70	-125.10	1.00	3.00	2806.84	113.70	1.01
724	4.80	1.00	2731.89	-6.50	0.99	2.00	2772.88	-124.90	1.00	3.00	2819.57	113.60	1.02
714	4.80	1.00	2732.78	-6.50	0.99	2.00	2772.36	-124.90	1.00	3.00	2822.04	113.60	1.02
718	4.80	1.00	2732.39	-6.50	0.99	2.00	2776.90	-124.90	1.00	3.00	2823.02	113.50	1.02
712	4.80	1.00	2735.25	-6.50	0.99	2.00	2776.85	-124.90	1.00	3.00	2823.60	113.60	1.02
742	4.80	1.00	2724.08	-6.70	0.98	2.00	2767.78	-124.80	1.00	3.00	2822.22	113.50	1.02
727	4.80	1.00	2717.78	-6.70	0.98	2.00	2763.69	-124.80	1.00	3.00	2819.65	113.40	1.02
730	4.80	1.00	2717.48	-6.70	0.98	2.00	2762.13	-124.80	1.00	3.00	2818.36	113.50	1.02
731	4.80	1.00	2712.05	-6.80	0.98	2.00	2758.88	-124.80	1.00	3.00	2818.34	113.40	1.02
708	4.80	1.00	2711.17	-6.80	0.98	2.00	2758.88	-124.80	1.00	3.00	2817.75	113.40	1.02
732	4.80	1.00	2708.73	-6.80	0.98	2.00	2755.87	-124.70	0.99	3.00	2817.93	113.40	1.02
733	4.80	1.00	2723.75	-6.70	0.98	2.00	2766.85	-124.80	1.00	3.00	2822.23	113.50	1.02
744	4.80	1.00	2724.82	-6.70	0.98	2.00	2767.36	-124.80	1.00	3.00	2823.60	113.50	1.02
729	4.80	1.00	2722.81	-6.70	0.98	2.00	2765.93	-124.80	1.00	3.00	2821.35	113.50	1.02
728	4.80	1.00	2703.76	-6.90	0.98	2.00	2752.32	-124.70	0.99	3.00	2817.08	113.40	1.02
734	4.80	1.00	2699.44	-7.00	0.97	2.00	2747.43	-124.70	0.99	3.00	2817.29	113.30	1.02
737	4.80	1.00	2697.72	-7.00	0.97	2.00	2746.40	-124.60	0.99	3.00	2817.29	113.30	1.02
738	4.80	1.00	2696.93	-6.90	0.97	2.00	2747.24	-124.60	0.99	3.00	2817.17	113.30	1.02
711	4.80	1.00	2697.46	-6.90	0.97	2.00	2748.08	-124.60	0.99	3.00	2817.69	113.30	1.02

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
741	4.80	1.00	2695.81	-6.90	0.97	2.00	2747.24	-124.60	0.99	3.00	2816.42	113.30	1.02
740	4.80	1.00	2703.84	-6.80	0.98	2.00	2753.70	-124.70	0.99	3.00	2816.26	113.40	1.02
710	4.80	1.00	2711.20	-6.70	0.98	2.00	2757.08	-124.70	0.99	3.00	2819.09	113.50	1.02
736	4.80	1.00	2702.72	-6.80	0.98	2.00	2753.70	-124.70	0.99	3.00	2815.51	113.30	1.02

Table 4-9: 50% DG Penetration Case Currents

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Vsource	2.80	149.74	2.30	25.33	2.42	-82.01	2.80	-30.26	2.30	-154.67	2.42	97.99
Subxf	2.80	-30.26	2.30	-154.67	2.42	97.99	134.04	149.74	110.28	25.33	115.85	-82.01
Xfm1	0.00	-96.74	0.00	145.20	0.00	23.43	0.00	-119.74	0.00	-153.43	0.00	0.00
Line.l1	113.04	-31.12	95.96	-156.19	97.58	95.28	113.07	148.85	95.99	23.77	97.60	-84.76
Line.l2	12.63	-104.47	3.00	-59.31	14.92	83.78	12.65	75.54	2.99	120.59	14.92	-96.26
Line.l3	24.01	-56.94	30.34	-117.82	47.00	88.70	24.02	123.04	30.34	62.15	47.00	-91.31
Line.l4	90.67	-16.75	75.79	-172.96	37.23	108.15	90.69	163.19	75.86	6.99	37.24	-71.99
Line.l5	9.55	-96.01	30.34	-117.85	39.39	67.34	9.57	83.99	30.33	62.11	39.41	-112.68
Line.l6	15.95	-94.46	29.81	-88.89	45.73	89.16	15.98	85.54	29.79	91.06	45.75	-90.87
Line.l7	0.03	83.52	8.64	-95.31	8.61	84.70	0.01	-96.48	8.63	84.56	8.62	-95.44
Line.l8	0.01	83.52	8.63	-95.44	8.62	84.56	0.00	22.31	8.63	84.50	8.63	-95.50
Line.l9	16.29	-160.93	21.22	-86.35	30.01	62.09	16.30	19.16	21.20	93.59	30.04	-117.95
Line.l10	4.37	-36.76	29.17	-95.51	31.66	91.28	4.38	143.20	29.17	84.49	31.66	-88.73
Line.l11	19.10	-171.77	8.89	62.34	15.64	-19.09	19.10	8.30	8.89	-117.51	15.66	160.97
Line.l12	6.39	87.86	15.07	168.54	17.28	-32.81	6.39	-92.14	15.07	-11.46	17.28	147.20
Line.l13	5.75	121.28	14.20	141.61	19.68	-44.18	5.73	-58.62	14.22	-38.38	19.69	135.86
Line.l14	17.66	-37.00	0.01	-34.87	17.67	143.00	17.66	142.97	0.00	63.43	17.66	-37.03

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Line.I15	17.33	-174.65	2. 8	-59.47	16.29	14.95	17.34	5.38	2.97	120.44	16.30	-165.05
Line.I16	18.21	-5.86	20.31	-171.98	5.10	67.02	18.21	174.11	20.32	8.00	5. 1	-113.04
Line.I17	72.89	-19.53	55.5	-173.38	33.56	113.73	72.89	160.45	55.56	6.60	33.56	-66.31
Line.I18	56.28	14.06	55.56	-173.40	20.02	88.25	56.28	165.94	55.57	6.60	20.02	-91.77
Line.I19	20.27	-173.38	3.32	-17.69	17.29	11.15	20.27	6.69	3.30	162.43	1 .31	-168.83
Line.I20	75.58	-8.63	58.62	-174.74	23.34	134.44	75.58	171.36	58.72	5.25	23.34	-45.59
Line.I21	8.76	-37."8	0.01	-34.77	8.77	14 .73	8.76	142.67	0.00	-10843	8.76	-37.33
Line.I22	68.0	-5.10	58.63	-174.75	14.72	129.46	68.02	174.89	58.64	5.24	14.71	-50.59
Line.I23	11.67	17.01	20.32	-172.00	8.98	-3.71	11.66	-163.04	20.33	7.98	8.99	176.32
Line.I24	12.11	173.93	13.51	103.27	20.91	-43.64	12.11	-6.03	13.52	-76.71	20.91	136.39
Line.I25	15.16	-5.97	15.17	-126.00	15.16	113. 9	15.16	174.00	15.17	53.98	15.1	-66.04
LinE.I26	53.35	-14.55	42.33	177.30	14.71	129.41	53.36	165.43	42.35	-2.71	14.71	-50.67
Line.I27	51.60	5.61	46.82	-172.16	5.13	165.20	51.60	-174.41	46.84	7.82	5.11	-14.97
Line.I28	25.80	-15.91	20.67	163.93	5.11	165.03	25.80	164.06	20.69	-16.08	5.09	-15.09
Line.I29	18.30	-89.38	17.60	74.41	5.09	164.91	18.32	90.62	17.60	-105.55	5.08	-15.20
Line.I30	15.79	-151.69	17.60	74.47	13.23	-45.91	15.80	28.35	17.61	-105.48	13.23	134.16
Line.I31	17.78	-37.52	0.01	-34.63	17.79	142.48	17.78	142.46	0.00	-63.43	17.78	-37.54
Line.I32	14.74	-116.95	9.33	64.03	5.40	61.21	14.76	63.07	9.33	-115.87	5.42	-118.89
Line.I33	20.94	-173.50	9.33	64.17	17.80	-19.87	20.95	6.60	9.34	-115.58	17.83	160.22
Line.I34	17.77	-37.39	0.01	-34.69	17.77	142.61	17.77	142.60	0.00	139.90	17.77	-37.40

Table 4-10: 50% DG Penetration Power Flow

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	320.78	127.15	255.36	124.40	300.28	68.91		0.00	-311.97	-81.17	-278.37	-126.91
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	291.08	106.22	238.41	114.81	271.84	63.07	-290.29	-105.69	-237.95	-114.52	-271.30	-62.60
Line.l2	-4.06	34.27	5.07	-8.19	38.30	21.38	4.08	-34.29	-5.07	8.15	-38.27	-21.40
Line.l3	44.69	50.09	87.41	-10.45	123.28	56.25	-44.66	-50.10	-87.35	10.44	-123.15	-56.22
Line.l4	249.66	21.34	145.47	133.16	109.73	-15.02	-248.98	-20.92	-145.12	-133.05	-109.60	14.93
Line.l5	3.01	25.61	87.35	-10.44	79.80	80.71	-3.00	-25.66	-87.28	10.42	-79.68	-80.70
Line.l6	2.30	43.78	68.77	-49.58	119.57	53.92	-2.26	-43.85	-68.66	49.55	-119.31	-53.86
Line.l7	0.00	-0.09	20.83	-11.89	21.20	11.72	0.00	0.03	-20.82	11.83	-21.19	-11.78
Line.l8	0.00	-0.03	20.82	-11.83	21.19	11.78	0.00	0.00	-20.82	11.80	-21.18	-11.80
Line.l9	-39.46	19.41	47.82	-37.66	54.84	66.67	39.53	-19.46	-47.70	37.62	-54.59	-66.67
Line.l10	10.49	6.14	71.28	-40.53	83.23	34.38	-10.49	-6.15	-71.25	40.52	-83.20	-34.38
Line.l11	-50.02	13.33	-23.59	2.91	-28.65	32.30	50.10	-13.37	23.60	-2.98	28.70	-32.35
Line.l12	0.70	-18.12	18.51	39.16	-39.90	26.78	-0.70	18.12	-18.50	-39.17	39.90	-26.79
Line.l13	-7.73	-13.06	-0.81	40.18	-50.84	20.71	7.74	13.01	0.84	-40.22	50.90	-20.74
Line.l14	41.67	24.50	0.00	-0.02	43.38	-24.53	-41.65	-24.51	0.00	0.00	-43.35	24.51
Line.l15	-45.75	9.79	5.07	-8.13	-5.11	45.93	45.78	-9.81	-5.07	8.10	5.13	-45.95
Line.l16	50.59	-0.68	38.82	41.43	10.38	10.16	-50.56	0.66	-38.79	-41.45	-10.38	-10.19
Line.l17	198.39	21.60	106.30	91.61	99.22	-25.09	-197.90	-21.38	-106.07	-91.56	-99.11	25.11
Line.l18	155.07	-3.85	106.07	91.56	54.27	0.13	-154.97	3.88	-105.99	-91.54	-54.26	-0.14
Line.l19	-53.07	12.86	-1.16	-9.42	-8.53	48.15	53.11	-12.91	1.16	9.36	8.56	-48.20
Line.l20	208.04	-16.75	107.15	100.97	62.79	-48.01	-207.75	16.88	-107.02	-100.93	-62.75	48.00
Line.l21	20.50	12.06	0.00	-0.03	21.51	-12.11	-20.50	-12.08	0.00	0.00	-21.50	12.08

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l22	187.25	-28.94	107.02	100.96	41.24	-35.89	-187.01	29.04	-106.88	-100.93	-41.22	35.87
Line.l23	30.02	-12.75	38.79	41.45	-11.08	22.27	-30.02	12.72	-38.77	-41.47	11.08	-22.30
Line.l24	-32.11	0.31	-24.41	28.13	-53.81	22.66	32.13	-0.33	24.42	-28.15	53.85	-22.67
Line.l25	41.34	-0.48	41.97	0.79	42.73	-0.35	-41.33	0.47	-41.96	-0.81	-42.72	0.34
Line.l26	145.29	-3.72	64.23	75.61	41.22	-35.87	-145.05	3.80	-64.12	-75.62	-41.19	35.83
Line.l27	137.75	-53.48	88.64	71.96	9.18	-35.92	-137.46	53.58	-88.47	-71.95	-9.16	35.87
Line.l28	69.03	-11.88	18.48	30.25	9.16	-35.87	-68.99	11.86	-18.47	-30.29	-9.15	35.83
Line.l29	6.71	26.12	-45.25	-7.70	9.15	-35.83	-6.70	-26.16	45.27	7.66	-9.14	35.79
Line.l30	-34.65	1.76	-45.27	-7.64	-34.54	-11.36	34.66	-1.80	45.28	7.61	34.55	11.32
Line.l31	41.36	24.40	0.00	-0.02	43.68	-24.42	-41.34	-24.41	0.00	0.00	-43.66	24.41
Line.l32	-13.16	37.62	-24.51	3.66	10.47	12.16	13.20	-37.65	24.53	-3.70	-10.47	-12.21
Line.l33	-54.63	13.21	-24.53	3.72	-33.14	36.68	54.79	-13.26	24.56	-3.82	33.25	-36.75
Line.l34	41.44	24.44	0.00	-0.02	43.60	-24.47	-41.42	-24.46	0.00	0.00	-43.58	24.46

4.2.4 25% DG penetration case

Table 4-11: 25% DG penetration case voltages

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
Source bus	230.00	1.00	120104.00	-9.60	0.90	2.00	122191.00	-127.90	0.92	3.00	124346.00	110.40	0.94
709	4.80	1.00	2621.70	-13.80	0.95	2.00	2704.47	-130.90	0.98	3.00	2781.58	106.20	1.00
775	0.48	1.00	262.17	-13.80	0.95	2.00	270.45	-130.90	0.98	3.00	278.16	106.20	1.00
701	4.80	1.00	2656.43	-13.30	0.96	2.00	2731.40	-130.70	0.99	3.00	2799.85	106.70	1.01
702	4.80	1.00	2644.50	-13.50	0.95	2.00	2722.83	-130.80	0.98	3.00	2791.10	106.50	1.01
705	4.80	1.00	2643.16	-13.50	0.95	2.00	2721.94	-130.80	0.98	3.00	2788.35	106.50	1.01
713	4.80	1.00	2642.12	-13.50	0.95	2.00	2720.63	-130.90	0.98	3.00	2787.52	106.50	1.01

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
703	4.80	1.00	2633.78	-13.70	0.95	2.00	2713.78	-130.90	0.98	3.00	2786.90	106.30	1.01
704	4.80	1.00	2640.44	-13.50	0.95	2.00	2717.44	-130.90	0.98	3.00	2783.19	106.40	1.00
720	4.80	1.00	2638.09	-13.50	0.95	2.00	2714.90	-131.00	0.98	3.00	2776.15	106.40	1.00
706	4.80	1.00	2638.04	-13.50	0.95	2.00	2714.40	-131.00	0.98	3.00	2775.23	106.40	1.00
725	4.80	1.00	2638.01	-13.50	0.95	2.00	2713.86	-131.10	0.98	3.00	2774.48	106.40	1.00
707	4.80	1.00	2639.42	-13.50	0.95	2.00	2709.58	-131.20	0.98	3.00	2767.23	106.40	1.00
722	4.80	1.00	2639.21	-13.50	0.95	2.00	2708.81	-131.20	0.98	3.00	2766.04	106.40	1.00
724	4.80	1.00	2641.81	-13.40	0.95	2.00	2710.05	-131.20	0.98	3.00	2767.38	106.50	1.00
714	4.80	1.00	2640.34	-13.50	0.95	2.00	2717.04	-130.90	0.98	3.00	2783.30	106.40	1.00
718	4.80	1.00	2640.09	-13.50	0.95	2.00	2715.52	-130.90	0.98	3.00	2784.70	106.50	1.00
712	4.80	1.00	2641.79	-13.40	0.95	2.00	2721.94	-130.80	0.98	3.00	2787.42	106.50	1.01
742	4.80	1.00	2643.92	-13.40	0.95	2.00	2721.22	-130.90	0.98	3.00	2787.38	106.50	1.01
727	4.80	1.00	2631.82	-13.70	0.95	2.00	2711.88	-130.90	0.98	3.00	2786.03	106.30	1.01
730	4.80	1.00	2624.23	-13.80	0.95	2.00	2706.80	-130.90	0.98	3.00	2782.67	106.20	1.00
731	4.80	1.00	2622.75	-13.80	0.95	2.00	2704.26	-130.90	0.98	3.00	2780.61	106.20	1.00
708	4.80	1.00	2617.07	-13.90	0.94	2.00	2700.85	-130.90	0.97	3.00	2780.34	106.10	1.00
732	4.80	1.00	2616.17	-13.90	0.94	2.00	2700.85	-130.90	0.97	3.00	2779.73	106.10	1.00
733	4.80	1.00	2612.99	-14.00	0.94	2.00	2697.24	-130.90	0.97	3.00	2779.37	106.10	1.00
744	4.80	1.00	2631.12	-13.70	0.95	2.00	2710.61	-130.90	0.98	3.00	2785.76	106.30	1.01
729	4.80	1.00	2631.48	-13.70	0.95	2.00	2710.49	-130.90	0.98	3.00	2786.50	106.30	1.01
728	4.80	1.00	2630.16	-13.70	0.95	2.00	2709.67	-130.90	0.98	3.00	2784.86	106.30	1.00
734	4.80	1.00	2606.67	-14.10	0.94	2.00	2692.63	-130.90	0.97	3.00	2777.56	106.00	1.00
737	4.80	1.00	2601.75	-14.20	0.94	2.00	2687.24	-130.90	0.97	3.00	2777.37	106.00	1.00
738	4.80	1.00	2599.65	-14.20	0.94	2.00	2685.89	-130.80	0.97	3.00	2777.12	105.90	1.00
711	4.80	1.00	2598.44	-14.20	0.94	2.00	2686.43	-130.80	0.97	3.00	2776.74	105.90	1.00
741	4.80	1.00	2598.60	-14.20	0.94	2.00	2686.98	-130.80	0.97	3.00	2777.03	105.90	1.00

Bus	BasekV	Node1	Magnitude1	Angle1	pu1	Node2	Magnitude2	Angle2	pu2	Node3	Magnitude3	Angle3	pu3
740	4.80	1.00	2597.29	-14.20	0.94	2.00	2686.43	-130.80	0.97	3.00	2775.96	105.90	1.00
710	4.80	1.00	2605.28	-14.00	0.94	2.00	2692.81	-130.90	0.97	3.00	2775.49	106.00	1.00
736	4.80	1.00	2609.23	-14.00	0.94	2.00	2693.24	-130.90	0.97	3.00	2775.41	106.10	1.00
735	4.80	1.00	2604.13	-14.00	0.94	2.00	2692.81	-130.90	0.97	3.00	2774.71	106.00	1.00

Table 4-12: 25% DG Penetration Case Currents

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Vsource	4.02	158.46	3.33	39.01	3.75	-72.14	4.02	-21.54	3.33	-140.99	3.75	107.86
Subxf	4.02	-21.54	3.33	-140.99	3.75	107.86	192.55	158.46	159.53	39.01	179.77	-72.14
Xfm1	0.00	-103.85	0.00	139.10	0.00	16.17	0.00	90.00	0.00	-165.96	0.00	-165.96
Line.l1	165.90	-21.28	139.98	-141.37	154.39	107.04	165.91	158.69	139.99	38.61	154.39	-72.99
Line.l2	12.94	-72.15	9.75	-104.36	21.83	94.09	12.95	107.83	9.75	75.57	21.83	-85.94
Line.l3	33.75	-33.19	46.93	-116.97	60.72	96.58	33.75	146.79	46.93	63.01	60.72	-83.44
Line.l4	125.87	-13.55	92.98	-157.17	75.09	119.22	125.87	166.41	93.01	22.78	75.07	-60.84
Line.l5	16.40	-20.85	46.93	-116.99	48.05	82.85	16.40	159.08	46.93	62.99	48.06	-97.17
Line.l6	13.75	-61.35	39.93	-95.46	51.90	93.08	13.77	118.57	39.92	84.50	51.91	-86.96
Line.l7	0.03	76.52	8.74	-101.80	8.71	78.21	0.01	-103.48	8.73	78.07	8.72	-101.93
Line.l8	0.01	76.52	8.73	-101.93	8.72	78.07	0.00	33.15	8.73	78.02	8.73	-101.98
Line.l9	6.41	174.98	31.24	-93.74	31.76	74.62	6.41	-4.78	31.22	86.22	31.78	-105.42
Line.l10	4.37	-44.24	29.17	-102.04	31.72	84.66	4.38	135.72	29.17	77.96	31.72	-95.34
Line.l11	10.17	159.37	4.81	-33.15	5.58	-9.75	10.17	-20.50	4.78	146.89	5.60	170.36
Line.l12	10.71	35.45	17.63	-173.31	9.71	-25.29	10.71	-144.56	17.63	6.69	9.72	154.72
Line.l13	7.40	43.56	13.67	165.86	11.54	-46.91	7.38	-136.51	13.68	-14.17	11.55	133.16
Line.l14	18.08	-44.36	0.01	-40.84	18.09	135.64	18.08	135.62	0.00	-8.75	18.08	-44.38

Element	I1_1	Ang1_1	I1_2	Ang1_2	I1_3	Ang1_3	I2_1	Ang2_1	I2_2	Ang2_2	I2_3	Ang2_3
Line.I15	8.97	178.02	9.74	-104.47	14.60	38.73	8.97	-1.92	9.74	75.48	14.61	-141.28
Line.I16	27.78	-8.70	26.10	-161.74	12.67	102.23	27.78	171.29	26.10	18.25	12.67	-77.80
Line.I17	98.22	-14.97	67.03	-155.46	63.06	122.51	98.22	165.02	67.04	24.52	63.06	-57.51
Line.I18	83.66	-9.09	67.04	-155.48	46.36	117.78	83.66	170.90	67.04	24.51	46.36	-62.23
Line.I19	11.19	158.19	11.53	-78.01	10.70	41.72	11.18	-21.69	11.51	101.92	10.73	-138.33
Line.I20	94.61	-10.59	65.52	-165.38	44.99	131.12	94.61	169.41	65.53	14.61	44.99	-48.90
Line.I21	8.98	-44.85	0.01	-40.89	8.99	135.15	8.99	135.10	0.00	-129.09	8.99	-44.90
Line.I22	87.33	-7.28	65.53	-165.40	36.03	130.09	87.33	172.72	65.54	14.60	36.02	-49.93
Line.I23	21.19	5.64	26.10	-161.75	7.12	58.79	21.19	-174.39	26.11	18.23	7.13	-121.27
Line.I24	3.80	136.73	8.24	132.09	12.03	-46.46	3.80	-43.16	8.24	-47.90	12.03	133.58
Line.I25	15.49	-12.73	15.52	-132.73	15.50	107.19	15.49	167.25	15.52	47.25	15.50	-72.83
Line.I26	71.74	-13.36	47.88	-166.71	36.02	130.07	71.74	166.62	47.89	13.27	36.01	-49.96
Line.I27	62.09	2.50	48.98	-166.46	16.85	148.73	62.08	-177.52	48.99	13.52	16.84	-31.33
Line.I28	34.88	-10.50	20.05	-173.10	16.84	148.67	34.87	169.47	20.06	6.87	16.82	-31.37
Line.I29	17.02	-60.54	8.52	45.22	16.82	148.63	17.03	119.43	8.52	-134.68	16.81	-31.41
Line.I30	4.86	-157.30	8.52	45.36	4.45	-109.55	4.87	22.84	8.52	-134.54	4.45	70.61
Line.I31	18.25	-45.23	0.01	-40.84	18.26	134.77	18.25	134.76	0.00	-108.00	18.25	-45.24
Line.I32	13.01	-83.79	1.11	25.31	12.68	100.94	13.02	96.19	1.10	-153.93	12.68	-79.13
Line.I33	11.48	-179.81	1.10	26.37	10.51	-2.51	11.49	0.38	1.09	-151.72	10.55	177.56
Line.I34	18.24	-45.05	0.01	-40.87	18.25	134.95	18.24	134.93	0.00	-115.99	18.24	-45.07

Table 4-13: 25% DG Penetration Power Flow

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	507.31	486.55	472.84	488.09	456.32	515.44	0.00	0.00	-394.41	-108.58	-411.53	-107.89
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	347.46	60.01	344.78	65.07	332.18	78.44	-321.82	-37.75	-323.25	-42.45	-310.44	-51.58
Line.l2	-12.34	-2.93	-12.43	-4.42	-10.69	-4.10	12.42	2.95	12.51	4.44	10.75	4.12
Line.l3	-21.26	-7.55	-10.24	-16.11	-7.77	-2.62	21.37	7.61	10.32	16.14	7.79	2.63
Line.l4	355.42	48.22	345.91	62.97	328.91	58.30	-312.41	-10.57	-311.47	-26.78	-295.24	-16.46
Line.l5	-23.01	-8.52	-10.32	-16.14	-9.38	-1.71	23.20	8.62	10.43	16.20	9.40	1.73
Line.l6	-11.84	-3.03	-1.07	-13.18	2.61	1.24	11.91	3.06	1.15	13.22	-2.60	-1.24
Line.l7	0.00	0.00	0.78	-0.47	0.76	0.46	0.00	0.00	-0.78	0.46	-0.76	-0.46
Line.l8	0.00	0.00	0.78	-0.46	0.76	0.46	0.00	0.00	-0.78	0.46	-0.76	-0.46
Line.l9	-13.59	-3.99	-1.93	-12.75	0.24	1.71	13.79	4.05	2.10	12.80	-0.24	-1.71
Line.l10	2.05	1.11	12.90	-7.79	14.38	6.69	-2.05	-1.11	-12.86	7.80	-14.35	-6.68
Line.l11	-15.84	-5.17	-15.00	-5.01	-14.15	-4.98	16.07	5.23	15.21	5.07	14.34	5.05
Line.l12	-11.36	-5.60	-9.36	-3.02	-12.01	-2.97	11.37	5.60	9.37	3.03	12.02	2.97
Line.l13	-12.98	-4.70	-12.87	-2.78	-13.92	-4.12	13.10	4.73	12.97	2.81	14.05	4.17
Line.l14	1.65	0.92	0.00	0.00	1.60	-0.92	-1.64	-0.92	0.00	0.00	-1.60	0.92
Line.l15	-14.06	-3.87	-12.51	-4.44	-12.35	-3.21	14.14	3.89	12.57	4.46	12.41	3.23
Line.l16	-7.59	-4.47	-8.22	-0.17	-11.53	-2.84	7.62	4.48	8.25	0.17	11.58	2.85
Line.l17	320.00	15.03	319.70	26.94	306.77	19.30	-269.50	11.89	-272.70	-2.62	-265.32	8.55
Line.l18	-16.21	-12.35	-20.38	2.62	-32.00	-8.08	16.31	12.41	20.47	-2.58	32.22	8.22
Line.l19	-13.20	-2.27	-12.44	-3.00	-12.65	-1.77	13.32	2.34	12.54	3.05	12.74	1.84
Line.l20	-3.11	-10.14	-8.03	5.57	-19.57	-6.45	3.15	10.16	8.06	-5.56	19.71	6.53
Line.l21	0.44	0.26	0.00	0.00	0.46	-0.26	-0.44	-0.26	0.00	0.00	-0.46	0.26
Line.l22	-3.60	-10.42	-8.06	5.56	-20.17	-6.27	3.64	10.45	8.09	-5.54	20.32	6.35

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l23	-8.23	-4.83	-8.25	-0.17	-12.19	-2.50	8.25	4.84	8.26	0.18	12.22	2.52
Line.l24	-10.10	-4.48	-10.12	-0.54	-13.45	-2.52	10.15	4.50	10.16	0.55	13.52	2.55
Line.l25	1.23	0.00	1.24	0.00	1.23	0.00	-1.23	0.00	-1.24	0.00	-1.22	0.00
Line.l26	-9.44	-6.96	-13.96	2.05	-20.32	-6.35	9.53	7.01	14.08	-1.99	20.57	6.51
Line.l27	1.28	-6.57	-2.37	3.96	-9.90	-4.57	-1.25	6.59	2.38	-3.95	9.98	4.61
Line.l28	-8.38	-0.71	-12.08	-1.93	-9.98	-4.61	8.41	0.72	12.14	1.96	10.02	4.64
Line.l29	-9.74	0.09	-13.49	-2.77	-10.02	-4.64	9.78	-0.07	13.56	2.81	10.07	4.67
Line.l30	-10.74	-0.48	-13.56	-2.81	-11.07	-4.11	10.79	0.51	13.64	2.85	11.12	4.14
Line.l31	0.95	0.56	0.00	0.00	1.01	-0.56	-0.95	-0.56	0.00	0.00	-1.01	0.56
Line.l32	-11.27	-0.71	-11.71	-1.96	-11.14	-1.67	11.41	0.75	11.86	2.01	11.26	1.71
Line.l33	-12.36	-1.31	-11.86	-2.01	-12.26	-1.16	12.76	1.43	12.21	2.11	12.60	1.28
Line.l34	0.95	0.55	0.00	0.00	0.99	-0.55	-0.95	-0.55	0.00	0.00	-0.99	0.55

4.3 Fault Location Algorithm

There are basically two stages in the fault location. They are 1) identifying the type of fault whether the fault is single line to ground, line to line or three phase to ground and 2) determining the location of the fault.

4.3.1 Identifying Fault Type

One of the most important aspects of the fault location algorithm is identifying the fault type. Each of the fault types considered, line to line (LL), single line to ground (SLG) and three phase to ground (3LG), can be identified based on the magnitudes of the sequence components of the current. The different sequence components of current are positive sequence current (I_1), negative sequence current (I_2) and the zero sequence current (I_0). Each of these components shows violation depending on the kind of fault occurring in the system. For identifying SLG, 3LG and LL faults the residual current (I_r), positive sequence current (I_1) and negative sequence current (I_2) magnitudes respectively are used. The residual current is the sum of positive, negative and zero sequence currents. The reason for using sequence current magnitudes for fault detection is due to the fact that when a fault occurs, depending on its type, the corresponding sequence current magnitudes are high in the affected lines; thus the sequence current magnitudes give a rough estimate of where the fault exists.

$$\begin{aligned} I_1 &= \frac{1}{3} * (I_a + \lambda * I_b + \lambda^2 * I_c) \\ I_2 &= \frac{1}{3} * (I_a + \lambda^2 I_b + \lambda * I_c) \\ I_0 &= \frac{1}{3} * (I_a + I_b + I_c) \end{aligned}$$

Where $\lambda = 1 \angle 120$

The thresholds (I_{rth} , I_{1th} , and I_{2th}) are set for these sequence currents and all the lines violating the limit are suspected of having a fault in them. So, the Switch Agent first checks all the lines that exceed these thresholds.

In order to determine these thresholds, a detailed short circuit analysis of the test system was performed. The detailed short circuit study for each of these penetration levels is provided in the section 4.4.

4.3.2 Determining The Fault Location

The next phase of the fault location algorithm is determining the fault location. Determination of the fault location is dependent on the location of the node, that is, whether it has generation sources on either side or only on one side (unidirectional flow).

For a node with generation sources on either side of it, the fault location can be determined by checking the current direction in all the lines that are connected to the violating line. The basic reason for checking for current direction for such a node is due to the simple fact that all the generation units on either side of the node will feed this node during a fault. Thus, the adjoining lines of such a node will have current flowing towards the faulty node and in the opposite direction. This is considered as the current reversal condition and the fault can be located based on it.

Figure 4.4: Power flow during fault

The current direction for an SLG fault is determined by looking at the phase angle of the zero sequence current. For a SLG fault at a node with generation sources on either side, the phase angle of the zero sequence current in the adjoining lines of the node will be of opposite sign. While for multiple phase faults like 3LG and LL, the current direction can be determined from the values of real power. For a 3LG fault, the real power values will be of opposite signs in all the 3 phases; while for a LL fault, this would be the case in the two faulted phases in the lines attached to the faulty node. To add further credibility for the determination of fault location in case of 3LG and LL faults, the phase angles of the

corresponding sequence components can be used. Similar to SLG fault, these phase angles in the adjoining lines of the faulty node will be of opposite sign.

In the scenario where the fault occurs at a node with unidirectional power flow, the condition for current reversal will not be satisfied. The sequence component current value in the line above the faulty node will exceed any of the thresholds I_{1th} , I_{2th} and I_{rth} depending on the type of the fault, and the line below will have a low value of the residual current.

The complete flow chart of the fault location algorithm is provided in Figure 4-5. As seen in the flow chart, first the conditions for current reversal are checked. When these conditions are not true, the condition for negligible residual current is checked.

Figure 4-5: Flow Chart for fault Location

4.4 Short Circuit Analysis:

In this section, the results of the short circuit analysis for the different penetration levels of the Distributed Generation in the Microgrid are presented. All the fault types considered in this work (LL, SLG and 3LG) are simulated at various nodes in each of the zones of the test system. The values of I_1 for 3LG, I_r for SLG and I_2 for LL fault in all the distribution lines in the system have been tabulated. Based on these values I_{1th} , I_{2th} and I_{rth} for each of zones have been determined. The values of these thresholds for the Switch Agent vary for the each of the zones in the test system. The resistance of the fault is considered as 0.5 ohm.

4.4.1 Short Circuit Analysis 50% DG Penetration

Table 4-14: I_1 value, zone 1, 3 phase fault, 50% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	17.15	17.36	16.95	16.85	16.32	15.86	15.33
Vsource	2	17.15	17.36	16.95	16.85	16.32	15.86	15.33
Subxf	1	17.15	17.36	16.95	16.85	16.32	15.86	15.33
Subxf	2	822.00	831.65	812.04	807.52	781.96	760.06	734.56
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	745.10	754.06	736.04	731.87	708.40	688.29	664.72
Line.l1	2	745.10	754.06	736.04	731.87	708.40	688.29	664.72
Line.l2	1	1037.53	56.58	54.74	54.29	51.92	49.89	47.33
Line.l2	2	1037.53	56.58	54.74	54.29	51.92	49.88	47.33
Line.l3	1	94.48	1013.47	985.86	979.35	943.62	912.94	875.77
Line.l3	2	94.48	1013.47	985.86	979.35	943.62	912.94	875.77
Line.l4	1	199.49	203.93	196.33	194.44	184.75	176.36	165.17
Line.l4	2	199.49	203.93	196.33	194.44	184.75	176.35	165.16
Line.l5	1	97.22	101.53	983.32	976.73	940.68	909.70	871.99
Line.l5	2	97.21	101.53	983.32	976.73	940.68	909.71	871.99
Line.l6	1	43.63	45.99	46.21	45.78	993.63	960.86	921.13
Line.l6	2	43.63	45.99	46.21	45.78	993.63	960.86	921.13
Line.l7	1	1.39	1.15	1.11	1.15	1.06	1005.05	1.50
Line.l7	2	1.39	1.15	1.11	1.15	1.06	1005.05	1.50
Line.l8	1	1.39	1.15	1.11	1.15	1.06	1.02	1.50

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l8	2	1.39	1.15	1.11	1.15	1.06	1.02	1.50
Line.l9	1	47.74	49.42	49.50	49.18	49.55	48.08	916.64
Line.l9	2	47.74	49.42	49.50	49.18	49.55	48.08	916.64
Line.l10	1	19.36	19.36	19.37	19.37	19.37	19.36	19.37
Line.l10	2	19.36	19.36	19.37	19.37	19.37	19.36	19.37
Line.l11	1	66.81	68.61	68.65	68.29	68.60	66.72	68.33
Line.l11	2	66.80	68.61	68.65	68.29	68.60	66.71	68.33
Line.l12	1	53.75	55.65	55.71	1021.59	53.22	51.41	49.34
Line.l12	2	53.75	55.65	55.71	1021.59	53.22	51.41	49.34
Line.l13	1	58.30	60.21	60.27	60.24	57.71	55.85	53.78
Line.l13	2	58.29	60.21	60.27	60.24	57.71	55.84	53.78
Line.l14	1	2.23	2.53	2.81	2.90	3.24	3.56	4.09
Line.l14	2	2.23	2.53	2.81	2.90	3.24	3.56	4.09
Line.l15	1	60.08	59.10	57.51	57.15	55.08	53.32	51.29
Line.l15	2	60.08	59.10	57.51	57.15	55.08	53.32	51.29
Line.l16	1	59.14	60.35	58.33	57.83	55.26	53.03	50.03
Line.l16	2	59.14	60.35	58.33	57.83	55.26	53.03	50.03
Line.l17	1	140.46	143.68	138.08	136.70	129.57	123.40	115.23
Line.l17	2	140.46	143.68	138.08	136.70	129.57	123.40	115.23
Line.l18	1	143.06	146.06	140.69	139.38	132.50	126.56	118.86
Line.l18	2	143.06	146.06	140.69	139.38	132.50	126.56	118.86
Line.l19	1	60.96	61.72	60.12	59.76	57.67	55.89	53.87
Line.l19	2	60.96	61.72	60.12	59.76	57.67	55.89	53.87
Line.l20	1	82.12	84.36	80.62	79.68	74.96	70.88	65.21
Line.l20	2	82.11	84.36	80.62	79.68	74.96	70.88	65.20
Line.l21	1	1.46	1.34	1.48	1.52	1.69	1.84	2.10
Line.l21	2	1.46	1.34	1.48	1.52	1.69	1.84	2.10
Line.l22	1	83.56	85.68	82.06	81.16	76.57	72.60	67.18
Line.l22	2	83.56	85.68	82.06	81.16	76.57	72.60	67.18
Line.l23	1	60.52	61.62	59.72	59.25	56.82	54.70	51.95
Line.l23	2	60.52	61.62	59.72	59.25	56.82	54.70	51.95
Line.l24	1	66.06	66.69	65.25	64.94	63.04	61.43	59.67
Line.l24	2	66.06	66.69	65.25	64.93	63.04	61.43	59.66
Line.l25	1	4.23	3.87	4.28	4.40	4.90	5.36	6.14
Line.l25	2	4.23	3.87	4.28	4.40	4.90	5.36	6.14
Line.l26	1	93.68	95.81	92.08	91.17	86.41	82.31	76.91
Line.l26	2	93.68	95.81	92.08	91.16	86.41	82.30	76.91
Line.l27	1	35.00	36.13	34.35	33.89	31.68	29.75	26.91
Line.l27	2	35.00	36.13	34.35	33.89	31.67	29.75	26.91

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l28	1	51.64	52.76	50.79	50.31	47.79	45.61	42.81
Line.l28	2	51.63	52.76	50.79	50.31	47.79	45.61	42.81
Line.l29	1	55.99	56.76	55.16	54.79	52.71	50.94	48.87
Line.l29	2	55.99	56.76	55.16	54.79	52.71	50.94	48.87
Line.l30	1	59.02	59.56	58.22	57.93	56.15	54.64	53.10
Line.l30	2	59.02	59.56	58.22	57.93	56.15	54.64	53.10
Line.l31	1	3.06	2.83	3.10	3.18	3.52	3.83	4.34
Line.l31	2	3.06	2.83	3.10	3.18	3.52	3.83	4.34
Line.l32	1	60.23	61.12	59.37	58.96	56.68	54.74	52.45
Line.l32	2	60.23	61.12	59.36	58.96	56.68	54.74	52.45
Line.l33	1	63.27	63.92	62.42	62.09	60.12	58.46	56.69
Line.l33	2	63.27	63.91	62.42	62.09	60.12	58.45	56.69
Line.l34	1	3.05	2.81	3.09	3.17	3.51	3.82	4.33
Line.l34	2	3.05	2.81	3.09	3.17	3.51	3.82	4.33

Table 4-15: I_r value, zone 1, SLG fault, 50% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.22	0.22	0.21	0.21	0.20	0.20	0.19
Line.l1	2	0.22	0.22	0.21	0.21	0.20	0.20	0.19
Line.l2	1	795.93	132.91	128.95	128.04	122.42	117.38	112.96
Line.l2	2	795.93	132.91	128.95	128.04	122.42	117.38	112.96
Line.l3	1	257.83	678.75	658.49	653.86	625.13	599.41	576.85
Line.l3	2	257.83	678.75	658.49	653.86	625.13	599.41	576.85
Line.l4	1	538.54	546.47	530.16	526.43	503.30	482.59	464.43
Line.l4	2	538.54	546.47	530.16	526.43	503.30	482.59	464.43
Line.l5	1	257.85	266.79	658.47	653.84	625.11	599.40	576.83
Line.l5	2	257.85	266.79	658.47	653.84	625.11	599.40	576.83
Line.l6	1	128.42	132.87	132.65	131.72	751.26	720.35	693.24
Line.l6	2	128.42	132.87	132.65	131.72	751.26	720.35	693.24
Line.l7	1	0.04	0.05	0.05	0.05	0.05	845.69	0.04
Line.l7	2	0.04	0.05	0.05	0.05	0.05	845.69	0.04

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l8	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l9	1	128.51	132.96	132.74	131.81	131.91	126.48	693.16
Line.l9	2	128.51	132.96	132.74	131.81	131.91	126.48	693.16
Line.l10	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l10	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l11	1	128.55	133.01	132.79	131.86	131.95	126.53	130.56
Line.l11	2	128.55	133.01	132.79	131.86	131.95	126.53	130.56
Line.l12	1	129.50	133.99	133.77	785.07	126.99	121.77	117.19
Line.l12	2	129.50	133.99	133.77	785.07	126.99	121.77	117.19
Line.l13	1	129.50	133.99	133.77	133.58	127.00	121.77	117.19
Line.l13	2	129.50	133.99	133.77	133.58	127.00	121.77	117.19
Line.l14	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l15	1	134.65	132.94	128.97	128.07	122.44	117.41	112.99
Line.l15	2	134.65	132.94	128.97	128.07	122.44	117.41	112.99
Line.l16	1	136.69	138.70	134.56	133.61	127.75	122.49	117.88
Line.l16	2	136.69	138.70	134.56	133.61	127.75	122.49	117.88
Line.l17	1	402.22	408.14	395.95	393.17	375.89	360.43	346.86
Line.l17	2	402.22	408.14	395.95	393.17	375.89	360.43	346.86
Line.l18	1	402.25	408.17	395.98	393.20	375.92	360.46	346.89
Line.l18	2	402.25	408.17	395.98	393.20	375.92	360.46	346.89
Line.l19	1	134.93	136.91	132.82	131.89	126.10	120.91	116.36
Line.l19	2	134.93	136.91	132.82	131.89	126.10	120.91	116.36
Line.l20	1	267.49	271.43	263.33	261.48	249.99	239.70	230.68
Line.l20	2	267.49	271.43	263.33	261.48	249.99	239.70	230.68
Line.l21	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l22	1	267.52	271.46	263.36	261.51	250.01	239.73	230.70
Line.l22	2	267.52	271.46	263.36	261.51	250.01	239.73	230.70
Line.l23	1	136.70	138.71	134.57	133.62	127.75	122.50	117.89
Line.l23	2	136.70	138.71	134.57	133.62	127.75	122.50	117.89
Line.l24	1	136.72	138.74	134.59	133.65	127.78	122.52	117.91
Line.l24	2	136.72	138.74	134.59	133.65	127.78	122.52	117.91
Line.l25	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l26	1	267.54	271.48	263.37	261.52	250.03	239.74	230.72
Line.l26	2	267.54	271.48	263.37	261.52	250.03	239.74	230.72
Line.l27	1	133.50	135.46	131.42	130.49	124.76	119.62	115.12

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l27	2	133.50	135.46	131.42	130.49	124.76	119.62	115.12
Line.l28	1	133.53	135.50	131.45	130.52	124.79	119.65	115.15
Line.l28	2	133.53	135.50	131.45	130.52	124.79	119.65	115.15
Line.l29	1	133.55	135.52	131.47	130.55	124.81	119.67	115.17
Line.l29	2	133.55	135.52	131.47	130.55	124.81	119.67	115.17
Line.l30	1	133.58	135.55	131.50	130.57	124.84	119.70	115.19
Line.l30	2	133.58	135.55	131.50	130.57	124.84	119.70	115.19
Line.l31	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l32	1	134.08	136.05	131.99	131.06	125.30	120.15	115.63
Line.l32	2	134.08	136.05	131.99	131.06	125.30	120.15	115.63
Line.l33	1	134.11	136.08	132.02	131.09	125.33	120.18	115.65
Line.l33	2	134.11	136.08	132.02	131.09	125.33	120.18	115.65
Line.l34	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 4-16: I₂ value, zone 1, LL fault, 50% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	7.54	7.66	7.45	7.39	7.12	6.87	6.59
Vsource	2	7.54	7.66	7.45	7.39	7.12	6.87	6.59
Subxf	1	7.54	7.66	7.45	7.39	7.12	6.87	6.59
Subxf	2	361.13	366.95	356.86	354.34	341.25	329.40	315.65
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	328.58	333.85	324.67	322.39	310.47	299.68	287.23
Line.l1	2	328.56	333.82	324.65	322.36	310.45	299.66	287.20
Line.l2	1	556.48	44.62	43.67	43.45	42.19	41.07	39.94
Line.l2	2	556.48	44.63	43.67	43.46	42.20	41.07	39.94
Line.l3	1	95.27	514.12	499.64	496.04	477.14	459.96	440.17
Line.l3	2	95.27	514.12	499.64	496.04	477.13	459.96	440.17
Line.l4	1	133.36	135.80	131.42	130.33	124.59	119.32	113.18
Line.l4	2	133.39	135.84	131.46	130.36	124.62	119.36	113.22
Line.l5	1	95.60	98.04	498.78	495.21	476.33	459.20	439.73
Line.l5	2	95.61	98.05	498.77	495.20	476.32	459.20	439.73
Line.l6	1	60.12	60.79	60.88	60.75	512.63	493.94	472.39
Line.l6	2	60.13	60.81	60.89	60.77	512.62	493.93	472.38

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l7	1	4.18	4.26	4.29	4.28	4.34	549.64	4.24
Line.l7	2	4.18	4.27	4.30	4.29	4.35	549.63	4.25
Line.l8	1	4.18	4.27	4.30	4.29	4.35	4.37	4.25
Line.l8	2	4.19	4.27	4.30	4.29	4.35	4.38	4.25
Line.l9	1	56.12	56.91	57.03	56.88	57.16	56.26	476.27
Line.l9	2	56.13	56.93	57.04	56.89	57.17	56.27	476.26
Line.l10	1	17.96	18.07	18.08	18.06	18.09	18.00	18.10
Line.l10	2	17.96	18.07	18.08	18.06	18.09	18.00	18.10
Line.l11	1	42.75	44.23	44.46	44.19	44.72	43.37	45.13
Line.l11	2	42.76	44.24	44.47	44.20	44.73	43.38	45.14
Line.l12	1	38.64	40.51	40.81	555.29	38.93	37.47	35.52
Line.l12	2	38.64	40.51	40.82	555.29	38.93	37.47	35.52
Line.l13	1	38.78	40.83	41.15	41.18	39.00	37.38	35.31
Line.l13	2	38.78	40.84	41.16	41.19	39.01	37.39	35.31
Line.l14	1	9.84	9.93	10.04	10.08	10.20	10.32	10.54
Line.l14	2	9.84	9.93	10.04	10.08	10.20	10.32	10.54
Line.l15	1	47.39	46.59	45.60	45.36	44.08	42.92	41.58
Line.l15	2	47.39	46.59	45.61	45.36	44.08	42.92	41.58
Line.l16	1	36.21	36.99	35.75	35.43	33.83	32.35	30.51
Line.l16	2	36.22	36.99	35.76	35.43	33.83	32.36	30.51
Line.l17	1	97.41	99.07	95.92	95.15	91.01	87.23	82.98
Line.l17	2	97.42	99.08	95.93	95.16	91.02	87.24	82.99
Line.l18	1	98.13	99.97	96.86	96.05	91.95	88.14	83.47
Line.l18	2	98.13	99.98	96.86	96.06	91.96	88.14	83.48
Line.l19	1	47.78	48.34	47.34	47.10	45.79	44.60	43.24
Line.l19	2	47.79	48.35	47.35	47.11	45.80	44.61	43.25
Line.l20	1	51.71	52.86	50.62	50.08	47.18	44.54	41.57
Line.l20	2	51.71	52.86	50.62	50.08	47.18	44.54	41.57
Line.l21	1	4.96	4.90	4.96	4.98	5.04	5.09	5.20
Line.l21	2	4.96	4.90	4.96	4.97	5.03	5.09	5.20
Line.l22	1	51.79	53.08	50.90	50.33	47.49	44.84	41.53
Line.l22	2	51.79	53.09	50.91	50.34	47.50	44.85	41.53
Line.l23	1	37.34	38.17	36.98	36.65	35.10	33.66	31.70
Line.l23	2	37.34	38.18	36.99	36.65	35.11	33.66	31.70
Line.l24	1	37.95	38.64	37.65	37.37	36.04	34.77	33.09
Line.l24	2	37.96	38.64	37.65	37.37	36.04	34.78	33.09
Line.l25	1	7.21	7.32	7.12	7.07	6.81	6.58	6.30
Line.l25	2	7.21	7.32	7.12	7.07	6.81	6.58	6.30
Line.l26	1	61.96	63.24	60.93	60.36	57.34	54.59	51.42

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l26	2	61.97	63.25	60.94	60.37	57.35	54.60	51.43
Line.l27	1	19.32	20.22	19.02	18.66	17.13	15.66	13.42
Line.l27	2	19.34	20.24	19.03	18.67	17.14	15.67	13.43
Line.l28	1	35.98	36.84	35.37	35.01	33.11	31.40	29.44
Line.l28	2	35.98	36.84	35.38	35.01	33.12	31.41	29.44
Line.l29	1	38.98	39.41	38.39	38.17	36.81	35.62	34.52
Line.l29	2	38.98	39.41	38.40	38.17	36.82	35.62	34.53
Line.l30	1	40.72	41.34	40.20	39.92	38.43	37.08	35.58
Line.l30	2	40.72	41.34	40.21	39.93	38.44	37.09	35.59
Line.l31	1	10.04	9.92	10.03	10.07	10.19	10.30	10.51
Line.l31	2	10.04	9.92	10.03	10.07	10.19	10.30	10.51
Line.l32	1	43.08	43.58	42.54	42.30	40.93	39.70	38.45
Line.l32	2	43.09	43.58	42.55	42.31	40.94	39.71	38.46
Line.l33	1	45.37	46.00	44.91	44.63	43.21	41.91	40.40
Line.l33	2	45.39	46.02	44.92	44.65	43.22	41.93	40.42
Line.l34	1	10.05	9.93	10.04	10.08	10.20	10.31	10.52
Line.l34	2	10.05	9.93	10.04	10.08	10.20	10.31	10.52
Line.l35	1	328.30	333.59	324.42	322.13	310.23	299.45	286.95

Table 4-17: I₁ value, zone 2, 3 phase fault, 50% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	16.61	16.82	16.67	16.53	16.29
Vsource	2	16.61	16.82	16.67	16.53	16.29
Subxf	1	16.61	16.82	16.67	16.53	16.29
Subxf	2	795.68	806.11	798.83	792.08	780.76
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	721.05	730.63	723.98	717.78	707.37
Line.l1	2	721.05	730.63	723.98	717.78	707.38
Line.l2	1	53.26	54.23	53.61	52.98	51.92
Line.l2	2	53.26	54.23	53.61	52.98	51.92
Line.l3	1	90.40	92.21	91.16	89.98	88.00
Line.l3	2	90.40	92.21	91.16	89.98	88.00
Line.l4	1	863.39	875.84	867.39	859.34	845.83
Line.l4	2	863.40	875.84	867.40	859.34	845.83
Line.l5	1	93.26	94.96	93.91	92.81	90.96
Line.l5	2	93.26	94.96	93.91	92.81	90.96

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l6	1	41.93	42.76	42.34	41.80	40.90
Line.l6	2	41.93	42.75	42.34	41.80	40.89
Line.l7	1	1.48	1.41	1.43	1.48	1.56
Line.l7	2	1.48	1.41	1.43	1.48	1.56
Line.l8	1	1.48	1.41	1.43	1.48	1.56
Line.l8	2	1.48	1.41	1.43	1.48	1.56
Line.l9	1	46.15	46.82	46.40	45.96	45.22
Line.l9	2	46.14	46.82	46.40	45.96	45.22
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	64.73	65.53	64.95	64.43	63.56
Line.l11	2	64.73	65.53	64.95	64.43	63.55
Line.l12	1	51.66	52.48	51.90	51.36	50.47
Line.l12	2	51.66	52.48	51.89	51.36	50.47
Line.l13	1	56.14	56.98	56.37	55.83	54.92
Line.l13	2	56.14	56.98	56.37	55.83	54.92
Line.l14	1	3.00	2.85	2.90	3.00	3.16
Line.l14	2	3.00	2.85	2.90	3.00	3.16
Line.l15	1	56.19	57.03	56.44	55.89	54.97
Line.l15	2	56.19	57.03	56.44	55.89	54.97
Line.l16	1	1005.21	1020.82	60.29	59.56	58.35
Line.l16	2	1005.21	1020.82	60.29	59.56	58.35
Line.l17	1	142.35	145.45	926.97	918.17	903.41
Line.l17	2	142.35	145.45	926.97	918.17	903.41
Line.l18	1	144.77	147.75	152.78	916.11	901.21
Line.l18	2	144.77	147.75	152.78	916.11	901.21
Line.l19	1	61.31	62.20	63.51	63.56	62.54
Line.l19	2	61.30	62.20	63.51	63.56	62.53
Line.l20	1	83.49	85.56	89.28	89.54	963.46
Line.l20	2	83.49	85.56	89.28	89.54	963.46
Line.l21	1	1.36	1.29	1.10	1.08	1.05
Line.l21	2	1.36	1.29	1.10	1.08	1.05
Line.l22	1	84.83	86.84	90.38	90.62	90.87
Line.l22	2	84.83	86.84	90.38	90.62	90.87
Line.l23	1	1004.05	63.67	61.53	60.84	59.69
Line.l23	2	1004.05	63.67	61.52	60.84	59.69
Line.l24	1	68.00	68.01	66.54	66.02	65.16
Line.l24	2	68.00	68.01	66.54	66.02	65.15
Line.l25	1	3.23	3.30	3.84	3.98	4.23

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l25	2	3.23	3.30	3.84	3.98	4.23
Line.l26	1	94.92	96.98	100.54	100.77	101.00
Line.l26	2	94.91	96.98	100.54	100.77	101.00
Line.l27	1	35.70	36.69	38.53	38.67	38.82
Line.l27	2	35.70	36.69	38.53	38.67	38.82
Line.l28	1	52.26	53.36	55.23	55.36	55.47
Line.l28	2	52.26	53.36	55.23	55.35	55.47
Line.l29	1	56.39	57.28	58.62	58.69	58.73
Line.l29	2	56.39	57.28	58.62	58.69	58.73
Line.l30	1	59.23	59.99	60.96	60.98	60.97
Line.l30	2	59.23	59.99	60.96	60.98	60.97
Line.l31	1	2.87	2.72	2.35	2.30	2.25
Line.l31	2	2.87	2.72	2.35	2.30	2.25
Line.l32	1	60.70	61.67	63.19	63.27	63.33
Line.l32	2	60.70	61.67	63.19	63.27	63.33
Line.l33	1	63.54	64.38	65.52	65.56	65.56
Line.l33	2	63.54	64.38	65.52	65.56	65.56
Line.l34	1	2.86	2.71	2.34	2.29	2.24
Line.l34	2	2.86	2.71	2.34	2.29	2.24

Table 4-18: I_r value, zone 2, SLG fault, 50% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.21	0.22	0.21	0.21	0.21
Line.l1	2	0.21	0.22	0.21	0.21	0.21
Line.l2	1	127.96	130.28	129.08	127.80	125.48
Line.l2	2	127.96	130.28	129.08	127.80	125.48
Line.l3	1	251.88	256.44	254.08	251.56	246.99
Line.l3	2	251.88	256.44	254.08	251.56	246.99
Line.l4	1	379.47	386.35	382.79	379.00	372.11
Line.l4	2	379.47	386.35	382.79	379.00	372.11

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l15	1	251.89	256.46	254.10	251.58	247.01
Line.l15	2	251.89	256.46	254.10	251.58	247.01
Line.l16	1	125.45	127.73	126.55	125.30	123.02
Line.l16	2	125.45	127.73	126.55	125.30	123.02
Line.l17	1	0.04	0.04	0.04	0.04	0.04
Line.l17	2	0.04	0.04	0.04	0.04	0.04
Line.l18	1	0.01	0.01	0.01	0.01	0.01
Line.l18	2	0.01	0.01	0.01	0.01	0.01
Line.l19	1	125.54	127.81	126.64	125.38	123.10
Line.l19	2	125.54	127.81	126.64	125.38	123.10
Line.l110	1	0.01	0.01	0.01	0.01	0.00
Line.l110	2	0.01	0.01	0.01	0.01	0.00
Line.l111	1	125.58	127.86	126.68	125.43	123.15
Line.l111	2	125.58	127.86	126.68	125.43	123.15
Line.l112	1	126.50	128.80	127.61	126.35	124.05
Line.l112	2	126.50	128.80	127.61	126.35	124.05
Line.l113	1	126.51	128.80	127.62	126.35	124.05
Line.l113	2	126.51	128.80	127.62	126.35	124.05
Line.l114	1	0.01	0.01	0.01	0.01	0.01
Line.l114	2	0.01	0.01	0.01	0.01	0.01
Line.l115	1	127.99	130.31	129.11	127.83	125.51
Line.l115	2	127.99	130.31	129.11	127.83	125.51
Line.l116	1	778.21	792.33	136.76	135.40	132.94
Line.l116	2	778.21	792.33	136.76	135.40	132.94
Line.l117	1	398.93	406.16	519.33	514.19	504.84
Line.l117	2	398.93	406.16	519.33	514.19	504.84
Line.l118	1	398.96	406.19	415.54	514.16	504.81
Line.l118	2	398.96	406.19	415.54	514.16	504.81
Line.l119	1	133.82	136.25	139.38	139.49	136.95
Line.l119	2	133.82	136.25	139.38	139.49	136.95
Line.l120	1	265.31	270.12	276.34	276.55	641.40
Line.l120	2	265.31	270.12	276.34	276.55	641.40
Line.l121	1	0.01	0.01	0.01	0.01	0.01
Line.l121	2	0.01	0.01	0.01	0.01	0.01
Line.l122	1	265.34	270.15	276.37	276.58	276.29
Line.l122	2	265.34	270.15	276.37	276.58	276.29
Line.l123	1	778.20	140.27	136.77	135.41	132.95
Line.l123	2	778.20	140.27	136.77	135.41	132.95
Line.l124	1	139.94	140.30	136.79	135.44	132.98

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l24	2	139.94	140.30	136.79	135.44	132.98
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	265.35	270.17	276.38	276.60	276.31
Line.l26	2	265.35	270.17	276.38	276.60	276.31
Line.l27	1	132.40	134.81	137.91	138.02	137.87
Line.l27	2	132.40	134.81	137.91	138.02	137.87
Line.l28	1	132.44	134.84	137.94	138.05	137.91
Line.l28	2	132.44	134.84	137.94	138.05	137.91
Line.l29	1	132.46	134.86	137.97	138.07	137.93
Line.l29	2	132.46	134.86	137.97	138.07	137.93
Line.l30	1	132.49	134.89	138.00	138.10	137.96
Line.l30	2	132.49	134.89	138.00	138.10	137.96
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	132.98	135.39	138.51	138.62	138.47
Line.l32	2	132.98	135.39	138.51	138.62	138.47
Line.l33	1	133.01	135.43	138.54	138.65	138.50
Line.l33	2	133.01	135.43	138.54	138.65	138.50
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-19: I₂ value, zone 2, LL fault, 50% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	7.23	7.35	7.26	7.18	7.05
Vsource	2	7.23	7.35	7.26	7.18	7.05
Subxf	1	7.23	7.35	7.26	7.18	7.05
Subxf	2	346.64	352.28	347.97	344.15	337.73
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	315.36	320.48	316.55	313.08	307.24
Line.l1	2	315.33	320.46	316.52	313.06	307.21
Line.l2	1	42.62	43.16	42.68	42.32	41.71
Line.l2	2	42.63	43.16	42.68	42.32	41.71
Line.l3	1	92.18	93.21	92.27	91.57	90.38
Line.l3	2	92.19	93.22	92.28	91.58	90.39
Line.l4	1	449.49	456.17	450.81	446.29	438.67
Line.l4	2	449.45	456.13	450.78	446.26	438.64
Line.l5	1	92.65	93.69	92.80	92.09	90.89
Line.l5	2	92.66	93.70	92.81	92.10	90.89
Line.l6	1	58.80	59.18	58.76	58.50	58.05
Line.l6	2	58.81	59.19	58.77	58.51	58.06
Line.l7	1	4.19	4.20	4.20	4.19	4.18
Line.l7	2	4.19	4.20	4.21	4.20	4.18
Line.l8	1	4.19	4.20	4.21	4.20	4.18
Line.l8	2	4.19	4.21	4.21	4.20	4.19
Line.l9	1	54.86	55.26	54.86	54.59	54.13
Line.l9	2	54.87	55.27	54.87	54.60	54.14
Line.l10	1	17.87	17.91	17.88	17.85	17.80
Line.l10	2	17.87	17.91	17.88	17.85	17.80
Line.l11	1	41.22	41.80	41.34	40.94	40.28
Line.l11	2	41.23	41.81	41.35	40.95	40.29
Line.l12	1	37.14	37.81	37.38	36.92	36.15
Line.l12	2	37.14	37.81	37.38	36.92	36.15
Line.l13	1	37.08	37.82	37.32	36.82	35.98
Line.l13	2	37.08	37.82	37.33	36.83	35.99
Line.l14	1	10.09	10.03	10.03	10.06	10.12
Line.l14	2	10.09	10.03	10.03	10.06	10.12
Line.l15	1	44.57	45.12	44.67	44.30	43.66
Line.l15	2	44.57	45.13	44.68	44.30	43.67
Line.l16	1	547.34	555.88	36.70	36.22	35.40

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	547.34	555.88	36.71	36.22	35.40
Line.l17	1	97.91	99.79	487.29	482.27	473.81
Line.l17	2	97.92	99.80	487.28	482.26	473.80
Line.l18	1	98.77	100.60	103.65	481.78	473.35
Line.l18	2	98.77	100.60	103.65	481.78	473.34
Line.l19	1	47.97	48.55	49.52	49.59	48.88
Line.l19	2	47.98	48.56	49.53	49.60	48.89
Line.l20	1	52.04	53.40	55.47	55.60	520.45
Line.l20	2	52.04	53.40	55.48	55.60	520.44
Line.l21	1	4.93	4.90	4.83	4.83	4.82
Line.l21	2	4.93	4.90	4.83	4.82	4.82
Line.l22	1	52.24	53.54	55.69	55.83	55.96
Line.l22	2	52.24	53.54	55.69	55.84	55.97
Line.l23	1	547.11	39.48	37.91	37.44	36.65
Line.l23	2	547.10	39.48	37.92	37.45	36.65
Line.l24	1	39.81	39.70	38.42	38.02	37.35
Line.l24	2	39.82	39.71	38.42	38.03	37.35
Line.l25	1	7.55	7.53	7.27	7.19	7.06
Line.l25	2	7.55	7.53	7.27	7.19	7.06
Line.l26	1	62.37	63.74	65.91	66.05	66.17
Line.l26	2	62.38	63.75	65.92	66.06	66.18
Line.l27	1	19.70	20.41	21.76	21.86	21.97
Line.l27	2	19.71	20.43	21.77	21.87	21.98
Line.l28	1	36.28	37.13	38.54	38.64	38.72
Line.l28	2	36.28	37.14	38.55	38.64	38.73
Line.l29	1	39.07	39.67	40.51	40.55	40.58
Line.l29	2	39.07	39.68	40.51	40.56	40.59
Line.l30	1	40.92	41.58	42.64	42.71	42.78
Line.l30	2	40.92	41.59	42.65	42.72	42.78
Line.l31	1	9.98	9.92	9.77	9.77	9.76
Line.l31	2	9.98	9.92	9.77	9.77	9.76
Line.l32	1	43.21	43.82	44.73	44.79	44.84
Line.l32	2	43.22	43.83	44.74	44.80	44.85
Line.l33	1	45.59	46.22	47.29	47.36	47.44
Line.l33	2	45.60	46.24	47.30	47.38	47.46
Line.l34	1	9.99	9.93	9.79	9.78	9.77
Line.l34	2	9.99	9.93	9.78	9.78	9.77
Line.l35	1	315.13	320.25	316.33	312.87	307.03

Table 4-20: I₁ value, zone 3, 3 phase fault, 50% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	15.68	15.16	15.24	14.98	14.73
Vsource	2	15.68	15.16	15.24	14.98	14.73
Subxf	1	15.68	15.16	15.24	14.98	14.73
Subxf	2	751.45	726.45	730.24	717.89	706.03
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	680.44	657.38	660.96	649.62	638.72
Line.l1	2	680.45	657.39	660.97	649.62	638.73
Line.l2	1	49.19	46.75	47.22	46.07	44.97
Line.l2	2	49.19	46.75	47.22	46.07	44.96
Line.l3	1	82.89	78.02	79.19	77.02	74.95
Line.l3	2	82.89	78.01	79.18	77.02	74.94
Line.l4	1	810.86	780.51	785.59	770.86	756.71
Line.l4	2	810.87	780.51	785.59	770.87	756.72
Line.l5	1	86.15	81.69	82.67	80.63	78.67
Line.l5	2	86.15	81.69	82.66	80.63	78.67
Line.l6	1	38.55	36.13	36.85	35.85	34.90
Line.l6	2	38.54	36.13	36.84	35.85	34.89
Line.l7	1	1.76	1.99	1.91	1.99	2.07
Line.l7	2	1.76	1.99	1.91	1.99	2.07
Line.l8	1	1.76	1.99	1.91	1.99	2.07
Line.l8	2	1.76	1.99	1.91	1.99	2.07
Line.l9	1	43.27	41.41	41.83	40.99	40.17
Line.l9	2	43.26	41.40	41.82	40.98	40.17
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	61.29	59.39	59.65	58.69	57.77
Line.l11	2	61.29	59.39	59.64	58.69	57.77
Line.l12	1	48.17	46.22	46.50	45.53	44.61
Line.l12	2	48.17	46.22	46.50	45.53	44.61
Line.l13	1	52.57	50.63	50.88	49.90	48.96
Line.l13	2	52.57	50.63	50.88	49.90	48.96
Line.l14	1	3.59	4.05	3.90	4.08	4.26
Line.l14	2	3.59	4.05	3.90	4.08	4.26
Line.l15	1	52.61	50.62	50.90	49.91	48.96
Line.l15	2	52.61	50.62	50.90	49.91	48.96
Line.l16	1	55.22	52.30	52.97	51.65	50.39

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	55.22	52.30	52.97	51.65	50.39
Line.l17	1	865.23	831.92	837.65	821.57	806.13
Line.l17	2	865.24	831.92	837.65	821.57	806.14
Line.l18	1	862.67	828.93	834.83	818.59	803.01
Line.l18	2	862.67	828.93	834.83	818.60	803.01
Line.l19	1	59.88	57.66	57.96	56.85	55.79
Line.l19	2	59.88	57.66	57.96	56.85	55.78
Line.l20	1	922.33	886.42	892.61	875.29	858.66
Line.l20	2	922.33	886.42	892.61	875.29	858.66
Line.l21	1	1.26	1.51	1.42	1.52	1.61
Line.l21	2	1.26	1.51	1.42	1.52	1.61
Line.l22	1	921.08	884.93	891.21	873.80	857.09
Line.l22	2	921.08	884.93	891.21	873.80	857.09
Line.l23	1	56.72	54.01	54.58	53.33	52.13
Line.l23	2	56.72	54.01	54.58	53.33	52.13
Line.l24	1	62.90	61.04	61.26	60.30	59.38
Line.l24	2	62.90	61.04	61.26	60.30	59.38
Line.l25	1	4.87	5.58	5.33	5.61	5.87
Line.l25	2	4.87	5.58	5.33	5.61	5.87
Line.l26	1	910.88	874.77	881.08	863.72	847.05
Line.l26	2	910.88	874.77	881.08	863.72	847.05
Line.l27	1	39.30	36.52	940.80	922.07	904.08
Line.l27	2	39.29	36.52	940.80	922.07	904.08
Line.l28	1	55.85	52.75	56.00	905.26	887.34
Line.l28	2	55.85	52.75	56.00	905.26	887.34
Line.l29	1	58.90	56.50	58.93	58.98	884.15
Line.l29	2	58.90	56.50	58.93	58.98	884.15
Line.l30	1	60.98	59.05	60.90	60.90	60.90
Line.l30	2	60.98	59.05	60.90	60.90	60.90
Line.l31	1	2.09	2.59	2.00	1.94	1.89
Line.l31	2	2.09	2.59	2.00	1.94	1.89
Line.l32	1	63.55	908.87	61.31	60.00	58.75
Line.l32	2	63.55	908.87	61.31	60.00	58.75
Line.l33	1	65.62	65.47	63.66	62.52	61.43
Line.l33	2	65.62	65.47	63.66	62.52	61.43
Line.l34	1	2.08	1.96	2.40	2.59	2.78
Line.l34	2	2.08	1.96	2.40	2.59	2.78

Table 4-21: I_r value, zone 3, SLG fault, 50% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.20	0.19	0.19	0.19	0.18
Line.l1	2	0.20	0.19	0.19	0.19	0.18
Line.l2	1	119.36	114.04	114.64	111.79	109.02
Line.l2	2	119.36	114.04	114.64	111.79	109.02
Line.l3	1	234.95	224.47	225.65	220.04	214.59
Line.l3	2	234.95	224.47	225.65	220.04	214.59
Line.l4	1	353.97	338.18	339.97	331.51	323.30
Line.l4	2	353.97	338.18	339.97	331.51	323.30
Line.l5	1	234.96	224.49	225.67	220.05	214.61
Line.l5	2	234.96	224.49	225.67	220.05	214.61
Line.l6	1	117.02	111.80	112.39	109.59	106.88
Line.l6	2	117.02	111.80	112.39	109.59	106.88
Line.l7	1	0.04	0.04	0.04	0.04	0.04
Line.l7	2	0.04	0.04	0.04	0.04	0.04
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	117.10	111.88	112.47	109.67	106.95
Line.l9	2	117.10	111.88	112.47	109.67	106.95
Line.l10	1	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00
Line.l11	1	117.14	111.92	112.51	109.71	106.99
Line.l11	2	117.14	111.92	112.51	109.71	106.99
Line.l12	1	118.00	112.74	113.33	110.51	107.78
Line.l12	2	118.00	112.74	113.33	110.51	107.78
Line.l13	1	118.01	112.74	113.34	110.52	107.78
Line.l13	2	118.01	112.74	113.34	110.52	107.78
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	119.39	114.06	114.66	111.81	109.04
Line.l15	2	119.39	114.06	114.66	111.81	109.04
Line.l16	1	126.46	120.82	121.46	118.44	115.50
Line.l16	2	126.46	120.82	121.46	118.44	115.50

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l17	1	480.23	458.81	461.23	449.76	438.62
Line.l17	2	480.23	458.81	461.23	449.76	438.62
Line.l18	1	480.20	458.78	461.20	449.73	438.59
Line.l18	2	480.20	458.78	461.20	449.73	438.59
Line.l19	1	130.28	124.47	125.12	122.01	118.99
Line.l19	2	130.28	124.47	125.12	122.01	118.99
Line.l20	1	610.12	582.91	585.99	571.41	557.26
Line.l20	2	610.12	582.91	585.99	571.41	557.26
Line.l21	1	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01
Line.l22	1	610.09	582.88	585.96	571.38	557.23
Line.l22	2	610.09	582.88	585.96	571.38	557.23
Line.l23	1	126.47	120.83	121.47	118.44	115.51
Line.l23	2	126.47	120.83	121.47	118.44	115.51
Line.l24	1	126.49	120.85	121.49	118.47	115.53
Line.l24	2	126.49	120.85	121.49	118.47	115.53
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	610.08	582.87	585.94	571.37	557.22
Line.l26	2	610.08	582.87	585.94	571.37	557.22
Line.l27	1	137.70	131.55	718.05	700.19	682.85
Line.l27	2	137.70	131.55	718.05	700.19	682.85
Line.l28	1	137.73	131.59	137.21	700.15	682.82
Line.l28	2	137.73	131.59	137.21	700.15	682.82
Line.l29	1	137.75	131.61	137.23	136.98	682.80
Line.l29	2	137.75	131.61	137.23	136.98	682.80
Line.l30	1	137.78	131.64	137.26	137.01	136.82
Line.l30	2	137.78	131.64	137.26	137.01	136.82
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	138.30	713.58	132.82	129.52	126.31
Line.l32	2	138.30	713.58	132.82	129.52	126.31
Line.l33	1	138.33	137.21	132.86	129.55	126.34
Line.l33	2	138.33	137.21	132.86	129.55	126.34
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-22: I₂ value, zone 3, LL fault, 50% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	6.70	6.41	6.46	6.32	6.18
Vsource	2	6.70	6.41	6.46	6.32	6.18
Subxf	1	6.70	6.41	6.46	6.32	6.18
Subxf	2	321.26	307.27	309.53	302.82	296.36
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	292.26	279.57	281.59	275.49	269.62
Line.l1	2	292.24	279.55	281.57	275.46	269.59
Line.l2	1	40.14	38.93	39.03	38.40	37.79
Line.l2	2	40.15	38.94	39.04	38.40	37.79
Line.l3	1	87.28	84.82	85.02	83.71	82.44
Line.l3	2	87.28	84.82	85.02	83.72	82.44
Line.l4	1	419.07	402.76	405.06	397.03	389.29
Line.l4	2	419.04	402.73	405.02	397.00	389.26
Line.l5	1	87.74	85.14	85.46	84.14	82.86
Line.l5	2	87.75	85.15	85.47	84.15	82.86
Line.l6	1	56.86	55.97	55.96	55.44	54.92
Line.l6	2	56.87	55.98	55.97	55.45	54.93
Line.l7	1	4.15	4.12	4.14	4.14	4.14
Line.l7	2	4.16	4.12	4.15	4.15	4.15
Line.l8	1	4.16	4.12	4.15	4.15	4.15
Line.l8	2	4.16	4.13	4.15	4.15	4.15
Line.l9	1	52.90	51.95	52.00	51.47	50.95
Line.l9	2	52.92	51.96	52.01	51.48	50.96
Line.l10	1	17.68	17.55	17.58	17.53	17.47
Line.l10	2	17.68	17.55	17.58	17.53	17.48
Line.l11	1	38.56	37.13	37.35	36.65	35.98
Line.l11	2	38.57	37.13	37.36	36.66	35.99
Line.l12	1	34.14	32.28	32.72	31.90	31.11
Line.l12	2	34.15	32.28	32.72	31.90	31.11
Line.l13	1	33.82	31.86	32.30	31.42	30.58
Line.l13	2	33.83	31.87	32.30	31.43	30.59
Line.l14	1	10.27	10.46	10.38	10.44	10.49
Line.l14	2	10.27	10.46	10.38	10.44	10.49
Line.l15	1	42.03	40.65	40.87	40.20	39.56
Line.l15	2	42.03	40.66	40.87	40.20	39.56
Line.l16	1	33.27	31.36	31.74	30.85	30.00

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	33.27	31.36	31.74	30.86	30.01
Line.l17	1	452.06	433.86	436.51	427.60	419.01
Line.l17	2	452.05	433.85	436.50	427.59	419.00
Line.l18	1	451.66	433.65	436.16	427.28	418.72
Line.l18	2	451.66	433.64	436.16	427.28	418.72
Line.l19	1	47.05	45.53	45.75	45.01	44.29
Line.l19	2	47.06	45.54	45.76	45.02	44.30
Line.l20	1	496.94	477.36	480.13	470.50	461.22
Line.l20	2	496.93	477.35	480.13	470.50	461.22
Line.l21	1	4.90	5.01	4.96	5.00	5.03
Line.l21	2	4.90	5.01	4.96	4.99	5.03
Line.l22	1	496.74	477.25	479.96	470.34	461.08
Line.l22	2	496.73	477.25	479.95	470.34	461.08
Line.l23	1	34.56	32.59	33.06	32.19	31.35
Line.l23	2	34.57	32.60	33.07	32.20	31.36
Line.l24	1	35.54	33.83	34.22	33.45	32.70
Line.l24	2	35.55	33.84	34.22	33.45	32.71
Line.l25	1	6.72	6.42	6.47	6.33	6.20
Line.l25	2	6.72	6.42	6.47	6.33	6.20
Line.l26	1	486.58	467.17	469.95	460.41	451.22
Line.l26	2	486.57	467.16	469.94	460.41	451.21
Line.l27	1	22.34	20.35	512.94	502.61	492.64
Line.l27	2	22.35	20.36	512.93	502.60	492.63
Line.l28	1	39.02	36.59	39.16	485.83	476.00
Line.l28	2	39.03	36.59	39.17	485.82	475.99
Line.l29	1	40.74	39.14	40.80	40.89	474.07
Line.l29	2	40.74	39.14	40.81	40.90	474.07
Line.l30	1	43.02	41.18	43.14	43.27	43.40
Line.l30	2	43.03	41.18	43.15	43.28	43.41
Line.l31	1	9.74	9.96	9.74	9.74	9.74
Line.l31	2	9.74	9.96	9.74	9.74	9.74
Line.l32	1	45.04	486.84	43.54	42.69	41.87
Line.l32	2	45.04	486.83	43.55	42.70	41.88
Line.l33	1	47.71	47.92	46.18	45.31	44.47
Line.l33	2	47.72	47.94	46.20	45.33	44.49
Line.l34	1	9.75	9.74	9.88	9.95	10.01
Line.l34	2	9.75	9.74	9.88	9.95	10.01

Table 4-23: Threshold values, 50% penetration

Zone #	I₁ th	I_r th	I₂ th
1	920	650	470
2	900	500	470
3	880	600	480

4.4.2 Short Circuit Analysis 100% DG Penetration**Table 4-24: I₁ value, zone 1, 3 phase fault, 100% penetration**

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	1.24	1.12	1.24	1.28	1.45	1.62	1.87
Line.l1	2	1.24	1.12	1.24	1.28	1.45	1.62	1.87
Line.l2	1	581.71	90.88	89.71	89.41	87.63	85.91	84.33
Line.l2	2	581.71	90.88	89.71	89.41	87.63	85.91	84.33
Line.l3	1	171.43	504.55	497.89	496.16	486.04	476.23	466.71
Line.l3	2	171.43	504.55	497.89	496.16	486.04	476.23	466.71
Line.l4	1	411.54	414.80	409.42	408.03	399.84	391.91	384.23
Line.l4	2	411.54	414.80	409.42	408.03	399.84	391.91	384.22
Line.l5	1	173.16	176.35	496.31	494.54	484.19	474.17	464.30
Line.l5	2	173.16	176.35	496.31	494.54	484.19	474.17	464.30
Line.l6	1	86.24	88.01	88.38	88.07	571.04	559.50	548.41
Line.l6	2	86.24	88.01	88.38	88.07	571.04	559.50	548.41
Line.l7	1	0.88	0.73	0.70	0.72	0.66	646.78	0.95
Line.l7	2	0.88	0.73	0.70	0.72	0.66	646.78	0.95
Line.l8	1	0.88	0.73	0.70	0.72	0.66	0.65	0.95

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l8	2	0.88	0.73	0.70	0.72	0.66	0.65	0.95
Line.l9	1	88.93	90.25	90.51	90.28	90.65	89.25	545.52
Line.l9	2	88.93	90.25	90.51	90.28	90.65	89.25	545.52
Line.l10	1	19.36	19.37	19.37	19.37	19.37	19.37	19.36
Line.l10	2	19.36	19.37	19.37	19.37	19.37	19.37	19.36
Line.l11	1	108.12	109.53	109.81	109.56	109.93	108.32	109.94
Line.l11	2	108.12	109.53	109.81	109.56	109.93	108.32	109.94
Line.l12	1	87.02	88.41	88.70	582.43	86.86	85.34	84.12
Line.l12	2	87.02	88.41	88.70	582.43	86.86	85.34	84.12
Line.l13	1	91.58	92.98	93.26	93.27	91.40	89.85	88.63
Line.l13	2	91.58	92.98	93.26	93.27	91.40	89.85	88.63
Line.l14	1	1.40	1.58	1.75	1.80	2.03	2.27	2.61
Line.l14	2	1.40	1.58	1.75	1.80	2.03	2.27	2.61
Line.l15	1	93.19	92.46	91.45	91.21	89.64	88.14	86.90
Line.l15	2	93.19	92.46	91.45	91.21	89.64	88.14	86.90
Line.l16	1	114.36	115.25	113.82	113.45	111.29	109.18	107.12
Line.l16	2	114.36	115.25	113.82	113.45	111.29	109.18	107.12
Line.l17	1	297.30	299.67	295.72	294.70	288.68	282.85	277.25
Line.l17	2	297.30	299.67	295.72	294.70	288.68	282.85	277.25
Line.l18	1	299.09	301.32	297.51	296.54	290.71	285.07	279.77
Line.l18	2	299.09	301.32	297.51	296.54	290.70	285.07	279.77
Line.l19	1	121.64	122.27	121.07	120.78	118.92	117.13	115.60
Line.l19	2	121.64	122.27	121.07	120.78	118.92	117.13	115.60
Line.l20	1	177.60	179.18	176.56	175.88	171.89	168.03	164.29
Line.l20	2	177.60	179.18	176.56	175.88	171.89	168.03	164.29
Line.l21	1	1.03	0.95	1.04	1.06	1.18	1.29	1.46
Line.l21	2	1.03	0.95	1.04	1.06	1.18	1.29	1.46
Line.l22	1	178.62	180.13	177.58	176.93	173.04	169.28	165.71
Line.l22	2	178.62	180.13	177.58	176.93	173.04	169.28	165.71
Line.l23	1	115.29	116.10	114.75	114.40	112.34	110.33	108.44
Line.l23	2	115.29	116.10	114.75	114.40	112.34	110.33	108.44
Line.l24	1	118.92	119.42	118.35	118.11	116.43	114.83	113.58
Line.l24	2	118.92	119.42	118.35	118.11	116.43	114.83	113.58
Line.l25	1	2.77	2.53	2.77	2.85	3.17	3.51	4.01
Line.l25	2	2.77	2.53	2.77	2.85	3.17	3.51	4.01
Line.l26	1	188.80	190.30	187.72	187.07	183.13	179.32	175.78
Line.l26	2	188.80	190.30	187.72	187.07	183.13	179.32	175.78
Line.l27	1	82.86	83.66	82.38	82.04	80.09	78.19	76.30
Line.l27	2	82.86	83.66	82.37	82.04	80.09	78.18	76.30

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l28	1	99.57	100.36	99.02	98.68	96.63	94.65	92.81
Line.l28	2	99.57	100.36	99.02	98.68	96.63	94.64	92.81
Line.l29	1	102.70	103.25	102.13	101.87	100.12	98.46	97.09
Line.l29	2	102.70	103.25	102.13	101.87	100.12	98.46	97.09
Line.l30	1	104.97	105.38	104.41	104.20	102.67	101.22	100.18
Line.l30	2	104.97	105.38	104.41	104.20	102.67	101.21	100.18
Line.l31	1	2.30	2.14	2.31	2.36	2.60	2.83	3.16
Line.l31	2	2.30	2.14	2.31	2.36	2.60	2.83	3.16
Line.l32	1	107.07	107.69	106.49	106.20	104.33	102.56	101.06
Line.l32	2	107.07	107.69	106.49	106.20	104.33	102.55	101.06
Line.l33	1	109.32	109.79	108.75	108.51	106.86	105.30	104.14
Line.l33	2	109.32	109.79	108.75	108.51	106.86	105.30	104.14
Line.l34	1	2.27	2.12	2.28	2.34	2.57	2.80	3.13
Line.l34	2	2.27	2.12	2.28	2.34	2.57	2.80	3.13

Table 4-25: I_r value, zone 1, SLG fault, 100% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.13	0.13	0.13	0.12	0.12	0.11	0.11
Line.l1	2	0.13	0.13	0.13	0.12	0.12	0.11	0.11
Line.l2	1	724.53	113.33	110.06	109.31	104.64	100.44	96.85
Line.l2	2	724.53	113.33	110.06	109.31	104.64	100.44	96.85
Line.l3	1	221.51	623.28	605.28	601.16	575.49	552.36	532.65
Line.l3	2	221.51	623.28	605.28	601.16	575.49	552.36	532.65
Line.l4	1	503.56	510.85	496.10	492.72	471.68	452.72	436.56
Line.l4	2	503.56	510.85	496.10	492.72	471.68	452.72	436.56
Line.l5	1	221.52	232.10	605.27	601.15	575.48	552.35	532.64
Line.l5	2	221.52	232.10	605.27	601.15	575.48	552.35	532.64
Line.l6	1	111.83	117.17	119.34	118.53	685.09	657.55	634.08
Line.l6	2	111.83	117.17	119.34	118.53	685.09	657.55	634.08
Line.l7	1	0.03	0.03	0.03	0.03	0.03	772.71	0.03

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l7	2	0.03	0.03	0.03	0.03	0.03	772.71	0.03
Line.l8	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l9	1	111.88	117.23	119.40	118.58	122.44	117.52	634.03
Line.l9	2	111.88	117.23	119.40	118.58	122.44	117.52	634.03
Line.l10	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l11	1	111.91	117.26	119.43	118.61	122.46	117.54	127.14
Line.l11	2	111.91	117.26	119.43	118.61	122.46	117.54	127.14
Line.l12	1	109.77	115.01	117.14	718.62	111.38	106.90	103.09
Line.l12	2	109.77	115.01	117.14	718.62	111.38	106.90	103.09
Line.l13	1	109.77	115.02	117.15	117.45	111.38	106.91	103.09
Line.l13	2	109.77	115.02	117.15	117.45	111.38	106.91	103.09
Line.l14	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l15	1	116.98	113.35	110.07	109.32	104.66	100.45	96.87
Line.l15	2	116.98	113.35	110.07	109.32	104.66	100.45	96.87
Line.l16	1	130.62	132.51	128.69	127.81	122.35	117.43	113.24
Line.l16	2	130.62	132.51	128.69	127.81	122.35	117.43	113.24
Line.l17	1	373.57	378.98	368.04	365.53	349.92	335.86	323.87
Line.l17	2	373.57	378.98	368.04	365.53	349.92	335.86	323.87
Line.l18	1	373.59	379.00	368.06	365.55	349.94	335.87	323.88
Line.l18	2	373.59	379.00	368.06	365.55	349.94	335.87	323.88
Line.l19	1	127.39	129.23	125.50	124.65	119.32	114.53	110.44
Line.l19	2	127.39	129.23	125.50	124.65	119.32	114.53	110.44
Line.l20	1	246.59	250.16	242.94	241.28	230.98	221.70	213.78
Line.l20	2	246.59	250.16	242.94	241.28	230.98	221.70	213.78
Line.l21	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l22	1	246.61	250.18	242.96	241.30	231.00	221.71	213.80
Line.l22	2	246.61	250.18	242.96	241.30	231.00	221.71	213.80
Line.l23	1	130.62	132.52	128.69	127.81	122.36	117.44	113.25
Line.l23	2	130.62	132.52	128.69	127.81	122.36	117.44	113.25
Line.l24	1	130.64	132.53	128.71	127.83	122.37	117.45	113.26
Line.l24	2	130.64	132.53	128.71	127.83	122.37	117.45	113.26
Line.l25	1	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Line.l25	2	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Line.l26	1	246.62	250.19	242.97	241.31	231.01	221.72	213.81
Line.l26	2	246.62	250.19	242.97	241.31	231.01	221.72	213.81

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l27	1	123.62	125.41	121.79	120.96	115.79	111.14	107.17
Line.l27	2	123.62	125.41	121.79	120.96	115.79	111.14	107.17
Line.l28	1	123.64	125.43	121.81	120.98	115.81	111.15	107.19
Line.l28	2	123.64	125.43	121.81	120.98	115.81	111.15	107.19
Line.l29	1	123.65	125.44	121.82	120.99	115.82	111.16	107.20
Line.l29	2	123.65	125.44	121.82	120.99	115.82	111.16	107.20
Line.l30	1	123.67	125.46	121.83	121.00	115.84	111.18	107.21
Line.l30	2	123.67	125.46	121.83	121.00	115.84	111.18	107.21
Line.l31	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l31	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l32	1	123.03	124.81	121.20	120.38	115.24	110.61	106.66
Line.l32	2	123.03	124.81	121.20	120.38	115.24	110.61	106.66
Line.l33	1	123.04	124.82	121.22	120.39	115.25	110.62	106.67
Line.l33	2	123.04	124.82	121.22	120.39	115.25	110.62	106.67
Line.l34	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l34	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4-26: I₂ value, zone 1, LL fault, 100% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	4.25	4.25	4.24	4.24	4.22	4.20	4.21
Line.l1	2	4.26	4.25	4.24	4.24	4.23	4.21	4.22
Line.l2	1	331.38	56.41	55.77	55.60	54.63	53.63	52.87
Line.l2	2	331.38	56.41	55.78	55.61	54.64	53.63	52.87
Line.l3	1	120.13	270.48	266.67	265.56	259.76	253.60	248.06
Line.l3	2	120.14	270.48	266.66	265.55	259.76	253.60	248.05
Line.l4	1	211.62	214.11	210.93	209.98	205.17	200.01	195.16
Line.l4	2	211.66	214.14	210.96	210.01	205.20	200.05	195.19
Line.l5	1	121.29	123.39	265.11	264.03	258.26	252.15	246.85
Line.l5	2	121.29	123.40	265.10	264.02	258.25	252.15	246.84
Line.l6	1	71.90	72.51	72.80	72.71	309.08	301.65	294.95

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l6	2	71.91	72.52	72.81	72.72	309.07	301.64	294.94
Line.l7	1	3.72	3.79	3.81	3.80	3.85	370.26	3.77
Line.l7	2	3.73	3.79	3.82	3.81	3.85	370.26	3.78
Line.l8	1	3.73	3.79	3.82	3.81	3.85	3.88	3.78
Line.l8	2	3.73	3.79	3.82	3.81	3.86	3.88	3.78
Line.l9	1	69.34	70.08	70.40	70.29	70.77	69.98	297.08
Line.l9	2	69.35	70.09	70.41	70.30	70.78	69.99	297.07
Line.l10	1	18.03	18.10	18.12	18.11	18.13	18.07	18.15
Line.l10	2	18.03	18.10	18.12	18.11	18.13	18.07	18.15
Line.l11	1	56.91	58.24	58.70	58.49	59.22	58.01	60.04
Line.l11	2	56.92	58.25	58.71	58.50	59.23	58.02	60.05
Line.l12	1	51.95	53.49	53.98	336.20	52.58	51.33	50.05
Line.l12	2	51.96	53.49	53.99	336.20	52.58	51.33	50.05
Line.l13	1	52.22	53.90	54.44	54.50	52.85	51.46	50.10
Line.l13	2	52.23	53.91	54.45	54.51	52.86	51.46	50.11
Line.l14	1	8.51	8.57	8.65	8.67	8.78	8.90	9.06
Line.l14	2	8.51	8.57	8.64	8.67	8.78	8.89	9.06
Line.l15	1	59.50	58.79	58.13	57.95	56.95	55.91	55.01
Line.l15	2	59.51	58.80	58.14	57.95	56.96	55.92	55.02
Line.l16	1	56.77	57.47	56.59	56.33	55.00	53.59	52.20
Line.l16	2	56.77	57.48	56.60	56.33	55.01	53.59	52.21
Line.l17	1	155.05	156.81	154.52	153.84	150.36	146.62	143.17
Line.l17	2	155.06	156.82	154.53	153.85	150.36	146.63	143.18
Line.l18	1	156.89	158.77	156.46	155.75	152.26	148.50	144.83
Line.l18	2	156.90	158.77	156.46	155.76	152.27	148.50	144.83
Line.l19	1	67.29	67.83	67.07	66.85	65.70	64.49	63.44
Line.l19	2	67.30	67.84	67.08	66.86	65.71	64.49	63.44
Line.l20	1	90.08	91.36	89.80	89.32	86.96	84.40	81.90
Line.l20	2	90.09	91.36	89.81	89.32	86.97	84.41	81.90
Line.l21	1	4.34	4.29	4.33	4.34	4.40	4.45	4.53
Line.l21	2	4.34	4.29	4.33	4.34	4.39	4.45	4.53
Line.l22	1	91.04	92.39	90.83	90.33	87.98	85.41	82.75
Line.l22	2	91.04	92.39	90.83	90.34	87.98	85.41	82.75
Line.l23	1	58.15	58.90	58.02	57.75	56.44	55.02	53.56
Line.l23	2	58.16	58.90	58.03	57.75	56.44	55.03	53.57
Line.l24	1	58.63	59.28	58.50	58.26	57.07	55.79	54.49
Line.l24	2	58.63	59.29	58.50	58.26	57.08	55.79	54.49
Line.l25	1	6.49	6.56	6.47	6.44	6.31	6.17	6.04
Line.l25	2	6.49	6.56	6.47	6.44	6.31	6.17	6.04

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l26	1	100.86	102.15	100.50	100.01	97.51	94.84	92.33
Line.l26	2	100.87	102.16	100.51	100.02	97.52	94.85	92.34
Line.l27	1	39.92	40.78	39.92	39.62	38.34	36.91	35.21
Line.l27	2	39.93	40.79	39.93	39.63	38.35	36.92	35.22
Line.l28	1	55.86	56.62	55.61	55.32	53.80	52.21	50.77
Line.l28	2	55.87	56.63	55.62	55.33	53.81	52.21	50.78
Line.l29	1	58.24	58.72	57.95	57.75	56.56	55.33	54.41
Line.l29	2	58.25	58.73	57.95	57.75	56.56	55.33	54.42
Line.l30	1	60.63	61.22	60.39	60.16	58.90	57.58	56.46
Line.l30	2	60.64	61.22	60.40	60.16	58.91	57.59	56.47
Line.l31	1	8.85	8.77	8.84	8.87	8.97	9.08	9.23
Line.l31	2	8.85	8.77	8.84	8.87	8.97	9.08	9.23
Line.l32	1	62.11	62.62	61.84	61.63	60.45	59.22	58.24
Line.l32	2	62.11	62.62	61.85	61.64	60.46	59.23	58.25
Line.l33	1	64.69	65.29	64.48	64.24	63.02	61.74	60.60
Line.l33	2	64.71	65.30	64.49	64.26	63.04	61.75	60.61
Line.l34	1	8.85	8.77	8.84	8.87	8.97	9.08	9.23
Line.l34	2	8.85	8.77	8.84	8.87	8.97	9.08	9.23

Table 4-27: I_1 value, zone 2, 3 phase fault, 100% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	1.30	1.23	1.22	1.26	1.33
Line.l1	2	1.30	1.23	1.22	1.26	1.33
Line.l2	1	89.22	89.92	89.82	89.51	88.82
Line.l2	2	89.22	89.92	89.82	89.51	88.82
Line.l3	1	169.57	170.92	170.75	170.13	168.78
Line.l3	2	169.57	170.92	170.75	170.13	168.78
Line.l4	1	257.47	259.59	259.33	258.35	256.25
Line.l4	2	257.47	259.59	259.33	258.36	256.25
Line.l5	1	171.36	172.63	172.44	171.86	170.60

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l5	2	171.36	172.63	172.44	171.86	170.60
Line.l6	1	85.37	86.03	85.97	85.66	84.99
Line.l6	2	85.37	86.03	85.97	85.66	84.99
Line.l7	1	0.91	0.87	0.86	0.88	0.93
Line.l7	2	0.91	0.87	0.86	0.88	0.93
Line.l8	1	0.91	0.87	0.86	0.88	0.93
Line.l8	2	0.91	0.87	0.86	0.88	0.93
Line.l9	1	88.14	88.68	88.59	88.34	87.81
Line.l9	2	88.14	88.68	88.59	88.34	87.81
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	107.20	107.81	107.69	107.42	106.83
Line.l11	2	107.20	107.81	107.69	107.42	106.83
Line.l12	1	86.12	86.71	86.59	86.32	85.74
Line.l12	2	86.12	86.71	86.59	86.32	85.74
Line.l13	1	90.66	91.27	91.14	90.87	90.28
Line.l13	2	90.66	91.27	91.14	90.87	90.28
Line.l14	1	1.82	1.72	1.71	1.76	1.85
Line.l14	2	1.82	1.72	1.71	1.76	1.85
Line.l15	1	91.03	91.64	91.52	91.25	90.66
Line.l15	2	91.03	91.64	91.52	91.25	90.66
Line.l16	1	559.52	564.08	116.83	116.42	115.55
Line.l16	2	559.52	564.08	116.83	116.42	115.55
Line.l17	1	302.08	304.51	376.10	374.72	371.74
Line.l17	2	302.08	304.51	376.10	374.72	371.74
Line.l18	1	303.70	306.05	311.69	373.39	370.33
Line.l18	2	303.70	306.05	311.69	373.39	370.33
Line.l19	1	123.08	123.82	125.53	125.81	125.06
Line.l19	2	123.08	123.82	125.53	125.81	125.06
Line.l20	1	180.79	182.41	186.37	187.02	495.33
Line.l20	2	180.79	182.41	186.37	187.02	495.33
Line.l21	1	0.94	0.89	0.75	0.72	0.70
Line.l21	2	0.94	0.89	0.75	0.72	0.70
Line.l22	1	181.72	183.30	187.11	187.74	188.31
Line.l22	2	181.72	183.30	187.11	187.74	188.31
Line.l23	1	558.78	118.89	117.62	117.24	116.41
Line.l23	2	558.78	118.89	117.62	117.23	116.41
Line.l24	1	121.75	121.67	120.77	120.48	119.83
Line.l24	2	121.75	121.67	120.77	120.48	119.83

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l25	1	2.05	2.10	2.38	2.45	2.59
Line.l25	2	2.05	2.10	2.38	2.45	2.59
Line.l26	1	191.93	193.52	197.34	197.96	198.53
Line.l26	2	191.92	193.52	197.34	197.96	198.53
Line.l27	1	84.40	85.20	87.15	87.47	87.76
Line.l27	2	84.40	85.20	87.15	87.47	87.76
Line.l28	1	101.17	102.00	103.98	104.30	104.59
Line.l28	2	101.17	101.99	103.98	104.30	104.59
Line.l29	1	104.09	104.78	106.36	106.63	106.86
Line.l29	2	104.09	104.78	106.36	106.63	106.86
Line.l30	1	106.18	106.79	108.08	108.30	108.48
Line.l30	2	106.18	106.79	108.08	108.30	108.48
Line.l31	1	2.11	2.01	1.72	1.68	1.63
Line.l31	2	2.11	2.01	1.72	1.68	1.63
Line.l32	1	108.54	109.28	111.00	111.29	111.54
Line.l32	2	108.54	109.28	111.00	111.29	111.54
Line.l33	1	110.62	111.27	112.70	112.94	113.14
Line.l33	2	110.62	111.27	112.70	112.94	113.14
Line.l34	1	2.08	1.99	1.70	1.65	1.60
Line.l34	2	2.08	1.99	1.70	1.65	1.60

Table 4-28: I_r value, zone 2, SLG fault, 100% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.13	0.13	0.13	0.13	0.12
Line.l1	2	0.13	0.13	0.13	0.13	0.12
Line.l2	1	110.72	112.64	111.81	110.82	108.93
Line.l2	2	110.72	112.64	111.81	110.82	108.93
Line.l3	1	219.54	223.36	221.70	219.73	215.98
Line.l3	2	219.54	223.36	221.70	219.73	215.98
Line.l4	1	329.97	335.70	333.21	330.25	324.61

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l4	2	329.97	335.70	333.21	330.25	324.61
Line.l5	1	219.56	223.37	221.71	219.74	215.99
Line.l5	2	219.56	223.37	221.71	219.74	215.99
Line.l6	1	110.84	112.76	111.93	110.93	109.04
Line.l6	2	110.84	112.76	111.93	110.93	109.04
Line.l7	1	0.03	0.03	0.03	0.03	0.03
Line.l7	2	0.03	0.03	0.03	0.03	0.03
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	110.89	112.82	111.98	110.99	109.09
Line.l9	2	110.89	112.82	111.98	110.99	109.09
Line.l10	1	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00
Line.l11	1	110.92	112.84	112.01	111.01	109.12
Line.l11	2	110.92	112.84	112.01	111.01	109.12
Line.l12	1	108.80	110.69	109.87	108.89	107.03
Line.l12	2	108.80	110.69	109.87	108.89	107.03
Line.l13	1	108.80	110.69	109.87	108.89	107.03
Line.l13	2	108.80	110.69	109.87	108.89	107.03
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	110.74	112.66	111.83	110.83	108.94
Line.l15	2	110.74	112.66	111.83	110.83	108.94
Line.l16	1	709.72	722.04	134.18	132.99	130.72
Line.l16	2	709.72	722.04	134.18	132.99	130.72
Line.l17	1	380.01	386.61	467.14	462.99	455.09
Line.l17	2	380.01	386.61	467.14	462.99	455.09
Line.l18	1	380.03	386.63	404.55	462.97	455.07
Line.l18	2	380.03	386.63	404.55	462.97	455.07
Line.l19	1	129.58	131.83	137.94	139.15	136.77
Line.l19	2	129.58	131.83	137.94	139.15	136.77
Line.l20	1	250.85	255.20	267.03	269.37	591.11
Line.l20	2	250.85	255.20	267.03	269.37	591.11
Line.l21	1	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01
Line.l22	1	250.86	255.22	267.05	269.39	272.45
Line.l22	2	250.86	255.22	267.05	269.39	272.45
Line.l23	1	709.71	138.85	134.18	132.99	130.72
Line.l23	2	709.71	138.85	134.18	132.99	130.72

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l24	1	140.02	138.86	134.20	133.01	130.74
Line.l24	2	140.02	138.86	134.20	133.01	130.74
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	250.87	255.23	267.06	269.40	272.46
Line.l26	2	250.87	255.23	267.06	269.40	272.46
Line.l27	1	125.75	127.94	133.87	135.04	136.57
Line.l27	2	125.75	127.94	133.87	135.04	136.57
Line.l28	1	125.77	127.96	133.89	135.06	136.59
Line.l28	2	125.77	127.96	133.89	135.06	136.59
Line.l29	1	125.78	127.97	133.90	135.07	136.61
Line.l29	2	125.78	127.97	133.90	135.07	136.61
Line.l30	1	125.80	127.99	133.92	135.09	136.63
Line.l30	2	125.80	127.99	133.92	135.09	136.63
Line.l31	1	0.00	0.00	0.01	0.01	0.01
Line.l31	2	0.00	0.00	0.01	0.01	0.01
Line.l32	1	125.15	127.32	133.22	134.39	135.91
Line.l32	2	125.15	127.32	133.22	134.39	135.91
Line.l33	1	125.17	127.34	133.24	134.41	135.93
Line.l33	2	125.17	127.34	133.24	134.41	135.93
Line.l34	1	0.00	0.00	0.01	0.01	0.01
Line.l34	2	0.00	0.00	0.01	0.01	0.01

Table 4-29: I₂ value, zone 2, LL fault, 100% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	4.22	4.23	4.21	4.21	4.20
Line.l1	2	4.23	4.23	4.22	4.21	4.20
Line.l2	1	55.18	55.60	55.39	55.16	54.70
Line.l2	2	55.19	55.60	55.39	55.17	54.70
Line.l3	1	118.53	119.30	118.89	118.47	117.61
Line.l3	2	118.54	119.31	118.89	118.47	117.62
Line.l4	1	173.91	175.09	174.46	173.82	172.51
Line.l4	2	173.88	175.06	174.43	173.79	172.48
Line.l5	1	119.72	120.51	120.11	119.68	118.80
Line.l5	2	119.73	120.52	120.12	119.69	118.81
Line.l6	1	71.19	71.47	71.24	71.09	70.78
Line.l6	2	71.20	71.48	71.26	71.10	70.79
Line.l7	1	3.72	3.73	3.73	3.72	3.70
Line.l7	2	3.72	3.73	3.73	3.72	3.71
Line.l8	1	3.72	3.73	3.73	3.72	3.71
Line.l8	2	3.72	3.73	3.73	3.73	3.71
Line.l9	1	68.63	68.94	68.73	68.56	68.21
Line.l9	2	68.64	68.95	68.74	68.57	68.23
Line.l10	1	17.99	18.02	18.02	18.00	17.97
Line.l10	2	17.99	18.02	18.02	18.00	17.97
Line.l11	1	56.05	56.52	56.32	56.06	55.54
Line.l11	2	56.06	56.53	56.33	56.07	55.55
Line.l12	1	51.14	51.65	51.49	51.21	50.63
Line.l12	2	51.14	51.65	51.49	51.21	50.64
Line.l13	1	51.32	51.88	51.71	51.40	50.77
Line.l13	2	51.32	51.89	51.71	51.41	50.78
Line.l14	1	8.68	8.63	8.61	8.63	8.67
Line.l14	2	8.67	8.63	8.61	8.63	8.67
Line.l15	1	57.52	57.95	57.76	57.52	57.03
Line.l15	2	57.52	57.96	57.76	57.52	57.03
Line.l16	1	331.07	333.79	58.14	57.81	57.16

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	331.07	333.79	58.14	57.82	57.16
Line.l17	1	157.66	159.18	231.77	230.80	228.81
Line.l17	2	157.67	159.19	231.76	230.79	228.80
Line.l18	1	159.49	161.00	164.82	229.84	227.89
Line.l18	2	159.49	161.01	164.83	229.84	227.88
Line.l19	1	68.18	68.70	69.98	70.20	69.59
Line.l19	2	68.19	68.71	69.99	70.20	69.60
Line.l20	1	91.83	92.87	95.45	95.88	295.55
Line.l20	2	91.84	92.87	95.45	95.88	295.54
Line.l21	1	4.31	4.28	4.22	4.21	4.20
Line.l21	2	4.30	4.28	4.22	4.21	4.20
Line.l22	1	92.76	93.78	96.38	96.81	97.24
Line.l22	2	92.77	93.79	96.39	96.81	97.24
Line.l23	1	330.51	60.72	59.51	59.19	58.54
Line.l23	2	330.50	60.73	59.52	59.20	58.54
Line.l24	1	61.09	60.89	59.82	59.53	58.95
Line.l24	2	61.09	60.90	59.82	59.54	58.95
Line.l25	1	6.78	6.76	6.63	6.60	6.53
Line.l25	2	6.78	6.76	6.63	6.60	6.53
Line.l26	1	102.72	103.81	106.53	106.97	107.42
Line.l26	2	102.73	103.82	106.54	106.98	107.43
Line.l27	1	40.83	41.38	42.86	43.09	43.32
Line.l27	2	40.84	41.39	42.87	43.10	43.33
Line.l28	1	57.00	57.68	59.35	59.62	59.88
Line.l28	2	57.01	57.68	59.35	59.63	59.89
Line.l29	1	59.15	59.68	60.90	61.11	61.32
Line.l29	2	59.16	59.68	60.91	61.12	61.32
Line.l30	1	61.59	62.15	63.51	63.73	63.96
Line.l30	2	61.60	62.16	63.51	63.74	63.97
Line.l31	1	8.79	8.74	8.61	8.60	8.59
Line.l31	2	8.79	8.74	8.61	8.60	8.59
Line.l32	1	63.01	63.54	64.79	65.00	65.21
Line.l32	2	63.02	63.54	64.79	65.01	65.22
Line.l33	1	65.62	66.17	67.52	67.75	67.98
Line.l33	2	65.64	66.19	67.54	67.77	67.99
Line.l34	1	8.79	8.74	8.61	8.60	8.59
Line.l34	2	8.79	8.74	8.61	8.60	8.59

Table 4-30: I_1 value, zone 3, 3 phase fault, 100% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	1.52	1.77	1.69	1.79	1.88
Line.l1	2	1.52	1.77	1.69	1.79	1.88
Line.l2	1	87.02	85.28	85.44	84.50	83.59
Line.l2	2	87.02	85.28	85.44	84.50	83.59
Line.l3	1	165.22	161.64	162.08	160.24	158.44
Line.l3	2	165.22	161.64	162.08	160.24	158.44
Line.l4	1	250.70	245.13	245.82	242.95	240.14
Line.l4	2	250.70	245.14	245.82	242.95	240.14
Line.l5	1	167.28	164.02	164.34	162.62	160.93
Line.l5	2	167.28	164.02	164.34	162.62	160.93
Line.l6	1	83.24	81.39	81.69	80.78	79.89
Line.l6	2	83.23	81.39	81.69	80.78	79.88
Line.l7	1	1.05	1.20	1.15	1.21	1.27
Line.l7	2	1.05	1.20	1.15	1.21	1.27
Line.l8	1	1.05	1.20	1.15	1.21	1.27
Line.l8	2	1.05	1.20	1.15	1.21	1.27
Line.l9	1	86.38	84.99	85.11	84.36	83.63
Line.l9	2	86.38	84.99	85.11	84.36	83.63
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	105.26	103.83	103.87	103.05	102.25
Line.l11	2	105.26	103.83	103.87	103.05	102.25
Line.l12	1	84.22	82.83	82.86	82.07	81.30
Line.l12	2	84.22	82.83	82.86	82.07	81.30
Line.l13	1	88.74	87.35	87.36	86.56	85.78
Line.l13	2	88.74	87.35	87.36	86.56	85.78
Line.l14	1	2.12	2.45	2.34	2.47	2.60
Line.l14	2	2.12	2.45	2.34	2.47	2.60
Line.l15	1	89.11	87.69	87.72	86.92	86.13
Line.l15	2	89.11	87.69	87.72	86.92	86.13
Line.l16	1	113.25	110.96	111.23	110.05	108.89

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	113.25	110.96	111.23	110.05	108.89
Line.l17	1	363.88	356.03	356.99	352.93	348.96
Line.l17	2	363.89	356.03	356.99	352.93	348.97
Line.l18	1	362.25	354.10	355.18	351.01	346.93
Line.l18	2	362.25	354.10	355.18	351.01	346.93
Line.l19	1	123.08	121.25	121.32	120.30	119.29
Line.l19	2	123.08	121.25	121.32	120.30	119.29
Line.l20	1	485.29	475.31	476.47	471.28	466.20
Line.l20	2	485.29	475.31	476.47	471.28	466.20
Line.l21	1	0.82	0.99	0.93	1.00	1.07
Line.l21	2	0.82	0.99	0.93	1.00	1.07
Line.l22	1	484.47	474.33	475.55	470.29	465.16
Line.l22	2	484.47	474.33	475.55	470.29	465.16
Line.l23	1	114.22	112.09	112.30	111.17	110.07
Line.l23	2	114.22	112.09	112.30	111.17	110.07
Line.l24	1	118.13	116.62	116.61	115.72	114.85
Line.l24	2	118.13	116.62	116.61	115.72	114.85
Line.l25	1	2.98	3.46	3.30	3.50	3.69
Line.l25	2	2.98	3.46	3.30	3.50	3.69
Line.l26	1	474.26	464.15	465.40	460.18	455.08
Line.l26	2	474.26	464.15	465.40	460.18	455.08
Line.l27	1	88.61	86.39	575.01	568.64	562.41
Line.l27	2	88.61	86.39	575.01	568.64	562.41
Line.l28	1	105.45	103.20	105.67	551.82	545.63
Line.l28	2	105.45	103.20	105.67	551.82	545.63
Line.l29	1	107.55	105.78	107.69	107.83	543.47
Line.l29	2	107.55	105.78	107.69	107.83	543.47
Line.l30	1	109.03	107.60	109.11	109.21	109.31
Line.l30	2	109.03	107.60	109.11	109.21	109.31
Line.l31	1	1.48	1.82	1.42	1.38	1.34
Line.l31	2	1.48	1.82	1.42	1.38	1.34
Line.l32	1	112.29	549.69	110.44	109.35	108.29
Line.l32	2	112.29	549.69	110.44	109.35	108.29
Line.l33	1	113.75	113.81	112.11	111.16	110.22
Line.l33	2	113.75	113.81	112.11	111.16	110.22
Line.l34	1	1.46	1.36	1.68	1.81	1.95
Line.l34	2	1.46	1.36	1.68	1.81	1.95

Table 4-31: I_r value, zone 3, SLG fault, 100% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.12	0.11	0.11	0.11	0.11
Line.l1	2	0.12	0.11	0.11	0.11	0.11
Line.l2	1	103.92	99.40	99.94	97.51	95.13
Line.l2	2	103.92	99.40	99.94	97.51	95.13
Line.l3	1	206.05	197.10	198.17	193.34	188.63
Line.l3	2	206.05	197.10	198.17	193.34	188.63
Line.l4	1	309.68	296.24	297.84	290.58	283.51
Line.l4	2	309.68	296.24	297.84	290.58	283.51
Line.l5	1	206.06	197.11	198.18	193.35	188.64
Line.l5	2	206.06	197.11	198.18	193.35	188.64
Line.l6	1	104.03	99.51	100.05	97.61	95.23
Line.l6	2	104.03	99.51	100.05	97.61	95.23
Line.l7	1	0.02	0.02	0.02	0.02	0.02
Line.l7	2	0.02	0.02	0.02	0.02	0.02
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	104.07	99.56	100.09	97.65	95.28
Line.l9	2	104.07	99.56	100.09	97.65	95.28
Line.l10	1	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00
Line.l11	1	104.10	99.58	100.12	97.68	95.30
Line.l11	2	104.10	99.58	100.12	97.68	95.30
Line.l12	1	102.11	97.68	98.20	95.81	93.48
Line.l12	2	102.11	97.68	98.20	95.81	93.48
Line.l13	1	102.11	97.68	98.21	95.81	93.48
Line.l13	2	102.11	97.68	98.21	95.81	93.48
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	103.93	99.42	99.96	97.52	95.15
Line.l15	2	103.93	99.42	99.96	97.52	95.15
Line.l16	1	124.70	119.29	119.94	117.01	114.16

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	124.70	119.29	119.94	117.01	114.16
Line.l17	1	434.16	415.31	417.55	407.38	397.46
Line.l17	2	434.16	415.31	417.55	407.38	397.46
Line.l18	1	434.14	415.29	417.54	407.36	397.44
Line.l18	2	434.14	415.29	417.54	407.36	397.44
Line.l19	1	130.49	124.82	125.50	122.44	119.46
Line.l19	2	130.49	124.82	125.50	122.44	119.46
Line.l20	1	563.93	539.45	542.36	529.14	516.26
Line.l20	2	563.93	539.45	542.36	529.14	516.26
Line.l21	1	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01
Line.l22	1	563.91	539.43	542.35	529.13	516.24
Line.l22	2	563.91	539.43	542.35	529.13	516.24
Line.l23	1	124.71	119.30	119.94	117.02	114.17
Line.l23	2	124.71	119.30	119.94	117.02	114.17
Line.l24	1	124.72	119.31	119.96	117.03	114.18
Line.l24	2	124.72	119.31	119.96	117.03	114.18
Line.l25	1	0.00	0.00	0.00	0.00	0.00
Line.l25	2	0.00	0.00	0.00	0.00	0.00
Line.l26	1	563.90	539.42	542.34	529.12	516.23
Line.l26	2	563.90	539.42	542.34	529.12	516.23
Line.l27	1	141.19	135.06	676.13	659.65	643.59
Line.l27	2	141.19	135.06	676.13	659.65	643.59
Line.l28	1	141.21	135.08	144.21	659.63	643.57
Line.l28	2	141.21	135.08	144.21	659.63	643.57
Line.l29	1	141.22	135.09	144.23	146.19	643.56
Line.l29	2	141.22	135.09	144.23	146.19	643.56
Line.l30	1	141.24	135.11	144.25	146.20	148.23
Line.l30	2	141.24	135.11	144.25	146.20	148.23
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	140.51	672.85	135.14	131.84	128.63
Line.l32	2	140.51	672.85	135.14	131.84	128.63
Line.l33	1	140.53	143.06	135.15	131.86	128.65
Line.l33	2	140.53	143.06	135.15	131.86	128.65
Line.l34	1	0.01	0.01	0.01	0.01	0.00
Line.l34	2	0.01	0.01	0.01	0.01	0.00

Table 4-32: I₂ value, zone 3, LL fault, 100% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	4.18	4.17	4.16	4.15	4.14
Line.l1	2	4.18	4.18	4.16	4.15	4.14
Line.l2	1	53.49	52.49	52.51	51.95	51.40
Line.l2	2	53.50	52.50	52.51	51.95	51.40
Line.l3	1	115.38	113.54	113.52	112.45	111.40
Line.l3	2	115.39	113.55	113.52	112.46	111.40
Line.l4	1	169.10	166.30	166.27	164.65	163.06
Line.l4	2	169.07	166.27	166.24	164.62	163.03
Line.l5	1	116.51	114.54	114.60	113.51	112.43
Line.l5	2	116.51	114.54	114.61	113.51	112.43
Line.l6	1	69.95	69.37	69.25	68.85	68.45
Line.l6	2	69.96	69.38	69.26	68.86	68.46
Line.l7	1	3.67	3.62	3.65	3.64	3.63
Line.l7	2	3.67	3.63	3.65	3.64	3.64
Line.l8	1	3.67	3.63	3.65	3.64	3.64
Line.l8	2	3.68	3.63	3.66	3.65	3.64
Line.l9	1	67.31	66.60	66.55	66.11	65.67
Line.l9	2	67.32	66.61	66.56	66.12	65.68
Line.l10	1	17.90	17.82	17.83	17.79	17.75
Line.l10	2	17.90	17.82	17.83	17.79	17.75
Line.l11	1	54.18	52.96	53.07	52.43	51.81
Line.l11	2	54.19	52.97	53.08	52.44	51.82
Line.l12	1	49.13	47.64	47.88	47.17	46.47
Line.l12	2	49.13	47.64	47.89	47.17	46.47
Line.l13	1	49.15	47.57	47.81	47.05	46.30
Line.l13	2	49.15	47.58	47.82	47.05	46.31
Line.l14	1	8.79	8.95	8.90	8.96	9.01
Line.l14	2	8.79	8.95	8.90	8.96	9.01
Line.l15	1	55.76	54.63	54.72	54.13	53.55
Line.l15	2	55.76	54.63	54.73	54.14	53.56
Line.l16	1	55.43	53.77	54.00	53.17	52.36

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	55.43	53.77	54.00	53.18	52.37
Line.l17	1	223.66	219.23	219.39	216.95	214.56
Line.l17	2	223.65	219.22	219.38	216.95	214.55
Line.l18	1	222.81	218.53	218.60	216.20	213.84
Line.l18	2	222.80	218.53	218.60	216.20	213.84
Line.l19	1	68.03	66.65	66.76	66.03	65.32
Line.l19	2	68.04	66.66	66.77	66.04	65.33
Line.l20	1	288.91	283.22	283.42	280.29	277.21
Line.l20	2	288.90	283.21	283.42	280.29	277.21
Line.l21	1	4.27	4.35	4.32	4.35	4.38
Line.l21	2	4.26	4.35	4.32	4.35	4.38
Line.l22	1	288.32	282.71	282.86	279.75	276.69
Line.l22	2	288.31	282.70	282.85	279.74	276.69
Line.l23	1	56.81	55.09	55.38	54.55	53.73
Line.l23	2	56.81	55.09	55.38	54.55	53.74
Line.l24	1	57.39	55.86	56.09	55.34	54.59
Line.l24	2	57.40	55.86	56.10	55.34	54.60
Line.l25	1	6.36	6.20	6.21	6.13	6.05
Line.l25	2	6.36	6.20	6.21	6.13	6.05
Line.l26	1	278.11	272.55	272.76	269.71	266.70
Line.l26	2	278.10	272.54	272.75	269.70	266.69
Line.l27	1	44.04	42.39	336.14	332.35	328.62
Line.l27	2	44.05	42.40	336.13	332.34	328.61
Line.l28	1	60.71	58.77	61.08	315.54	311.90
Line.l28	2	60.72	58.77	61.08	315.53	311.90
Line.l29	1	61.97	60.58	62.27	62.52	310.53
Line.l29	2	61.98	60.59	62.27	62.53	310.53
Line.l30	1	64.68	63.13	65.01	65.29	65.57
Line.l30	2	64.68	63.13	65.01	65.29	65.57
Line.l31	1	8.56	8.73	8.56	8.56	8.56
Line.l31	2	8.56	8.73	8.56	8.56	8.56
Line.l32	1	65.89	313.62	64.51	63.73	62.97
Line.l32	2	65.90	313.62	64.52	63.74	62.97
Line.l33	1	68.70	69.17	67.28	66.48	65.69
Line.l33	2	68.71	69.19	67.30	66.49	65.70
Line.l34	1	8.56	8.54	8.67	8.74	8.80
Line.l34	2	8.56	8.54	8.67	8.73	8.80

4.4.3 Short Circuit Analysis 75% DG Penetration

Table 4-33: I_1 value, zone 1, 3 phase fault, 75% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	12.99	13.15	12.84	12.77	12.35	11.99	11.58
Vsource	2	12.99	13.15	12.84	12.77	12.35	11.99	11.58
Subxf	1	12.99	13.15	12.84	12.77	12.35	11.99	11.58
Subxf	2	622.22	630.01	615.27	611.76	591.92	574.43	554.93
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	563.46	570.73	557.14	553.89	535.61	519.50	501.38
Line.l1	2	563.46	570.73	557.14	553.89	535.62	519.50	501.38
Line.l2	1	1047.76	80.77	78.49	77.95	74.89	72.21	69.20
Line.l2	2	1047.76	80.77	78.49	77.95	74.89	72.21	69.20
Line.l3	1	144.13	997.52	971.43	965.14	930.18	899.33	864.14
Line.l3	2	144.13	997.52	971.43	965.14	930.18	899.33	864.14
Line.l4	1	340.71	346.43	336.23	333.73	320.13	308.11	293.97
Line.l4	2	340.70	346.42	336.22	333.73	320.12	308.10	293.96
Line.l5	1	146.98	152.49	968.81	962.44	927.14	896.00	860.27
Line.l5	2	146.98	152.49	968.81	962.44	927.14	896.00	860.27
Line.l6	1	68.98	72.00	72.29	71.72	1004.37	970.76	932.49
Line.l6	2	68.98	72.00	72.29	71.72	1004.37	970.76	932.50
Line.l7	1	1.45	1.20	1.15	1.19	1.09	1040.64	1.54
Line.l7	2	1.45	1.20	1.15	1.19	1.09	1040.64	1.54
Line.l8	1	1.45	1.20	1.15	1.19	1.09	1.06	1.54
Line.l8	2	1.45	1.20	1.15	1.19	1.09	1.06	1.54
Line.l9	1	73.33	75.62	75.74	75.30	75.73	73.46	927.87
Line.l9	2	73.33	75.62	75.74	75.30	75.73	73.46	927.87
Line.l10	1	19.36	19.36	19.37	19.37	19.37	19.37	19.37
Line.l10	2	19.36	19.36	19.37	19.37	19.37	19.37	19.37
Line.l11	1	92.52	94.89	95.00	94.53	94.92	92.34	94.52
Line.l11	2	92.52	94.89	95.00	94.53	94.92	92.34	94.52
Line.l12	1	78.12	80.56	80.68	1033.60	77.35	74.85	72.30
Line.l12	2	78.12	80.56	80.68	1033.60	77.35	74.85	72.30
Line.l13	1	82.67	85.13	85.25	85.20	81.87	79.34	76.78
Line.l13	2	82.67	85.13	85.25	85.20	81.87	79.34	76.78
Line.l14	1	2.31	2.62	2.90	2.99	3.34	3.66	4.20
Line.l14	2	2.31	2.62	2.90	2.99	3.34	3.66	4.20
Line.l15	1	84.55	83.39	81.37	80.91	78.18	75.78	73.31

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l15	2	84.55	83.39	81.37	80.91	78.18	75.78	73.31
Line.l16	1	94.27	95.81	93.13	92.47	88.91	85.76	82.00
Line.l16	2	94.27	95.81	93.13	92.47	88.91	85.76	82.00
Line.l17	1	246.55	250.72	243.20	241.37	231.32	222.45	212.09
Line.l17	2	246.55	250.72	243.20	241.37	231.31	222.45	212.09
Line.l18	1	249.32	253.27	245.97	244.22	234.44	225.82	215.94
Line.l18	2	249.32	253.27	245.97	244.22	234.44	225.82	215.94
Line.l19	1	92.86	93.88	91.71	91.22	88.26	85.67	83.05
Line.l19	2	92.86	93.88	91.71	91.22	88.26	85.67	83.05
Line.l20	1	156.50	159.42	154.33	153.07	146.31	140.33	133.08
Line.l20	2	156.50	159.42	154.33	153.07	146.31	140.33	133.08
Line.l21	1	1.56	1.44	1.58	1.62	1.79	1.95	2.21
Line.l21	2	1.56	1.44	1.58	1.62	1.79	1.95	2.21
Line.l22	1	158.04	160.85	155.88	154.66	148.04	142.19	135.20
Line.l22	2	158.04	160.85	155.88	154.66	148.04	142.19	135.20
Line.l23	1	95.74	97.16	94.60	93.98	90.57	87.54	84.04
Line.l23	2	95.74	97.16	94.60	93.98	90.57	87.54	84.04
Line.l24	1	101.58	102.51	100.44	99.98	97.14	94.67	92.18
Line.l24	2	101.58	102.51	100.44	99.98	97.14	94.66	92.18
Line.l25	1	4.44	4.07	4.47	4.60	5.11	5.58	6.37
Line.l25	2	4.44	4.07	4.47	4.60	5.11	5.58	6.37
Line.l26	1	168.19	170.99	165.96	164.73	158.00	152.06	145.10
Line.l26	2	168.19	170.99	165.95	164.73	158.00	152.06	145.10
Line.l27	1	66.85	68.26	65.78	65.17	61.89	58.98	55.50
Line.l27	2	66.85	68.26	65.78	65.17	61.89	58.98	55.50
Line.l28	1	83.60	85.00	82.44	81.82	78.39	75.36	71.94
Line.l28	2	83.60	85.00	82.44	81.82	78.39	75.36	71.94
Line.l29	1	88.36	89.39	87.21	86.71	83.74	81.15	78.48
Line.l29	2	88.35	89.39	87.21	86.71	83.74	81.15	78.48
Line.l30	1	91.69	92.48	90.55	90.14	87.48	85.18	83.04
Line.l30	2	91.68	92.48	90.55	90.14	87.48	85.18	83.04
Line.l31	1	3.35	3.11	3.38	3.46	3.81	4.12	4.63
Line.l31	2	3.35	3.11	3.38	3.46	3.81	4.12	4.63
Line.l32	1	102.94	104.22	101.78	101.20	97.90	95.00	91.77
Line.l32	2	102.94	104.22	101.78	101.20	97.90	95.00	91.77
Line.l33	1	106.24	107.28	105.09	104.59	101.59	98.96	96.25
Line.l33	2	106.24	107.28	105.08	104.58	101.59	98.96	96.25
Line.l34	1	3.34	3.09	3.37	3.45	3.80	4.11	4.62
Line.l34	2	3.34	3.09	3.37	3.45	3.80	4.11	4.62

Table 4-34: I_r value, zone 1, SLG fault, 75% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.18	0.18	0.18	0.18	0.17	0.16	0.15
Line.l1	2	0.18	0.18	0.18	0.18	0.17	0.16	0.15
Line.l2	1	945.93	152.69	147.13	145.87	138.17	131.41	125.46
Line.l2	2	945.93	152.69	147.13	145.87	138.17	131.41	125.46
Line.l3	1	292.71	817.35	787.61	780.85	739.64	703.45	671.59
Line.l3	2	292.71	817.35	787.61	780.85	739.64	703.45	671.59
Line.l4	1	653.87	665.73	641.50	635.99	602.43	572.95	547.00
Line.l4	2	653.87	665.73	641.50	635.99	602.43	572.95	547.00
Line.l5	1	292.72	306.87	787.59	780.83	739.63	703.43	671.58
Line.l5	2	292.72	306.87	787.59	780.83	739.63	703.43	671.58
Line.l6	1	144.43	151.41	152.33	151.02	884.63	841.35	803.25
Line.l6	2	144.43	151.41	152.33	151.02	884.63	841.35	803.25
Line.l7	1	0.04	0.04	0.04	0.04	0.04	984.58	0.04
Line.l7	2	0.04	0.04	0.04	0.04	0.04	984.58	0.04
Line.l8	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l9	1	144.50	151.49	152.41	151.10	153.28	145.78	803.18
Line.l9	2	144.50	151.49	152.41	151.10	153.28	145.78	803.18
Line.l10	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l11	1	144.54	151.53	152.45	151.14	153.32	145.82	154.56
Line.l11	2	144.54	151.53	152.45	151.14	153.32	145.82	154.56
Line.l12	1	148.39	155.56	156.50	930.69	146.97	139.78	133.45
Line.l12	2	148.39	155.56	156.50	930.69	146.97	139.78	133.45
Line.l13	1	148.39	155.56	156.50	156.48	146.97	139.78	133.45
Line.l13	2	148.39	155.56	156.50	156.48	146.97	139.78	133.45
Line.l14	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l15	1	156.34	152.71	147.15	145.89	138.19	131.43	125.48
Line.l15	2	156.34	152.71	147.15	145.89	138.19	131.43	125.48
Line.l16	1	168.15	171.19	164.97	163.55	154.92	147.34	140.67

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l16	2	168.15	171.19	164.97	163.55	154.92	147.34	140.67
Line.l17	1	486.43	495.26	477.23	473.14	448.17	426.24	406.93
Line.l17	2	486.43	495.26	477.23	473.14	448.17	426.24	406.93
Line.l18	1	486.46	495.29	477.26	473.16	448.19	426.26	406.95
Line.l18	2	486.46	495.29	477.26	473.16	448.19	426.26	406.95
Line.l19	1	164.65	167.64	161.54	160.15	151.70	144.28	137.75
Line.l19	2	164.65	167.64	161.54	160.15	151.70	144.28	137.75
Line.l20	1	322.23	328.08	316.14	313.42	296.88	282.35	269.56
Line.l20	2	322.23	328.08	316.14	313.42	296.88	282.35	269.56
Line.l21	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l22	1	322.26	328.10	316.16	313.45	296.90	282.37	269.58
Line.l22	2	322.26	328.10	316.16	313.45	296.90	282.37	269.58
Line.l23	1	168.15	171.20	164.97	163.56	154.93	147.35	140.68
Line.l23	2	168.15	171.20	164.97	163.56	154.93	147.35	140.68
Line.l24	1	168.17	171.22	164.99	163.58	154.95	147.37	140.69
Line.l24	2	168.17	171.22	164.99	163.58	154.95	147.37	140.69
Line.l25	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l26	1	322.27	328.12	316.17	313.46	296.92	282.39	269.60
Line.l26	2	322.27	328.12	316.17	313.46	296.92	282.39	269.60
Line.l27	1	161.49	164.42	158.44	157.08	148.79	141.51	135.10
Line.l27	2	161.49	164.42	158.44	157.08	148.79	141.51	135.10
Line.l28	1	161.52	164.45	158.47	157.11	148.81	141.53	135.12
Line.l28	2	161.52	164.45	158.47	157.11	148.81	141.53	135.12
Line.l29	1	161.54	164.47	158.48	157.12	148.83	141.54	135.13
Line.l29	2	161.54	164.47	158.48	157.12	148.83	141.54	135.13
Line.l30	1	161.56	164.49	158.51	157.14	148.85	141.56	135.15
Line.l30	2	161.56	164.49	158.51	157.14	148.85	141.56	135.15
Line.l31	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l32	1	160.81	163.73	157.77	156.41	148.16	140.91	134.53
Line.l32	2	160.81	163.73	157.77	156.41	148.16	140.91	134.53
Line.l33	1	160.84	163.75	157.79	156.44	148.18	140.93	134.55
Line.l33	2	160.84	163.75	157.79	156.44	148.18	140.93	134.55
Line.l34	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 4-35: I_2 value, zone 1, LL fault, 75% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	5.63	5.72	5.56	5.53	5.32	5.13	4.93
Vsource	2	5.63	5.72	5.56	5.53	5.32	5.13	4.93
Subxf	1	5.63	5.72	5.56	5.53	5.32	5.13	4.93
Subxf	2	269.59	273.92	266.61	264.76	254.96	245.89	236.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	245.36	249.27	242.63	240.95	232.04	223.78	214.85
Line.l1	2	245.34	249.25	242.60	240.93	232.01	223.76	214.82
Line.l2	1	574.82	58.73	57.43	57.13	55.36	53.74	52.17
Line.l2	2	574.81	58.73	57.44	57.13	55.37	53.75	52.18
Line.l3	1	122.01	519.38	505.18	501.60	482.44	464.64	445.42
Line.l3	2	122.01	519.37	505.17	501.59	482.44	464.64	445.42
Line.l4	1	207.81	211.53	205.28	203.68	195.21	187.27	178.50
Line.l4	2	207.84	211.57	205.32	203.71	195.24	187.30	178.53
Line.l5	1	122.99	126.45	504.01	500.47	481.35	463.62	444.75
Line.l5	2	123.00	126.46	504.00	500.46	481.34	463.62	444.75
Line.l6	1	72.67	73.71	73.91	73.72	532.10	512.23	490.76
Line.l6	2	72.68	73.73	73.92	73.73	532.08	512.22	490.75
Line.l7	1	4.07	4.16	4.20	4.18	4.25	581.10	4.15
Line.l7	2	4.07	4.17	4.20	4.19	4.26	581.09	4.15
Line.l8	1	4.07	4.17	4.20	4.19	4.26	4.29	4.15
Line.l8	2	4.08	4.17	4.21	4.19	4.26	4.29	4.16
Line.l9	1	69.50	70.74	70.98	70.76	71.24	69.88	494.23
Line.l9	2	69.51	70.75	70.99	70.77	71.26	69.89	494.21
Line.l10	1	17.95	18.06	18.07	18.05	18.08	17.98	18.10
Line.l10	2	17.95	18.06	18.08	18.06	18.09	17.98	18.10
Line.l11	1	56.35	58.39	58.78	58.42	59.22	57.32	59.91
Line.l11	2	56.36	58.40	58.79	58.43	59.23	57.33	59.93
Line.l12	1	53.05	55.56	56.05	573.84	53.45	51.40	48.92
Line.l12	2	53.05	55.57	56.05	573.84	53.45	51.41	48.92
Line.l13	1	53.19	55.89	56.39	56.44	53.55	51.34	48.73
Line.l13	2	53.19	55.90	56.40	56.45	53.55	51.35	48.73
Line.l14	1	9.72	9.83	9.95	9.99	10.13	10.27	10.50
Line.l14	2	9.72	9.83	9.95	9.99	10.13	10.27	10.50
Line.l15	1	62.23	61.12	59.78	59.44	57.64	55.98	54.17
Line.l15	2	62.24	61.12	59.78	59.45	57.65	55.98	54.18
Line.l16	1	55.18	56.27	54.56	54.11	51.81	49.65	47.15

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l16	2	55.19	56.28	54.56	54.11	51.81	49.65	47.15
Line.l17	1	152.86	155.48	150.95	149.80	143.64	137.87	131.63
Line.l17	2	152.87	155.49	150.96	149.81	143.64	137.88	131.64
Line.l18	1	154.36	157.16	152.61	151.42	145.24	139.42	132.81
Line.l18	2	154.36	157.16	152.61	151.42	145.25	139.42	132.81
Line.l19	1	66.91	67.77	66.29	65.92	63.92	62.07	60.06
Line.l19	2	66.92	67.78	66.30	65.93	63.93	62.08	60.07
Line.l20	1	88.29	90.13	87.02	86.22	82.00	78.03	73.64
Line.l20	2	88.29	90.14	87.03	86.22	82.00	78.03	73.64
Line.l21	1	4.95	4.88	4.94	4.96	5.03	5.09	5.21
Line.l21	2	4.95	4.88	4.94	4.96	5.03	5.09	5.21
Line.l22	1	88.97	90.93	87.82	86.99	82.78	78.78	74.13
Line.l22	2	88.97	90.94	87.83	87.00	82.79	78.79	74.13
Line.l23	1	56.52	57.68	55.97	55.51	53.23	51.08	48.46
Line.l23	2	56.53	57.68	55.98	55.51	53.24	51.09	48.46
Line.l24	1	57.28	58.28	56.75	56.34	54.26	52.29	49.94
Line.l24	2	57.28	58.29	56.76	56.34	54.26	52.29	49.95
Line.l25	1	7.06	7.17	6.98	6.94	6.68	6.44	6.18
Line.l25	2	7.06	7.17	6.98	6.94	6.68	6.44	6.18
Line.l26	1	99.00	100.94	97.70	96.86	92.48	88.37	83.87
Line.l26	2	99.01	100.95	97.71	96.87	92.49	88.38	83.87
Line.l27	1	38.06	39.31	37.60	37.11	34.83	32.62	29.73
Line.l27	2	38.07	39.32	37.61	37.12	34.84	32.63	29.74
Line.l28	1	54.42	55.61	53.66	53.16	50.57	48.16	45.52
Line.l28	2	54.42	55.61	53.67	53.17	50.57	48.16	45.52
Line.l29	1	57.82	58.57	57.06	56.70	54.64	52.75	50.99
Line.l29	2	57.82	58.57	57.06	56.71	54.64	52.76	50.99
Line.l30	1	60.08	61.01	59.39	58.99	56.80	54.78	52.64
Line.l30	2	60.09	61.02	59.40	58.99	56.81	54.79	52.64
Line.l31	1	10.06	9.93	10.04	10.08	10.22	10.35	10.57
Line.l31	2	10.05	9.93	10.04	10.08	10.22	10.35	10.57
Line.l32	1	61.86	62.65	61.14	60.78	58.73	56.84	54.97
Line.l32	2	61.86	62.66	61.15	60.79	58.74	56.85	54.97
Line.l33	1	64.38	65.31	63.74	63.34	61.23	59.26	57.10
Line.l33	2	64.39	65.33	63.76	63.36	61.24	59.28	57.12
Line.l34	1	10.07	9.94	10.06	10.10	10.23	10.36	10.58
Line.l34	2	10.07	9.94	10.05	10.09	10.23	10.36	10.58

Table 4-36: I₁ value, zone 2, 3 phase fault, 75% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	12.62	12.78	12.70	12.60	12.42
Vsource	2	12.62	12.78	12.70	12.60	12.42
Subxf	1	12.62	12.78	12.70	12.60	12.42
Subxf	2	604.51	612.58	608.34	603.57	595.15
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	547.23	554.67	550.81	546.41	538.64
Line.l1	2	547.23	554.68	550.81	546.41	538.64
Line.l2	1	76.85	78.09	77.45	76.72	75.42
Line.l2	2	76.84	78.09	77.45	76.72	75.42
Line.l3	1	139.04	141.44	140.27	138.84	136.32
Line.l3	2	139.04	141.44	140.27	138.84	136.32
Line.l4	1	762.67	773.78	768.07	761.49	749.90
Line.l4	2	762.67	773.78	768.07	761.50	749.90
Line.l5	1	142.04	144.32	143.15	141.80	139.42
Line.l5	2	142.04	144.31	143.15	141.80	139.42
Line.l6	1	66.63	67.79	67.27	66.58	65.36
Line.l6	2	66.63	67.79	67.27	66.58	65.36
Line.l7	1	1.53	1.46	1.47	1.51	1.59
Line.l7	2	1.53	1.46	1.47	1.51	1.59
Line.l8	1	1.53	1.46	1.47	1.51	1.59
Line.l8	2	1.53	1.46	1.47	1.51	1.59
Line.l9	1	71.16	72.13	71.62	71.04	70.01
Line.l9	2	71.15	72.13	71.62	71.04	70.01
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	90.06	91.13	90.53	89.90	88.79
Line.l11	2	90.06	91.13	90.52	89.90	88.79
Line.l12	1	75.61	76.69	76.07	75.43	74.30
Line.l12	2	75.61	76.69	76.07	75.43	74.30
Line.l13	1	80.13	81.23	80.59	79.95	78.80
Line.l13	2	80.13	81.23	80.59	79.95	78.80
Line.l14	1	3.08	2.92	2.95	3.05	3.21
Line.l14	2	3.08	2.92	2.95	3.05	3.21
Line.l15	1	79.88	80.98	80.37	79.72	78.57
Line.l15	2	79.88	80.98	80.36	79.72	78.57
Line.l16	1	1012.73	1028.16	96.38	95.47	93.87

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	1012.73	1028.16	96.38	95.47	93.87
Line.l17	1	250.26	254.58	864.00	856.51	843.31
Line.l17	2	250.26	254.58	864.00	856.51	843.31
Line.l18	1	252.83	257.02	264.44	854.36	841.01
Line.l18	2	252.83	257.02	264.44	854.36	841.01
Line.l19	1	93.76	95.02	97.02	97.17	95.79
Line.l19	2	93.76	95.02	97.02	97.17	95.79
Line.l20	1	159.11	162.02	167.43	167.94	936.66
Line.l20	2	159.11	162.02	167.43	167.94	936.66
Line.l21	1	1.45	1.38	1.17	1.14	1.11
Line.l21	2	1.45	1.38	1.17	1.14	1.11
Line.l22	1	160.54	163.39	168.60	169.08	169.51
Line.l22	2	160.54	163.39	168.60	169.08	169.51
Line.l23	1	1011.52	100.32	97.68	96.81	95.28
Line.l23	2	1011.52	100.32	97.68	96.81	95.28
Line.l24	1	104.86	104.88	102.92	102.23	100.98
Line.l24	2	104.86	104.88	102.92	102.23	100.98
Line.l25	1	3.37	3.44	3.97	4.11	4.35
Line.l25	2	3.37	3.44	3.97	4.11	4.35
Line.l26	1	170.68	173.56	178.79	179.27	179.70
Line.l26	2	170.68	173.56	178.79	179.27	179.69
Line.l27	1	68.09	69.52	72.12	72.36	72.58
Line.l27	2	68.09	69.51	72.12	72.36	72.58
Line.l28	1	84.82	86.29	88.92	89.16	89.36
Line.l28	2	84.82	86.29	88.92	89.16	89.36
Line.l29	1	89.32	90.58	92.61	92.78	92.89
Line.l29	2	89.32	90.57	92.61	92.78	92.89
Line.l30	1	92.42	93.54	95.17	95.29	95.32
Line.l30	2	92.42	93.54	95.17	95.28	95.32
Line.l31	1	3.12	2.98	2.56	2.51	2.44
Line.l31	2	3.12	2.98	2.56	2.51	2.44
Line.l32	1	104.08	105.48	107.90	108.11	108.28
Line.l32	2	104.08	105.48	107.90	108.11	108.28
Line.l33	1	107.16	108.43	110.45	110.60	110.70
Line.l33	2	107.16	108.43	110.44	110.60	110.70
Line.l34	1	3.11	2.96	2.55	2.50	2.43
Line.l34	2	3.11	2.96	2.55	2.50	2.43

Table 4-37: I_r value, zone 2, SLG fault, 75% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.18	0.18	0.18	0.18	0.17
Line.l1	2	0.18	0.18	0.18	0.18	0.17
Line.l2	1	146.54	149.75	148.19	146.45	143.27
Line.l2	2	146.54	149.75	148.19	146.45	143.27
Line.l3	1	286.01	292.29	289.23	285.84	279.63
Line.l3	2	286.01	292.29	289.23	285.84	279.63
Line.l4	1	432.17	441.65	437.03	431.91	422.53
Line.l4	2	432.17	441.65	437.03	431.91	422.53
Line.l5	1	286.03	292.31	289.25	285.85	279.65
Line.l5	2	286.03	292.31	289.25	285.85	279.65
Line.l6	1	141.13	144.22	142.72	141.04	137.98
Line.l6	2	141.13	144.22	142.72	141.04	137.98
Line.l7	1	0.04	0.04	0.04	0.04	0.04
Line.l7	2	0.04	0.04	0.04	0.04	0.04
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	141.20	144.30	142.79	141.11	138.05
Line.l9	2	141.20	144.30	142.79	141.11	138.05
Line.l10	1	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00
Line.l11	1	141.24	144.33	142.82	141.15	138.08
Line.l11	2	141.24	144.33	142.82	141.15	138.08
Line.l12	1	144.99	148.17	146.63	144.90	141.76
Line.l12	2	144.99	148.17	146.63	144.90	141.76
Line.l13	1	145.00	148.18	146.63	144.91	141.76
Line.l13	2	145.00	148.18	146.63	144.91	141.76
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	146.56	149.78	148.21	146.47	143.29
Line.l15	2	146.56	149.78	148.21	146.47	143.29
Line.l16	1	918.40	938.56	170.07	168.08	164.43

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	918.40	938.56	170.07	168.08	164.43
Line.l17	1	486.54	497.22	606.81	599.69	586.67
Line.l17	2	486.54	497.22	606.81	599.69	586.67
Line.l18	1	486.56	497.24	516.12	599.66	586.64
Line.l18	2	486.56	497.24	516.12	599.66	586.64
Line.l19	1	164.69	168.30	174.69	175.43	171.62
Line.l19	2	164.69	168.30	174.69	175.43	171.62
Line.l20	1	322.30	329.38	341.88	343.32	757.46
Line.l20	2	322.30	329.38	341.88	343.32	757.46
Line.l21	1	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01
Line.l22	1	322.33	329.40	341.91	343.34	344.68
Line.l22	2	322.33	329.40	341.91	343.34	344.68
Line.l23	1	918.39	176.08	170.08	168.09	164.44
Line.l23	2	918.39	176.08	170.08	168.09	164.44
Line.l24	1	176.36	176.10	170.10	168.11	164.46
Line.l24	2	176.36	176.10	170.10	168.11	164.46
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	322.34	329.42	341.92	343.36	344.70
Line.l26	2	322.34	329.42	341.92	343.36	344.70
Line.l27	1	161.53	165.07	171.34	172.06	172.73
Line.l27	2	161.53	165.07	171.34	172.06	172.73
Line.l28	1	161.56	165.10	171.37	172.09	172.76
Line.l28	2	161.56	165.10	171.37	172.09	172.76
Line.l29	1	161.57	165.12	171.39	172.11	172.78
Line.l29	2	161.57	165.12	171.39	172.11	172.78
Line.l30	1	161.60	165.14	171.41	172.14	172.81
Line.l30	2	161.60	165.14	171.41	172.14	172.81
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	160.84	164.37	170.61	171.33	172.00
Line.l32	2	160.84	164.37	170.61	171.33	172.00
Line.l33	1	160.87	164.40	170.64	171.36	172.03
Line.l33	2	160.87	164.40	170.64	171.36	172.03
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-38: I₂ value, zone 2, LL fault, 75% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	5.42	5.51	5.46	5.40	5.30
Vsource	2	5.42	5.51	5.46	5.40	5.30
Subxf	1	5.42	5.51	5.46	5.40	5.30
Subxf	2	259.85	264.04	261.39	258.76	254.13
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	236.47	240.28	237.86	235.46	231.26
Line.l1	2	236.44	240.26	237.83	235.44	231.24
Line.l2	1	56.16	56.91	56.36	55.89	55.07
Line.l2	2	56.17	56.92	56.37	55.90	55.08
Line.l3	1	118.29	119.71	118.65	117.76	116.20
Line.l3	2	118.30	119.72	118.65	117.77	116.20
Line.l4	1	410.74	416.71	412.68	408.94	402.35
Line.l4	2	410.70	416.67	412.64	408.90	402.32
Line.l5	1	119.37	120.81	119.79	118.89	117.29
Line.l5	2	119.38	120.82	119.80	118.89	117.30
Line.l6	1	71.05	71.59	71.10	70.76	70.16
Line.l6	2	71.06	71.60	71.11	70.77	70.17
Line.l7	1	4.07	4.08	4.09	4.08	4.06
Line.l7	2	4.08	4.09	4.09	4.08	4.07
Line.l8	1	4.08	4.09	4.09	4.08	4.07
Line.l8	2	4.08	4.09	4.09	4.08	4.07
Line.l9	1	67.91	68.48	68.01	67.64	67.00
Line.l9	2	67.92	68.49	68.02	67.66	67.01
Line.l10	1	17.86	17.90	17.88	17.85	17.80
Line.l10	2	17.86	17.90	17.88	17.85	17.81
Line.l11	1	54.47	55.26	54.74	54.24	53.36
Line.l11	2	54.48	55.27	54.75	54.25	53.37
Line.l12	1	51.13	52.04	51.54	50.96	49.94
Line.l12	2	51.13	52.04	51.54	50.96	49.94
Line.l13	1	51.10	52.08	51.53	50.92	49.84
Line.l13	2	51.11	52.09	51.54	50.93	49.84
Line.l14	1	10.00	9.94	9.92	9.96	10.03
Line.l14	2	10.00	9.93	9.92	9.96	10.03
Line.l15	1	58.50	59.27	58.75	58.26	57.41
Line.l15	2	58.51	59.28	58.76	58.27	57.41
Line.l16	1	565.28	574.00	56.36	55.71	54.58

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	565.27	574.00	56.36	55.72	54.58
Line.l17	1	154.77	157.51	468.40	464.00	456.27
Line.l17	2	154.78	157.52	468.39	463.99	456.26
Line.l18	1	156.36	159.09	164.21	463.28	455.58
Line.l18	2	156.36	159.09	164.22	463.28	455.58
Line.l19	1	67.54	68.43	70.09	70.26	69.22
Line.l19	2	67.55	68.44	70.10	70.27	69.23
Line.l20	1	89.62	91.51	94.97	95.32	522.43
Line.l20	2	89.62	91.51	94.97	95.33	522.42
Line.l21	1	4.91	4.88	4.79	4.79	4.78
Line.l21	2	4.91	4.88	4.79	4.78	4.78
Line.l22	1	90.36	92.23	95.77	96.14	96.52
Line.l22	2	90.36	92.23	95.77	96.15	96.53
Line.l23	1	564.87	59.92	57.76	57.11	55.98
Line.l23	2	564.87	59.93	57.76	57.12	55.99
Line.l24	1	60.46	60.28	58.35	57.77	56.74
Line.l24	2	60.46	60.28	58.35	57.77	56.75
Line.l25	1	7.44	7.42	7.18	7.11	6.99
Line.l25	2	7.44	7.42	7.18	7.11	6.99
Line.l26	1	100.39	102.34	105.94	106.32	106.69
Line.l26	2	100.40	102.35	105.95	106.33	106.70
Line.l27	1	38.90	39.92	42.00	42.22	42.47
Line.l27	2	38.91	39.93	42.01	42.24	42.48
Line.l28	1	55.26	56.43	58.62	58.85	59.07
Line.l28	2	55.27	56.43	58.63	58.85	59.07
Line.l29	1	58.39	59.31	60.86	61.02	61.16
Line.l29	2	58.40	59.32	60.87	61.02	61.17
Line.l30	1	60.76	61.73	63.51	63.69	63.87
Line.l30	2	60.77	61.74	63.51	63.70	63.88
Line.l31	1	9.98	9.91	9.75	9.73	9.72
Line.l31	2	9.98	9.91	9.74	9.73	9.72
Line.l32	1	62.45	63.37	64.96	65.13	65.29
Line.l32	2	62.46	63.37	64.97	65.14	65.30
Line.l33	1	65.05	66.00	67.77	67.96	68.15
Line.l33	2	65.07	66.02	67.79	67.97	68.17
Line.l34	1	9.99	9.93	9.76	9.74	9.73
Line.l34	2	9.99	9.93	9.76	9.74	9.73

Table 4-39: I₁ value, zone 3, 3 phase fault, 75% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	11.96	11.56	11.62	11.41	11.22
Vsource	2	11.96	11.56	11.62	11.41	11.22
Subxf	1	11.96	11.56	11.62	11.41	11.22
Subxf	2	573.27	553.70	556.58	546.84	537.48
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	518.46	500.33	503.08	494.10	485.48
Line.l1	2	518.47	500.34	503.09	494.11	485.48
Line.l2	1	72.07	69.06	69.52	68.03	66.60
Line.l2	2	72.07	69.06	69.52	68.03	66.60
Line.l3	1	129.78	123.68	124.80	121.88	119.08
Line.l3	2	129.78	123.68	124.80	121.88	119.07
Line.l4	1	719.79	692.58	696.85	683.46	670.59
Line.l4	2	719.80	692.59	696.86	683.47	670.59
Line.l5	1	133.24	127.58	128.51	125.75	123.09
Line.l5	2	133.24	127.58	128.51	125.75	123.09
Line.l6	1	62.20	59.10	59.78	58.36	57.00
Line.l6	2	62.19	59.10	59.77	58.36	56.99
Line.l7	1	1.79	2.02	1.94	2.03	2.11
Line.l7	2	1.79	2.02	1.94	2.03	2.11
Line.l8	1	1.79	2.02	1.94	2.03	2.11
Line.l8	2	1.79	2.02	1.94	2.03	2.11
Line.l9	1	67.33	64.87	65.27	64.06	62.89
Line.l9	2	67.33	64.87	65.26	64.05	62.89
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	85.90	83.41	83.68	82.39	81.15
Line.l11	2	85.90	83.41	83.68	82.39	81.15
Line.l12	1	71.37	68.86	69.13	67.83	66.58
Line.l12	2	71.37	68.86	69.13	67.83	66.58
Line.l13	1	75.84	73.34	73.59	72.28	71.02
Line.l13	2	75.84	73.34	73.59	72.28	71.02
Line.l14	1	3.63	4.11	3.95	4.13	4.32
Line.l14	2	3.63	4.10	3.95	4.13	4.32
Line.l15	1	75.60	73.05	73.33	72.01	70.74
Line.l15	2	75.60	73.05	73.33	72.01	70.74
Line.l16	1	89.72	85.88	86.57	84.73	82.96

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	89.72	85.87	86.57	84.73	82.96
Line.l17	1	809.03	777.97	782.93	767.68	753.03
Line.l17	2	809.04	777.97	782.93	767.69	753.04
Line.l18	1	806.38	774.88	780.01	764.61	749.81
Line.l18	2	806.38	774.88	780.01	764.61	749.81
Line.l19	1	92.21	89.16	89.47	87.89	86.36
Line.l19	2	92.21	89.16	89.47	87.88	86.36
Line.l20	1	898.50	863.99	869.43	852.45	836.14
Line.l20	2	898.50	863.99	869.43	852.45	836.14
Line.l21	1	1.32	1.57	1.48	1.58	1.67
Line.l21	2	1.32	1.57	1.48	1.58	1.67
Line.l22	1	897.19	862.44	867.96	850.90	834.50
Line.l22	2	897.19	862.44	867.97	850.90	834.50
Line.l23	1	91.30	87.68	88.28	86.51	84.82
Line.l23	2	91.30	87.68	88.28	86.51	84.82
Line.l24	1	97.76	95.03	95.29	93.84	92.45
Line.l24	2	97.76	95.03	95.28	93.84	92.45
Line.l25	1	4.98	5.70	5.46	5.74	6.00
Line.l25	2	4.98	5.70	5.46	5.74	6.00
Line.l26	1	886.98	852.27	857.82	840.79	824.43
Line.l26	2	886.98	852.27	857.82	840.79	824.43
Line.l27	1	73.27	69.38	961.35	942.36	924.11
Line.l27	2	73.27	69.37	961.36	942.36	924.11
Line.l28	1	90.02	85.96	90.17	925.55	907.35
Line.l28	2	90.02	85.96	90.17	925.55	907.35
Line.l29	1	93.29	89.96	93.30	93.37	904.00
Line.l29	2	93.29	89.96	93.30	93.37	904.00
Line.l30	1	95.52	92.69	95.43	95.43	95.45
Line.l30	2	95.52	92.69	95.42	95.43	95.45
Line.l31	1	2.24	2.75	2.13	2.07	2.01
Line.l31	2	2.24	2.75	2.13	2.07	2.01
Line.l32	1	108.84	919.73	105.58	103.68	101.85
Line.l32	2	108.84	919.73	105.58	103.68	101.84
Line.l33	1	111.06	110.89	108.09	106.35	104.69
Line.l33	2	111.06	110.89	108.08	106.35	104.68
Line.l34	1	2.23	2.08	2.55	2.76	2.95
Line.l34	2	2.23	2.08	2.55	2.76	2.95

Table 4-40: I_r value, zone 3, SLG fault, 75% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.16	0.15	0.16	0.15	0.15
Line.l1	2	0.16	0.15	0.16	0.15	0.15
Line.l2	1	134.99	127.80	128.62	124.81	121.16
Line.l2	2	134.99	127.80	128.62	124.81	121.16
Line.l3	1	263.47	249.44	251.03	243.61	236.47
Line.l3	2	263.47	249.44	251.03	243.61	236.47
Line.l4	1	398.11	376.92	379.32	368.10	357.32
Line.l4	2	398.11	376.92	379.32	368.10	357.32
Line.l5	1	263.49	249.46	251.05	243.62	236.49
Line.l5	2	263.49	249.46	251.05	243.62	236.49
Line.l6	1	130.01	123.08	123.87	120.20	116.68
Line.l6	2	130.01	123.08	123.87	120.20	116.68
Line.l7	1	0.03	0.03	0.03	0.03	0.03
Line.l7	2	0.03	0.03	0.03	0.03	0.03
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	130.07	123.15	123.93	120.26	116.74
Line.l9	2	130.07	123.15	123.93	120.26	116.74
Line.l10	1	0.00	0.00	0.00	0.00	0.00
Line.l10	2	0.00	0.00	0.00	0.00	0.00
Line.l11	1	130.10	123.18	123.96	120.29	116.77
Line.l11	2	130.10	123.18	123.96	120.29	116.77
Line.l12	1	133.57	126.46	127.26	123.50	119.88
Line.l12	2	133.57	126.46	127.26	123.50	119.88
Line.l13	1	133.57	126.46	127.26	123.50	119.88
Line.l13	2	133.57	126.46	127.26	123.50	119.88
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	135.01	127.82	128.64	124.83	121.18
Line.l15	2	135.01	127.82	128.64	124.83	121.18
Line.l16	1	154.93	146.68	147.62	143.25	139.05

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	154.93	146.68	147.62	143.25	139.05
Line.l17	1	552.77	523.34	526.67	511.09	496.13
Line.l17	2	552.77	523.34	526.67	511.09	496.13
Line.l18	1	552.75	523.32	526.65	511.07	496.10
Line.l18	2	552.75	523.32	526.65	511.07	496.10
Line.l19	1	161.70	153.09	154.07	149.51	145.13
Line.l19	2	161.70	153.09	154.07	149.51	145.13
Line.l20	1	713.70	675.70	680.00	659.88	640.56
Line.l20	2	713.70	675.70	680.00	659.88	640.56
Line.l21	1	0.01	0.01	0.01	0.01	0.01
Line.l21	2	0.01	0.01	0.01	0.01	0.01
Line.l22	1	713.67	675.67	679.98	659.86	640.54
Line.l22	2	713.67	675.67	679.98	659.86	640.54
Line.l23	1	154.94	146.69	147.62	143.26	139.06
Line.l23	2	154.94	146.69	147.62	143.26	139.06
Line.l24	1	154.96	146.71	147.64	143.27	139.08
Line.l24	2	154.96	146.71	147.64	143.27	139.08
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	713.66	675.66	679.96	659.85	640.52
Line.l26	2	713.66	675.66	679.96	659.85	640.52
Line.l27	1	175.05	165.72	844.57	819.59	795.59
Line.l27	2	175.05	165.72	844.57	819.59	795.59
Line.l28	1	175.08	165.75	176.15	819.56	795.56
Line.l28	2	175.08	165.75	176.15	819.56	795.56
Line.l29	1	175.09	165.77	176.17	177.00	795.54
Line.l29	2	175.09	165.77	176.17	177.00	795.54
Line.l30	1	175.12	165.79	176.20	177.03	177.97
Line.l30	2	175.12	165.79	176.20	177.03	177.97
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	174.30	839.62	166.07	161.16	156.44
Line.l32	2	174.30	839.62	166.07	161.16	156.44
Line.l33	1	174.33	174.62	166.10	161.18	156.46
Line.l33	2	174.33	174.62	166.10	161.18	156.46
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-41: I₂ value, zone 3, LL fault, 75% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	5.06	4.84	4.87	4.76	4.66
Vsource	2	5.06	4.84	4.87	4.76	4.66
Subxf	1	5.06	4.84	4.87	4.76	4.66
Subxf	2	242.23	231.87	233.37	228.28	223.39
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	220.45	211.06	212.39	207.77	203.32
Line.l1	2	220.42	211.04	212.37	207.74	203.30
Line.l2	1	52.96	51.24	51.38	50.48	49.61
Line.l2	2	52.96	51.24	51.38	50.48	49.61
Line.l3	1	112.11	108.75	109.00	107.21	105.46
Line.l3	2	112.11	108.75	109.01	107.21	105.46
Line.l4	1	385.36	370.92	372.64	365.33	358.27
Line.l4	2	385.32	370.89	372.61	365.30	358.24
Line.l5	1	113.12	109.58	109.97	108.14	106.37
Line.l5	2	113.13	109.59	109.98	108.15	106.37
Line.l6	1	68.55	67.31	67.30	66.57	65.85
Line.l6	2	68.56	67.32	67.31	66.58	65.86
Line.l7	1	4.03	4.00	4.02	4.02	4.02
Line.l7	2	4.04	4.00	4.03	4.03	4.03
Line.l8	1	4.04	4.00	4.03	4.03	4.03
Line.l8	2	4.04	4.01	4.03	4.03	4.03
Line.l9	1	65.30	63.92	64.00	63.23	62.48
Line.l9	2	65.31	63.93	64.01	63.24	62.49
Line.l10	1	17.68	17.55	17.58	17.52	17.46
Line.l10	2	17.68	17.55	17.58	17.52	17.46
Line.l11	1	51.11	49.16	49.43	48.46	47.54
Line.l11	2	51.12	49.17	49.44	48.47	47.54
Line.l12	1	47.32	44.88	45.36	44.24	43.15
Line.l12	2	47.32	44.88	45.37	44.24	43.15
Line.l13	1	47.06	44.51	45.00	43.82	42.68
Line.l13	2	47.07	44.52	45.01	43.83	42.69
Line.l14	1	10.19	10.39	10.31	10.38	10.44
Line.l14	2	10.19	10.39	10.31	10.38	10.44
Line.l15	1	55.20	53.29	53.55	52.61	51.70
Line.l15	2	55.20	53.29	53.56	52.61	51.70
Line.l16	1	51.63	48.95	49.41	48.14	46.91

Line.l16	2	51.63	48.96	49.42	48.14	46.91
Line.l17	1	436.31	419.25	421.39	412.81	404.53
Line.l17	2	436.30	419.24	421.38	412.80	404.52
Line.l18	1	435.72	418.87	420.86	412.33	404.09
Line.l18	2	435.71	418.87	420.86	412.32	404.09
Line.l19	1	66.53	64.23	64.53	63.38	62.27
Line.l19	2	66.54	64.24	64.54	63.39	62.28
Line.l20	1	499.89	480.71	483.05	473.36	464.02
Line.l20	2	499.89	480.71	483.04	473.36	464.02
Line.l21	1	4.87	4.98	4.94	4.98	5.01
Line.l21	2	4.87	4.98	4.94	4.97	5.01
Line.l22	1	499.53	480.46	482.72	473.06	463.74
Line.l22	2	499.53	480.46	482.72	473.06	463.74
Line.l23	1	53.04	50.29	50.83	49.55	48.32
Line.l23	2	53.04	50.29	50.83	49.56	48.32
Line.l24	1	54.06	51.58	52.03	50.86	49.72
Line.l24	2	54.06	51.58	52.03	50.86	49.72
Line.l25	1	6.66	6.37	6.41	6.27	6.14
Line.l25	2	6.66	6.37	6.41	6.27	6.14
Line.l26	1	489.35	470.34	472.66	463.07	453.81
Line.l26	2	489.34	470.33	472.66	463.06	453.81
Line.l27	1	43.23	40.37	534.99	524.19	513.76
Line.l27	2	43.24	40.38	534.98	524.18	513.76
Line.l28	1	59.79	56.47	60.11	507.39	497.08
Line.l28	2	59.80	56.48	60.12	507.38	497.08
Line.l29	1	61.66	59.18	61.87	62.09	495.02
Line.l29	2	61.67	59.19	61.88	62.09	495.01
Line.l30	1	64.48	61.79	64.77	65.02	65.28
Line.l30	2	64.49	61.79	64.77	65.03	65.29
Line.l31	1	9.69	9.93	9.69	9.69	9.68
Line.l31	2	9.69	9.93	9.69	9.68	9.68
Line.l32	1	65.83	509.12	63.58	62.30	61.06
Line.l32	2	65.84	509.11	63.59	62.30	61.06
Line.l33	1	68.78	69.20	66.50	65.19	63.92
Line.l33	2	68.80	69.22	66.51	65.20	63.94
Line.l34	1	9.70	9.68	9.84	9.93	10.00
Line.l34	2	9.70	9.68	9.84	9.92	10.00

4.4.4 Short Circuit Analysis 25% DG Penetration

Table 4-42: I₁ value, zone 1, 3 phase fault, 25% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	14.91	15.02	14.77	14.71	14.39	14.12	13.80
Vsource	2	14.91	15.02	14.77	14.71	14.39	14.12	13.80
Subxf	1	14.91	15.02	14.77	14.71	14.39	14.12	13.80
Subxf	2	714.60	719.55	707.61	705.02	689.54	676.68	661.23
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	648.06	652.70	641.69	639.29	625.03	613.17	598.81
Line.l1	2	648.06	652.70	641.69	639.29	625.03	613.17	598.81
Line.l2	1	751.16	25.84	24.95	24.73	23.62	22.67	21.23
Line.l2	2	751.16	25.84	24.95	24.73	23.62	22.67	21.23
Line.l3	1	31.14	754.06	738.27	734.65	714.47	697.53	675.37
Line.l3	2	31.14	754.06	738.27	734.65	714.47	697.53	675.37
Line.l4	1	76.14	78.48	75.31	74.43	70.62	67.31	61.22
Line.l4	2	76.14	78.47	75.31	74.42	70.62	67.30	61.21
Line.l5	1	33.00	34.75	736.44	732.76	712.31	695.14	672.55
Line.l5	2	33.00	34.75	736.44	732.76	712.31	695.14	672.55
Line.l6	1	10.51	11.10	11.28	11.20	735.11	717.21	693.65
Line.l6	2	10.51	11.09	11.28	11.20	735.11	717.21	693.65
Line.l7	1	0.97	0.80	0.78	0.81	0.76	726.90	1.10
Line.l7	2	0.97	0.80	0.78	0.81	0.76	726.90	1.10
Line.l8	1	0.97	0.80	0.78	0.81	0.76	0.74	1.10
Line.l8	2	0.97	0.80	0.78	0.81	0.76	0.74	1.10
Line.l9	1	12.97	13.29	13.39	13.36	13.56	13.73	690.32
Line.l9	2	12.97	13.29	13.39	13.35	13.56	13.73	690.32
Line.l10	1	19.36	19.37	19.37	19.37	19.37	19.37	19.37
Line.l10	2	19.36	19.37	19.37	19.37	19.37	19.37	19.37
Line.l11	1	31.32	32.03	32.05	31.90	32.04	31.33	31.97
Line.l11	2	31.32	32.03	32.05	31.90	32.04	31.33	31.97
Line.l12	1	23.29	24.11	24.16	742.31	23.16	22.44	21.45
Line.l12	2	23.29	24.11	24.16	742.31	23.16	22.44	21.45
Line.l13	1	27.79	28.65	28.68	28.68	27.58	26.79	25.79
Line.l13	2	27.79	28.65	28.68	28.68	27.58	26.79	25.79
Line.l14	1	1.59	1.81	2.03	2.09	2.38	2.62	3.06
Line.l14	2	1.59	1.81	2.03	2.09	2.38	2.62	3.06

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l15	1	28.12	27.62	26.93	26.77	25.88	25.14	24.13
Line.l15	2	28.12	27.62	26.93	26.77	25.88	25.14	24.13
Line.l16	1	20.62	21.23	20.30	20.06	18.91	17.93	16.31
Line.l16	2	20.61	21.23	20.30	20.06	18.91	17.93	16.31
Line.l17	1	55.62	57.33	55.12	54.49	51.87	49.58	45.13
Line.l17	2	55.61	57.33	55.12	54.49	51.87	49.58	45.12
Line.l18	1	57.37	58.93	56.85	56.26	53.75	51.54	47.37
Line.l18	2	57.37	58.93	56.85	56.26	53.75	51.54	47.37
Line.l19	1	32.74	33.11	32.39	32.22	31.30	30.52	29.45
Line.l19	2	32.74	33.11	32.39	32.22	31.30	30.52	29.45
Line.l20	1	25.04	26.19	25.17	24.82	23.83	22.96	20.37
Line.l20	2	25.04	26.19	25.17	24.82	23.82	22.96	20.37
Line.l21	1	1.02	0.94	1.05	1.08	1.22	1.34	1.55
Line.l21	2	1.02	0.94	1.05	1.08	1.22	1.34	1.55
Line.l22	1	25.96	27.04	26.05	25.71	24.69	23.79	21.23
Line.l22	2	25.96	27.04	26.05	25.71	24.69	23.78	21.23
Line.l23	1	21.59	22.12	21.28	21.06	20.02	19.11	17.69
Line.l23	2	21.59	22.12	21.28	21.06	20.02	19.11	17.69
Line.l24	1	25.46	25.64	25.16	25.06	24.43	23.90	23.28
Line.l24	2	25.46	25.64	25.16	25.06	24.43	23.90	23.28
Line.l25	1	2.97	2.70	3.02	3.12	3.52	3.88	4.52
Line.l25	2	2.97	2.70	3.02	3.12	3.52	3.88	4.52
Line.l26	1	35.48	36.61	35.13	34.71	32.96	31.43	28.48
Line.l26	2	35.48	36.61	35.13	34.71	32.95	31.42	28.48
Line.l27	1	9.79	10.26	10.38	10.31	10.65	10.88	10.19
Line.l27	2	9.79	10.26	10.37	10.30	10.65	10.87	10.19
Line.l28	1	24.83	25.46	24.54	24.29	23.16	22.18	20.53
Line.l28	2	24.83	25.46	24.54	24.29	23.16	22.18	20.53
Line.l29	1	27.70	28.07	27.40	27.23	26.38	25.65	24.53
Line.l29	2	27.69	28.07	27.40	27.23	26.38	25.65	24.53
Line.l30	1	29.76	29.97	29.47	29.36	28.72	28.17	27.46
Line.l30	2	29.76	29.97	29.47	29.36	28.72	28.17	27.46
Line.l31	1	2.12	1.95	2.17	2.23	2.51	2.75	3.18
Line.l31	2	2.12	1.95	2.17	2.23	2.51	2.75	3.18
Line.l32	1	28.04	28.47	27.66	27.46	26.43	25.56	24.34
Line.l32	2	28.04	28.47	27.66	27.46	26.43	25.56	24.34
Line.l33	1	30.13	30.39	29.78	29.65	28.85	28.19	27.39
Line.l33	2	30.13	30.39	29.78	29.64	28.85	28.19	27.39
Line.l34	1	2.12	1.94	2.16	2.23	2.50	2.75	3.17
Line.l34	2	2.12	1.94	2.16	2.23	2.50	2.75	3.17

Table 4-43: I_r value, zone 1, SLG fault, 25% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.26	0.26	0.25	0.25	0.25	0.24	0.23
Line.l1	2	0.26	0.26	0.25	0.25	0.25	0.24	0.23
Line.l2	1	475.26	77.69	76.31	76.01	73.98	72.15	70.54
Line.l2	2	475.26	77.69	76.31	76.01	73.98	72.15	70.54
Line.l3	1	152.57	402.96	395.80	394.20	383.71	374.21	365.82
Line.l3	2	152.57	402.96	395.80	394.20	383.71	374.21	365.82
Line.l4	1	323.08	325.68	319.90	318.60	310.12	302.44	295.66
Line.l4	2	323.08	325.68	319.90	318.60	310.12	302.44	295.66
Line.l5	1	152.59	155.25	395.78	394.18	383.68	374.19	365.80
Line.l5	2	152.59	155.25	395.78	394.18	383.68	374.19	365.80
Line.l6	1	74.79	76.09	75.76	75.45	459.96	448.57	438.52
Line.l6	2	74.79	76.09	75.76	75.45	459.96	448.57	438.52
Line.l7	1	0.05	0.05	0.05	0.05	0.05	521.60	0.05
Line.l7	2	0.05	0.05	0.05	0.05	0.05	521.60	0.05
Line.l8	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l9	1	74.89	76.20	75.86	75.55	75.13	73.27	438.42
Line.l9	2	74.89	76.20	75.86	75.55	75.13	73.27	438.42
Line.l10	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l10	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l11	1	74.95	76.25	75.92	75.61	75.18	73.32	74.01
Line.l11	2	74.95	76.25	75.92	75.61	75.18	73.32	74.01
Line.l12	1	77.84	79.20	78.85	469.52	76.44	74.55	72.88
Line.l12	2	77.84	79.20	78.85	469.52	76.44	74.55	72.88
Line.l13	1	77.84	79.20	78.85	78.74	76.44	74.55	72.88
Line.l13	2	77.84	79.20	78.85	78.74	76.44	74.55	72.88
Line.l14	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l15	1	78.10	77.73	76.35	76.04	74.01	72.18	70.57
Line.l15	2	78.10	77.73	76.35	76.04	74.01	72.18	70.57
Line.l16	1	80.56	81.21	79.77	79.44	77.33	75.41	73.73

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l16	2	80.56	81.21	79.77	79.44	77.33	75.41	73.73
Line.l17	1	242.70	244.66	240.31	239.34	232.97	227.20	222.11
Line.l17	2	242.70	244.66	240.31	239.34	232.97	227.20	222.11
Line.l18	1	242.74	244.70	240.35	239.38	233.00	227.24	222.14
Line.l18	2	242.74	244.70	240.35	239.38	233.00	227.24	222.14
Line.l19	1	80.81	81.46	80.02	79.69	77.57	75.65	73.96
Line.l19	2	80.81	81.46	80.02	79.69	77.57	75.65	73.96
Line.l20	1	161.96	163.27	160.37	159.72	155.47	151.62	148.22
Line.l20	2	161.96	163.27	160.37	159.72	155.47	151.62	148.22
Line.l21	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Line.l21	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Line.l22	1	162.00	163.31	160.41	159.76	155.50	151.65	148.25
Line.l22	2	162.00	163.31	160.41	159.76	155.50	151.65	148.25
Line.l23	1	80.57	81.22	79.78	79.46	77.34	75.43	73.74
Line.l23	2	80.57	81.22	79.78	79.46	77.34	75.43	73.74
Line.l24	1	80.60	81.25	79.81	79.48	77.37	75.45	73.76
Line.l24	2	80.60	81.25	79.81	79.48	77.37	75.45	73.76
Line.l25	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l26	1	162.02	163.33	160.43	159.78	155.52	151.67	148.27
Line.l26	2	162.02	163.33	160.43	159.78	155.52	151.67	148.27
Line.l27	1	80.78	81.43	79.99	79.66	77.54	75.62	73.93
Line.l27	2	80.78	81.43	79.99	79.66	77.54	75.62	73.93
Line.l28	1	80.82	81.48	80.03	79.70	77.58	75.66	73.96
Line.l28	2	80.82	81.48	80.03	79.70	77.58	75.66	73.96
Line.l29	1	80.85	81.50	80.05	79.73	77.61	75.68	73.99
Line.l29	2	80.85	81.50	80.05	79.73	77.61	75.68	73.99
Line.l30	1	80.88	81.54	80.09	79.76	77.64	75.72	74.02
Line.l30	2	80.88	81.54	80.09	79.76	77.64	75.72	74.02
Line.l31	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l32	1	81.27	81.93	80.47	80.15	78.01	76.08	74.38
Line.l32	2	81.27	81.93	80.47	80.15	78.01	76.08	74.38
Line.l33	1	81.31	81.97	80.51	80.18	78.05	76.12	74.41
Line.l33	2	81.31	81.97	80.51	80.18	78.05	76.12	74.41
Line.l34	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 4-44: I₂ value, zone 1, LL fault, 25% penetration

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Vsource	1	6.29	6.36	6.23	6.20	6.03	5.87	5.68
Vsource	2	6.29	6.36	6.23	6.20	6.03	5.87	5.68
Subxf	1	6.29	6.36	6.23	6.20	6.03	5.87	5.68
Subxf	2	301.27	304.98	298.57	296.96	288.75	281.33	272.08
Xfm1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1	274.07	277.43	271.59	270.13	262.65	255.89	247.50
Line.l1	2	274.04	277.40	271.57	270.10	262.62	255.86	247.47
Line.l2	1	384.48	25.51	25.19	25.12	24.70	24.33	23.97
Line.l2	2	384.48	25.52	25.20	25.13	24.71	24.33	23.97
Line.l3	1	59.69	356.81	349.17	347.23	337.38	328.38	317.03
Line.l3	2	59.69	356.80	349.16	347.23	337.38	328.37	317.02
Line.l4	1	58.62	59.38	57.26	56.84	54.40	52.35	50.18
Line.l4	2	58.65	59.41	57.29	56.87	54.43	52.37	50.21
Line.l5	1	57.96	58.84	348.68	346.76	336.89	327.89	316.76
Line.l5	2	57.97	58.85	348.67	346.75	336.88	327.88	316.75
Line.l6	1	42.58	42.78	42.81	42.78	354.63	344.99	332.86
Line.l6	2	42.59	42.79	42.82	42.78	354.61	344.98	332.85
Line.l7	1	4.21	4.27	4.29	4.28	4.31	381.32	4.24
Line.l7	2	4.22	4.28	4.30	4.29	4.32	381.31	4.24
Line.l8	1	4.22	4.28	4.30	4.29	4.32	4.34	4.24
Line.l8	2	4.22	4.28	4.30	4.29	4.32	4.34	4.24
Line.l9	1	36.49	36.66	36.68	36.65	36.72	36.50	336.90
Line.l9	2	36.50	36.67	36.69	36.66	36.73	36.51	336.89
Line.l10	1	18.04	18.12	18.12	18.11	18.13	18.06	18.13
Line.l10	2	18.04	18.12	18.12	18.11	18.13	18.06	18.13
Line.l11	1	22.23	22.73	22.80	22.71	22.89	22.44	23.02
Line.l11	2	22.24	22.74	22.81	22.72	22.90	22.45	23.03
Line.l12	1	19.33	20.06	20.17	387.10	19.53	19.01	18.15
Line.l12	2	19.33	20.06	20.17	387.10	19.53	19.01	18.15
Line.l13	1	19.50	20.39	20.51	20.53	19.63	18.96	18.00
Line.l13	2	19.51	20.40	20.52	20.53	19.63	18.97	18.01
Line.l14	1	9.46	9.52	9.59	9.62	9.70	9.78	9.94
Line.l14	2	9.46	9.52	9.59	9.61	9.70	9.78	9.94
Line.l15	1	26.20	25.92	25.59	25.50	25.08	24.69	24.22
Line.l15	2	26.20	25.92	25.59	25.51	25.08	24.70	24.22
Line.l16	1	16.62	16.95	16.41	16.27	15.60	14.98	14.15

Element	Terminal	Faulty Node						
		705	713	704	714	720	706	707
Line.l16	2	16.63	16.95	16.41	16.27	15.60	14.98	14.15
Line.l17	1	42.59	43.02	41.40	41.12	39.32	37.88	36.61
Line.l17	2	42.60	43.03	41.40	41.13	39.33	37.89	36.62
Line.l18	1	40.14	40.75	39.36	39.06	37.46	36.05	34.29
Line.l18	2	40.14	40.75	39.36	39.06	37.47	36.05	34.29
Line.l19	1	26.85	27.03	26.70	26.62	26.19	25.79	25.32
Line.l19	2	26.86	27.04	26.71	26.62	26.19	25.80	25.33
Line.l20	1	19.07	19.18	17.45	17.25	15.55	14.44	14.21
Line.l20	2	19.07	19.18	17.45	17.25	15.56	14.44	14.21
Line.l21	1	4.72	4.68	4.72	4.73	4.77	4.81	4.89
Line.l21	2	4.72	4.68	4.71	4.73	4.77	4.81	4.89
Line.l22	1	16.04	16.31	14.76	14.53	12.98	11.84	11.01
Line.l22	2	16.04	16.32	14.76	14.53	12.99	11.84	11.01
Line.l23	1	16.93	17.30	16.87	16.74	16.19	15.64	14.72
Line.l23	2	16.94	17.31	16.88	16.74	16.19	15.64	14.72
Line.l24	1	17.12	17.37	17.20	17.12	16.82	16.46	15.76
Line.l24	2	17.12	17.38	17.21	17.12	16.83	16.47	15.77
Line.l25	1	7.23	7.32	7.17	7.13	6.94	6.76	6.53
Line.l25	2	7.23	7.32	7.17	7.13	6.94	6.76	6.53
Line.l26	1	25.49	25.84	24.67	24.45	23.11	22.02	21.03
Line.l26	2	25.49	25.85	24.67	24.46	23.12	22.03	21.04
Line.l27	1	3.46	3.44	2.17	2.07	1.06	1.10	2.27
Line.l27	2	3.46	3.43	2.17	2.07	1.05	1.09	2.26
Line.l28	1	18.09	18.43	17.78	17.63	16.79	16.05	15.22
Line.l28	2	18.09	18.43	17.79	17.63	16.80	16.06	15.22
Line.l29	1	19.95	20.00	19.71	19.66	19.27	18.94	18.74
Line.l29	2	19.96	20.01	19.72	19.67	19.27	18.95	18.75
Line.l30	1	19.83	20.04	19.62	19.51	18.96	18.46	17.89
Line.l30	2	19.83	20.05	19.62	19.52	18.96	18.46	17.90
Line.l31	1	9.52	9.44	9.52	9.54	9.63	9.71	9.87
Line.l31	2	9.52	9.44	9.51	9.54	9.63	9.71	9.87
Line.l32	1	22.95	23.08	22.74	22.66	22.20	21.80	21.42
Line.l32	2	22.96	23.09	22.74	22.67	22.21	21.81	21.42
Line.l33	1	24.20	24.42	24.03	23.93	23.43	22.97	22.41
Line.l33	2	24.21	24.44	24.05	23.95	23.45	22.99	22.43
Line.l34	1	9.53	9.45	9.52	9.55	9.64	9.72	9.88
Line.l34	2	9.53	9.45	9.52	9.55	9.63	9.71	9.87

Table 4-45: I₁ value, zone 2, 3 phase fault, 25% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	14.55	14.68	14.56	14.48	14.33
Vsource	2	14.55	14.68	14.56	14.48	14.33
Subxf	1	14.55	14.68	14.56	14.48	14.33
Subxf	2	697.02	703.20	697.88	693.60	686.59
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	631.96	637.67	632.80	628.86	622.40
Line.l1	2	631.96	637.67	632.80	628.86	622.40
Line.l2	1	24.27	24.73	24.44	24.13	23.61
Line.l2	2	24.27	24.73	24.44	24.13	23.61
Line.l3	1	30.37	30.94	30.84	30.46	29.82
Line.l3	2	30.37	30.94	30.84	30.45	29.82
Line.l4	1	683.42	690.46	684.77	679.93	671.97
Line.l4	2	683.42	690.46	684.78	679.93	671.97
Line.l5	1	32.20	32.73	32.58	32.23	31.63
Line.l5	2	32.20	32.72	32.58	32.22	31.63
Line.l6	1	11.35	11.31	11.66	11.69	11.72
Line.l6	2	11.35	11.31	11.66	11.68	11.72
Line.l7	1	1.05	1.00	1.02	1.05	1.12
Line.l7	2	1.05	1.00	1.02	1.05	1.12
Line.l8	1	1.05	1.00	1.02	1.05	1.12
Line.l8	2	1.05	1.00	1.02	1.05	1.12
Line.l9	1	13.41	13.41	13.60	13.59	13.56
Line.l9	2	13.40	13.41	13.59	13.58	13.55
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	30.47	30.79	30.53	30.32	29.96
Line.l11	2	30.47	30.79	30.53	30.32	29.96
Line.l12	1	22.45	22.78	22.54	22.31	21.92
Line.l12	2	22.45	22.78	22.54	22.31	21.92
Line.l13	1	26.83	27.19	26.90	26.65	26.24
Line.l13	2	26.83	27.19	26.90	26.65	26.24
Line.l14	1	2.18	2.06	2.10	2.18	2.31
Line.l14	2	2.18	2.06	2.10	2.18	2.31
Line.l15	1	26.35	26.71	26.44	26.19	25.78
Line.l15	2	26.35	26.71	26.44	26.19	25.78
Line.l16	1	737.38	745.96	21.10	20.77	20.22

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	737.38	745.96	21.10	20.77	20.22
Line.l17	1	56.59	57.77	705.43	700.22	691.66
Line.l17	2	56.59	57.76	705.43	700.22	691.66
Line.l18	1	58.22	59.34	61.66	698.75	690.07
Line.l18	2	58.22	59.34	61.66	698.75	690.07
Line.l19	1	32.83	33.22	33.81	33.83	33.38
Line.l19	2	32.83	33.22	33.81	33.83	33.37
Line.l20	1	25.89	26.44	28.07	28.24	722.76
Line.l20	2	25.89	26.44	28.07	28.24	722.76
Line.l21	1	0.97	0.91	0.78	0.77	0.75
Line.l21	2	0.97	0.91	0.78	0.77	0.75
Line.l22	1	26.75	27.28	28.81	28.96	29.18
Line.l22	2	26.75	27.28	28.81	28.96	29.18
Line.l23	1	736.55	22.98	21.98	21.67	21.17
Line.l23	2	736.55	22.98	21.98	21.67	21.17
Line.l24	1	26.04	26.04	25.52	25.34	25.05
Line.l24	2	26.04	26.04	25.52	25.34	25.05
Line.l25	1	2.30	2.33	2.73	2.85	3.04
Line.l25	2	2.30	2.33	2.73	2.85	3.04
Line.l26	1	36.11	36.90	38.57	38.70	38.86
Line.l26	2	36.10	36.90	38.57	38.70	38.86
Line.l27	1	10.36	10.30	10.87	10.98	11.16
Line.l27	2	10.36	10.30	10.87	10.98	11.16
Line.l28	1	25.11	25.60	26.55	26.60	26.67
Line.l28	2	25.11	25.60	26.55	26.60	26.67
Line.l29	1	27.86	28.21	28.82	28.85	28.88
Line.l29	2	27.86	28.21	28.82	28.85	28.88
Line.l30	1	29.80	30.07	30.42	30.43	30.43
Line.l30	2	29.80	30.07	30.42	30.43	30.43
Line.l31	1	2.01	1.90	1.63	1.61	1.58
Line.l31	2	2.01	1.90	1.63	1.61	1.58
Line.l32	1	28.20	28.63	29.33	29.37	29.40
Line.l32	2	28.20	28.63	29.33	29.37	29.40
Line.l33	1	30.17	30.51	30.95	30.96	30.96
Line.l33	2	30.17	30.51	30.95	30.96	30.96
Line.l34	1	2.01	1.89	1.63	1.60	1.57
Line.l34	2	2.01	1.89	1.63	1.60	1.57

Table 4-46: I_r value, zone 2, SLG fault, 25% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.25	0.25	0.25	0.25	0.25
Line.l1	2	0.25	0.25	0.25	0.25	0.25
Line.l2	1	75.87	76.67	76.23	75.78	74.96
Line.l2	2	75.87	76.67	76.23	75.78	74.96
Line.l3	1	150.18	151.77	150.89	150.00	148.37
Line.l3	2	150.18	151.77	150.89	150.00	148.37
Line.l4	1	225.68	228.07	226.75	225.41	222.97
Line.l4	2	225.68	228.07	226.75	225.41	222.97
Line.l5	1	150.20	151.79	150.91	150.02	148.40
Line.l5	2	150.20	151.79	150.91	150.02	148.40
Line.l6	1	73.62	74.40	73.97	73.53	72.73
Line.l6	2	73.62	74.40	73.97	73.53	72.73
Line.l7	1	0.05	0.05	0.05	0.05	0.05
Line.l7	2	0.05	0.05	0.05	0.05	0.05
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	73.72	74.50	74.07	73.63	72.83
Line.l9	2	73.72	74.50	74.07	73.63	72.83
Line.l10	1	0.01	0.01	0.01	0.01	0.01
Line.l10	2	0.01	0.01	0.01	0.01	0.01
Line.l11	1	73.77	74.56	74.12	73.69	72.89
Line.l11	2	73.77	74.56	74.12	73.69	72.89
Line.l12	1	76.62	77.43	76.99	76.53	75.70
Line.l12	2	76.62	77.43	76.99	76.53	75.70
Line.l13	1	76.63	77.44	76.99	76.54	75.71
Line.l13	2	76.63	77.44	76.99	76.54	75.71
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	75.90	76.70	76.26	75.81	74.99
Line.l15	2	75.90	76.70	76.26	75.81	74.99
Line.l16	1	466.09	471.04	80.23	79.76	78.89

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	466.09	471.04	80.23	79.76	78.89
Line.l17	1	240.57	243.12	306.82	305.01	301.71
Line.l17	2	240.57	243.12	306.82	305.01	301.71
Line.l18	1	240.61	243.16	245.47	304.97	301.67
Line.l18	2	240.61	243.16	245.47	304.97	301.67
Line.l19	1	80.10	80.95	81.72	81.65	80.77
Line.l19	2	80.10	80.95	81.72	81.65	80.77
Line.l20	1	160.54	162.24	163.78	163.65	382.37
Line.l20	2	160.54	162.24	163.78	163.65	382.37
Line.l21	1	0.02	0.02	0.02	0.02	0.02
Line.l21	2	0.02	0.02	0.02	0.02	0.02
Line.l22	1	160.58	162.28	163.82	163.69	163.25
Line.l22	2	160.58	162.28	163.82	163.69	163.25
Line.l23	1	466.08	81.32	80.24	79.77	78.90
Line.l23	2	466.08	81.32	80.24	79.77	78.90
Line.l24	1	81.09	81.35	80.27	79.80	78.93
Line.l24	2	81.09	81.35	80.27	79.80	78.93
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	160.60	162.30	163.84	163.71	163.27
Line.l26	2	160.60	162.30	163.84	163.71	163.27
Line.l27	1	80.07	80.92	81.69	81.62	81.40
Line.l27	2	80.07	80.92	81.69	81.62	81.40
Line.l28	1	80.11	80.96	81.73	81.67	81.45
Line.l28	2	80.11	80.96	81.73	81.67	81.45
Line.l29	1	80.14	80.99	81.76	81.69	81.47
Line.l29	2	80.14	80.99	81.76	81.69	81.47
Line.l30	1	80.17	81.02	81.79	81.73	81.51
Line.l30	2	80.17	81.02	81.79	81.73	81.51
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	80.56	81.41	82.19	82.12	81.90
Line.l32	2	80.56	81.41	82.19	82.12	81.90
Line.l33	1	80.60	81.45	82.22	82.16	81.94
Line.l33	2	80.60	81.45	82.22	82.16	81.94
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-47: I₂ value, zone 2, LL fault, 25% penetration

Element	Terminal	Faulty Node				
		744	727	730	709	708
Vsource	1	6.08	6.16	6.09	6.04	5.95
Vsource	2	6.08	6.16	6.09	6.04	5.95
Subxf	1	6.08	6.16	6.09	6.04	5.95
Subxf	2	291.43	295.00	291.87	289.28	285.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	265.08	268.33	265.46	263.11	259.21
Line.l1	2	265.05	268.30	265.44	263.09	259.18
Line.l2	1	24.77	24.95	24.75	24.61	24.39
Line.l2	2	24.78	24.96	24.75	24.62	24.40
Line.l3	1	58.31	58.70	58.25	57.96	57.48
Line.l3	2	58.31	58.71	58.26	57.97	57.49
Line.l4	1	343.38	347.13	343.66	340.93	336.40
Line.l4	2	343.35	347.10	343.62	340.90	336.37
Line.l5	1	56.74	57.13	56.74	56.46	55.99
Line.l5	2	56.75	57.13	56.74	56.46	55.99
Line.l6	1	42.05	42.18	41.99	41.90	41.73
Line.l6	2	42.06	42.19	42.00	41.91	41.74
Line.l7	1	4.22	4.23	4.23	4.22	4.21
Line.l7	2	4.22	4.23	4.23	4.23	4.21
Line.l8	1	4.22	4.23	4.23	4.23	4.21
Line.l8	2	4.22	4.23	4.24	4.23	4.22
Line.l9	1	36.08	36.18	36.03	35.95	35.82
Line.l9	2	36.09	36.19	36.04	35.96	35.83
Line.l10	1	17.96	18.00	17.97	17.95	17.91
Line.l10	2	17.96	18.00	17.97	17.95	17.91
Line.l11	1	21.65	21.85	21.67	21.52	21.28
Line.l11	2	21.66	21.86	21.68	21.53	21.29
Line.l12	1	18.86	19.11	18.97	18.79	18.48
Line.l12	2	18.86	19.11	18.97	18.79	18.48
Line.l13	1	18.80	19.11	18.90	18.68	18.31
Line.l13	2	18.81	19.12	18.90	18.68	18.31
Line.l14	1	9.62	9.58	9.58	9.60	9.64
Line.l14	2	9.62	9.58	9.58	9.60	9.64
Line.l15	1	25.19	25.38	25.20	25.06	24.84
Line.l15	2	25.20	25.38	25.21	25.07	24.84
Line.l16	1	382.31	386.71	16.69	16.47	16.10

Element	Terminal	Faulty Node				
		744	727	730	709	708
Line.l16	2	382.30	386.71	16.69	16.47	16.11
Line.l17	1	42.23	43.26	360.22	357.28	352.42
Line.l17	2	42.24	43.27	360.21	357.27	352.41
Line.l18	1	40.00	40.86	42.03	357.04	352.18
Line.l18	2	40.00	40.86	42.03	357.04	352.18
Line.l19	1	26.84	27.03	27.32	27.33	27.09
Line.l19	2	26.85	27.04	27.33	27.34	27.10
Line.l20	1	18.45	19.58	20.66	20.56	378.59
Line.l20	2	18.45	19.59	20.66	20.56	378.58
Line.l21	1	4.70	4.68	4.64	4.64	4.64
Line.l21	2	4.70	4.68	4.64	4.64	4.64
Line.l22	1	15.60	16.62	17.72	17.65	17.48
Line.l22	2	15.60	16.62	17.72	17.66	17.48
Line.l23	1	382.33	17.72	17.13	16.95	16.66
Line.l23	2	382.32	17.72	17.13	16.96	16.66
Line.l24	1	17.58	17.54	17.33	17.26	17.11
Line.l24	2	17.58	17.54	17.34	17.26	17.11
Line.l25	1	7.46	7.45	7.25	7.18	7.08
Line.l25	2	7.46	7.45	7.25	7.18	7.08
Line.l26	1	25.26	25.99	26.85	26.83	26.76
Line.l26	2	25.27	26.00	26.85	26.84	26.76
Line.l27	1	2.95	3.77	4.48	4.41	4.22
Line.l27	2	2.95	3.77	4.48	4.40	4.22
Line.l28	1	18.08	18.45	18.98	18.99	18.99
Line.l28	2	18.08	18.46	18.98	18.99	18.99
Line.l29	1	19.87	20.04	20.19	20.19	20.18
Line.l29	2	19.88	20.05	20.20	20.20	20.19
Line.l30	1	19.81	20.06	20.39	20.41	20.41
Line.l30	2	19.82	20.06	20.40	20.41	20.41
Line.l31	1	9.49	9.45	9.36	9.36	9.36
Line.l31	2	9.49	9.44	9.36	9.35	9.35
Line.l32	1	22.90	23.10	23.34	23.35	23.35
Line.l32	2	22.91	23.11	23.35	23.36	23.36
Line.l33	1	24.20	24.42	24.76	24.77	24.78
Line.l33	2	24.22	24.44	24.78	24.79	24.80
Line.l34	1	9.50	9.46	9.37	9.36	9.36
Line.l34	2	9.50	9.45	9.37	9.36	9.36

Table 4-48: I₁ value, zone 3, 3 phase fault, 100% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	13.95	13.64	13.67	13.52	13.36
Vsource	2	13.95	13.64	13.67	13.52	13.36
Subxf	1	13.95	13.64	13.67	13.52	13.36
Subxf	2	668.28	653.44	655.24	647.63	640.25
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	605.52	591.76	593.49	586.48	579.68
Line.l1	2	605.52	591.76	593.50	586.48	579.68
Line.l2	1	22.27	21.01	21.32	20.77	20.23
Line.l2	2	22.27	21.01	21.32	20.76	20.23
Line.l3	1	28.17	26.04	27.00	26.32	25.68
Line.l3	2	28.17	26.04	27.00	26.32	25.67
Line.l4	1	651.19	633.65	636.38	627.73	619.34
Line.l4	2	651.20	633.65	636.39	627.73	619.35
Line.l5	1	30.04	28.08	28.89	28.21	27.56
Line.l5	2	30.04	28.08	28.88	28.21	27.55
Line.l6	1	11.80	11.26	11.84	11.88	11.92
Line.l6	2	11.79	11.25	11.83	11.87	11.91
Line.l7	1	1.28	1.46	1.40	1.47	1.53
Line.l7	2	1.28	1.46	1.40	1.47	1.53
Line.l8	1	1.28	1.46	1.40	1.47	1.53
Line.l8	2	1.28	1.46	1.40	1.47	1.53
Line.l9	1	13.40	12.80	13.23	13.12	13.01
Line.l9	2	13.40	12.80	13.22	13.12	13.00
Line.l10	1	19.36	19.36	19.36	19.36	19.36
Line.l10	2	19.36	19.36	19.36	19.36	19.36
Line.l11	1	29.03	28.25	28.37	27.98	27.61
Line.l11	2	29.03	28.25	28.37	27.98	27.61
Line.l12	1	20.92	20.01	20.20	19.78	19.37
Line.l12	2	20.92	20.01	20.20	19.78	19.37
Line.l13	1	25.16	24.25	24.40	23.96	23.53
Line.l13	2	25.16	24.25	24.40	23.96	23.53
Line.l14	1	2.67	3.04	2.92	3.07	3.21
Line.l14	2	2.67	3.04	2.92	3.07	3.21
Line.l15	1	24.72	23.79	23.96	23.52	23.09
Line.l15	2	24.72	23.79	23.96	23.52	23.09
Line.l16	1	18.79	17.35	17.79	17.19	16.62

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	18.79	17.35	17.79	17.19	16.62
Line.l17	1	669.32	650.28	653.40	644.09	635.08
Line.l17	2	669.32	650.28	653.40	644.10	635.08
Line.l18	1	667.44	648.07	651.32	641.88	632.75
Line.l18	2	667.44	648.07	651.32	641.88	632.75
Line.l19	1	32.19	31.14	31.34	30.84	30.37
Line.l19	2	32.18	31.14	31.34	30.84	30.36
Line.l20	1	698.96	678.57	682.01	672.09	662.49
Line.l20	2	698.96	678.57	682.01	672.09	662.49
Line.l21	1	0.92	1.11	1.05	1.13	1.20
Line.l21	2	0.92	1.11	1.05	1.13	1.20
Line.l22	1	698.05	677.46	680.98	670.99	661.32
Line.l22	2	698.05	677.46	680.98	670.99	661.32
Line.l23	1	19.85	18.57	18.92	18.37	17.84
Line.l23	2	19.85	18.56	18.92	18.37	17.84
Line.l24	1	24.28	23.65	23.72	23.39	23.07
Line.l24	2	24.28	23.65	23.72	23.39	23.07
Line.l25	1	3.56	4.12	3.93	4.15	4.37
Line.l25	2	3.56	4.12	3.93	4.15	4.37
Line.l26	1	687.85	667.31	670.85	660.91	651.27
Line.l26	2	687.85	667.31	670.85	660.91	651.28
Line.l27	1	11.64	11.48	698.10	687.51	677.25
Line.l27	2	11.63	11.47	698.10	687.51	677.25
Line.l28	1	26.88	25.36	26.99	670.70	660.50
Line.l28	2	26.88	25.36	26.99	670.70	660.50
Line.l29	1	28.98	27.95	29.04	29.08	658.18
Line.l29	2	28.98	27.95	29.04	29.08	658.18
Line.l30	1	30.44	29.75	30.44	30.45	30.46
Line.l30	2	30.44	29.75	30.44	30.45	30.46
Line.l31	1	1.49	1.88	1.44	1.41	1.39
Line.l31	2	1.49	1.88	1.44	1.41	1.39
Line.l32	1	29.50	673.76	28.51	27.92	27.36
Line.l32	2	29.50	673.76	28.50	27.92	27.36
Line.l33	1	30.97	30.95	30.19	29.74	29.30
Line.l33	2	30.97	30.95	30.19	29.74	29.30
Line.l34	1	1.49	1.42	1.74	1.89	2.05
Line.l34	2	1.49	1.42	1.74	1.89	2.05

Table 4-49: I_r value, zone 3, SLG fault, 25% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	0.00	0.00	0.00	0.00	0.00
Vsource	2	0.00	0.00	0.00	0.00	0.00
Subxf	1	0.00	0.00	0.00	0.00	0.00
Subxf	2	0.00	0.00	0.00	0.00	0.00
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	0.24	0.23	0.24	0.23	0.23
Line.l1	2	0.24	0.23	0.24	0.23	0.23
Line.l2	1	72.75	70.82	71.01	69.94	68.87
Line.l2	2	72.75	70.82	71.01	69.94	68.87
Line.l3	1	144.00	140.18	140.57	138.44	136.33
Line.l3	2	144.00	140.18	140.57	138.44	136.33
Line.l4	1	216.40	210.66	211.24	208.05	204.88
Line.l4	2	216.40	210.66	211.24	208.05	204.88
Line.l5	1	144.03	140.20	140.59	138.46	136.36
Line.l5	2	144.03	140.20	140.59	138.46	136.36
Line.l6	1	70.59	68.72	68.91	67.86	66.83
Line.l6	2	70.59	68.72	68.91	67.86	66.83
Line.l7	1	0.05	0.05	0.05	0.05	0.05
Line.l7	2	0.05	0.05	0.05	0.05	0.05
Line.l8	1	0.01	0.01	0.01	0.01	0.01
Line.l8	2	0.01	0.01	0.01	0.01	0.01
Line.l9	1	70.69	68.81	69.00	67.96	66.92
Line.l9	2	70.69	68.81	69.00	67.96	66.92
Line.l10	1	0.01	0.01	0.01	0.01	0.01
Line.l10	2	0.01	0.01	0.01	0.01	0.01
Line.l11	1	70.74	68.86	69.05	68.01	66.97
Line.l11	2	70.74	68.86	69.05	68.01	66.97
Line.l12	1	73.47	71.52	71.72	70.63	69.56
Line.l12	2	73.47	71.52	71.72	70.63	69.56
Line.l13	1	73.48	71.53	71.72	70.64	69.56
Line.l13	2	73.48	71.53	71.72	70.64	69.56
Line.l14	1	0.01	0.01	0.01	0.01	0.01
Line.l14	2	0.01	0.01	0.01	0.01	0.01
Line.l15	1	72.78	70.85	71.04	69.97	68.90
Line.l15	2	72.78	70.85	71.04	69.97	68.90
Line.l16	1	76.57	74.54	74.74	73.61	72.49

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	2	76.57	74.54	74.74	73.61	72.49
Line.l17	1	292.82	285.05	285.84	281.51	277.22
Line.l17	2	292.82	285.05	285.84	281.51	277.22
Line.l18	1	292.78	285.01	285.80	281.48	277.19
Line.l18	2	292.78	285.01	285.80	281.48	277.19
Line.l19	1	78.39	76.31	76.52	75.36	74.21
Line.l19	2	78.39	76.31	76.52	75.36	74.21
Line.l20	1	371.11	361.26	362.26	356.78	351.34
Line.l20	2	371.11	361.26	362.26	356.78	351.34
Line.l21	1	0.02	0.02	0.02	0.02	0.02
Line.l21	2	0.02	0.02	0.02	0.02	0.02
Line.l22	1	371.07	361.22	362.22	356.74	351.31
Line.l22	2	371.07	361.22	362.22	356.74	351.31
Line.l23	1	76.58	74.55	74.75	73.62	72.50
Line.l23	2	76.58	74.55	74.75	73.62	72.50
Line.l24	1	76.61	74.57	74.78	73.65	72.53
Line.l24	2	76.61	74.57	74.78	73.65	72.53
Line.l25	1	0.01	0.01	0.01	0.01	0.01
Line.l25	2	0.01	0.01	0.01	0.01	0.01
Line.l26	1	371.05	361.21	362.21	356.72	351.29
Line.l26	2	371.05	361.21	362.21	356.72	351.29
Line.l27	1	80.84	78.69	441.45	434.76	428.14
Line.l27	2	80.84	78.69	441.45	434.76	428.14
Line.l28	1	80.88	78.73	80.31	434.72	428.10
Line.l28	2	80.88	78.73	80.31	434.72	428.10
Line.l29	1	80.91	78.76	80.34	79.99	428.08
Line.l29	2	80.91	78.76	80.34	79.99	428.08
Line.l30	1	80.94	78.79	80.37	80.02	79.68
Line.l30	2	80.94	78.79	80.37	80.02	79.68
Line.l31	1	0.01	0.01	0.01	0.01	0.01
Line.l31	2	0.01	0.01	0.01	0.01	0.01
Line.l32	1	81.33	439.73	79.39	78.19	77.00
Line.l32	2	81.33	439.73	79.39	78.19	77.00
Line.l33	1	81.37	80.59	79.43	78.22	77.03
Line.l33	2	81.37	80.59	79.43	78.22	77.03
Line.l34	1	0.01	0.01	0.01	0.01	0.01
Line.l34	2	0.01	0.01	0.01	0.01	0.01

Table 4-50: I₂ value, zone 3, LL fault, 25% penetration

Element	Terminal	Faulty Node				
		734	710	737	738	711
Vsource	1	5.72	5.52	5.56	5.46	5.38
Vsource	2	5.72	5.52	5.56	5.46	5.38
Subxf	1	5.72	5.52	5.56	5.46	5.38
Subxf	2	273.97	264.73	266.25	261.85	257.58
Xfm1	1	0.00	0.00	0.00	0.00	0.00
Xfm1	2	0.00	0.00	0.00	0.00	0.00
Line.l1	1	249.17	240.77	242.13	238.13	234.24
Line.l1	2	249.14	240.75	242.11	238.11	234.22
Line.l2	1	23.83	23.43	23.44	23.21	23.00
Line.l2	2	23.83	23.43	23.44	23.22	23.00
Line.l3	1	56.22	55.27	55.31	54.79	54.27
Line.l3	2	56.22	55.27	55.31	54.79	54.28
Line.l4	1	324.72	315.18	316.52	311.84	307.30
Line.l4	2	324.69	315.15	316.49	311.81	307.27
Line.l5	1	54.75	53.75	53.87	53.36	52.85
Line.l5	2	54.76	53.76	53.87	53.36	52.86
Line.l6	1	41.29	40.98	40.96	40.77	40.58
Line.l6	2	41.30	40.99	40.97	40.78	40.58
Line.l7	1	4.18	4.15	4.17	4.17	4.16
Line.l7	2	4.19	4.16	4.18	4.17	4.17
Line.l8	1	4.19	4.16	4.18	4.17	4.17
Line.l8	2	4.19	4.16	4.18	4.18	4.17
Line.l9	1	35.47	35.23	35.21	35.06	34.90
Line.l9	2	35.48	35.24	35.22	35.07	34.91
Line.l10	1	17.81	17.73	17.74	17.70	17.66
Line.l10	2	17.82	17.73	17.75	17.71	17.67
Line.l11	1	20.65	20.14	20.22	19.97	19.72
Line.l11	2	20.66	20.15	20.22	19.97	19.73
Line.l12	1	17.67	16.86	17.11	16.78	16.46
Line.l12	2	17.67	16.86	17.11	16.78	16.46
Line.l13	1	17.36	16.48	16.71	16.33	15.97
Line.l13	2	17.37	16.49	16.71	16.34	15.98
Line.l14	1	9.75	9.88	9.82	9.86	9.90
Line.l14	2	9.75	9.88	9.82	9.86	9.90
Line.l15	1	24.25	23.76	23.84	23.61	23.38
Line.l15	2	24.25	23.77	23.84	23.61	23.38

Element	Terminal	Faulty Node				
		734	710	737	738	711
Line.l16	1	15.17	14.33	14.51	14.13	13.76
Line.l16	2	15.18	14.33	14.52	14.14	13.76
Line.l17	1	339.83	329.44	330.97	325.92	321.01
Line.l17	2	339.82	329.44	330.97	325.92	321.00
Line.l18	1	339.62	329.34	330.78	325.74	320.84
Line.l18	2	339.61	329.34	330.77	325.74	320.84
Line.l19	1	26.45	25.94	26.01	25.76	25.51
Line.l19	2	26.46	25.95	26.02	25.77	25.52
Line.l20	1	365.36	354.53	356.06	350.76	345.60
Line.l20	2	365.36	354.52	356.06	350.76	345.60
Line.l21	1	4.69	4.76	4.73	4.76	4.78
Line.l21	2	4.69	4.76	4.73	4.75	4.78
Line.l22	1	365.32	354.54	356.03	350.73	345.58
Line.l22	2	365.32	354.54	356.02	350.73	345.58
Line.l23	1	15.85	14.98	15.26	14.91	14.57
Line.l23	2	15.85	14.98	15.26	14.92	14.58
Line.l24	1	16.61	15.96	16.20	15.95	15.70
Line.l24	2	16.61	15.96	16.21	15.96	15.71
Line.l25	1	6.80	6.57	6.61	6.50	6.40
Line.l25	2	6.80	6.57	6.61	6.50	6.40
Line.l26	1	355.22	344.53	346.11	340.91	335.83
Line.l26	2	355.21	344.52	346.10	340.90	335.82
Line.l27	1	3.86	1.99	369.07	363.57	358.21
Line.l27	2	3.86	1.99	369.06	363.56	358.21
Line.l28	1	19.02	17.98	19.04	346.83	341.63
Line.l28	2	19.03	17.98	19.04	346.82	341.63
Line.l29	1	20.17	19.77	20.16	20.18	340.28
Line.l29	2	20.18	19.78	20.17	20.19	340.27
Line.l30	1	20.44	19.77	20.46	20.50	20.54
Line.l30	2	20.45	19.77	20.47	20.51	20.54
Line.l31	1	9.35	9.50	9.36	9.36	9.36
Line.l31	2	9.35	9.50	9.36	9.36	9.36
Line.l32	1	23.37	345.54	22.86	22.57	22.29
Line.l32	2	23.38	345.53	22.86	22.58	22.30
Line.l33	1	24.84	24.90	24.29	23.98	23.68
Line.l33	2	24.85	24.92	24.31	24.00	23.70
Line.l34	1	9.36	9.36	9.45	9.49	9.54
Line.l34	2	9.36	9.36	9.45	9.49	9.54

Figure 4-6: Test System with Agents

4.5 Fault Location Test Cases

The fault location algorithm discussed in section 4.3, is embedded in the Switch Agents. These Switch Agents only act after receiving the recloser lock out signal from its Zone Agent, which in turn receives the signal from the Recloser Agent.

The first step in the simulation process is to create the fault at a particular node in the OpenDSS software. Once the fault simulation is done, the power flow results, along with the values of sequence currents with their phase angles for all the lines in the system at an instant before opening the substation transformer, are written to an Excel file.

In order to mimic the locking out action of the recloser, the substation transformer is opened after the fault simulation. The Recloser Agent, then seeing no current in the substation transformer, will inform each of the Zone Agents about the lock out. In turn the Zone Agents inform their respective Switch Agents to implement the fault location algorithm.

The algorithm for fault location has been implemented for different penetration levels of Distributed Generation like 25%, 50%, 75% and 100%. The only difference observed between these penetration levels is the change in the threshold values of the sequence current magnitudes, while remainder of the observations discussed in the algorithm for fault location in section 4.3 remain valid. In the following section, the various test cases for the fault location for 50% penetration level are presented.

4.5.1 Single line to ground Fault at node 713

A SLG fault is simulated in OpenDSS, then the power flow results along with values of sequence currents of all the lines along with their phase angles at the instant before opening substation transformer are written to an Excel file. The Recloser Agent informs its locking out action to all the Zonal Agents ZA1, ZA2 & ZA3, which in turn pass the message to their corresponding Switch Agents SW1, SW2 & SW3. Then, each of these agents starts reading the sequence current magnitudes of the lines in their zone. For a SLG fault in zone1 I_{rth} is 650A (Table 4-23) and the values of I_r in all the lines in the test system for the SLG fault at node 713 (zone1) can be seen in the Table 4-15. SW1, upon reading the values of I_r from the Excel file, observes that threshold of 650A for I_r is

violated by the line L3. The current reversal is determined by looking at the phase angle of the zero sequence current (I_0). If the fault exists at a node which has DG unit feeding it on either side, then the phase angles of I_0 for the adjoining lines will be opposite. The Switch Agent, after checking this condition for current reversal, observes the current reversal between lines L3 and L5. Hence, the faulty node would be 713. The plot of the I_0 phase angles for the lines L3 and L5 shown in the Figure4-7 confirms the current reversal. The fault is simulated at 0.007 seconds.

Figure 4-7: I_0 phase angle reversal for fault at 713

The output screen of the JADE output in the command prompt is shown in the figure below:

```

ca: Command Prompt - java jade.Boot Recloser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent2 ZA...
INFO: Service jade.core.event.Notification initialized
Nov 29, 2011 5:01:42 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 29, 2011 5:01:42 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParser
Nov 29, 2011 5:01:42 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 29, 2011 5:01:43 PM jade.core.AgentContainerImpl joinPlatform
INFO: -----
Agent container Main-Container@arunalwala-PC is ready.

hey this is- ZA1 understand : recloserlockedoutFromRecloser
hey this is- ZA2 understand that recloserlockedoutFromRecloser
hey this is- SW1 i got the : Locate faultFromZA1
hey this is- ZA3 understand recloserlockedoutFromRecloser
The fault location is "Line.13""Line.15"
- Recloser received: will inform SwitchAgent to take actionFromZA1
hey this is- SW2 i got the : Locate faultFromZA2
- Recloser received: will inform SwitchAgent to take actionFromZA2
hey this is- ZA1 understand : FaultLocation is node 713FromSW1
hey this is- SW3 i got the : Locate faultFromZA3
- Recloser received: will inform SwitchAgent to take actionFromZA3

```

Figure 4-8: JADE Output for fault at 713 Node

4.5.2 Single line to ground Fault at node 706:

Upon receiving the lock out signal from their respective Zone Agents, the Switch Agents start looking for threshold limit violations in the magnitude of sequence current components in all the distribution lines in their zone. For a SLG fault in zone1, I_{rth} is 650A (Table 4-23) and the values of I_r in all the lines in the test system for the SLG fault at 706 (zone1) can be seen from the Table 4-15. Since this is a SLG fault in Zone 1, SwitchAgent1 sees a violation in I_{rth} in the lines L6 and L7. First, the adjoining lines of L6 and L7 are checked for current reversal and these lines do not satisfy this condition. But, the agent observes that the line L8, which is located after L7, has a low value of residual current and decides that the fault exists between the lines L7 and L8, that is at 706. The output screen of the JADE output in the command prompt is shown in the Figure 4-8 shown below:

```
Command Prompt - java jade.Boot -gui Recloser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent...
INFO: Service jade.core.event.Notification initialized
Nov 10, 2011 6:32:35 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 10, 2011 6:32:35 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParser
rImpl$JAXPSAXParser
Nov 10, 2011 6:32:35 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 10, 2011 6:32:35 PM jade.core.AgentContainerImpl joinPlatform
INFO: -----
Agent container Main-Container@arunalwala-PC is ready.

hey this is- ZA1 understand : recloserlockedoutFromRecloser
hey this is- ZA2 understand that recloserlockedoutFromRecloser
- Recloser received: will inform SwitchAgent to take actionFromZA1
hey this is- ZA3 understand recloserlockedoutFromRecloser
hey this is- SW1 i got the : Locate faultFromZA1
hey this is- SW3 i got the : Locate faultFromZA3
hey this is- SW2 i got the : recloserlockedoutFromZA2
- Recloser received: will inform SwitchAgent to take actionFromZA2
It is SLG fault and location is the node 706 located between "Line.17""Line.18"
- Recloser received: will inform SwitchAgent to take actionFromZA3
hey this is- ZA1 understand : FaultLocationFromSW1
```

Figure 4-9: JADE Output for fault at 706 Node

The agent message passing for fault location in zone1 is represented from sniffer agent GUI shown in the Figure 4-9.

Figure 4-10: Agent Message exchange for Fault Location in Zone1

4.5.3 Three phase to ground fault at node 730

In this test case, a 3LG fault is simulated in zone2. So, one of the Switch Agents will find a violation in I_1 th. The Switch Agents in all the zones start checking sequence current magnitudes and SW2 notices a violation in I_1 th of L17. For a 3LG fault in zone2, I_1 th is 900A (Table 4-23) and the values of I_1 in all the lines in the test system for the 3LG fault at node 730 (zone2) can be seen from Table 4-17. The current reversal for three phase fault is determined by checking direction of real power in all the 3 phases of the distribution line. When there is a faulty node with generation sources on either side of it, the real power in all the three phases of the adjoining lines of it will be opposite, that is the real power will be flowing towards the faulty node. The power flow in all the lines after the fault is shown in Table 4-51. The power flow results show that the real power in all the three phases in the lines L17 and L18 are in the opposite direction and flowing towards the node 730. Hence, the faulty node is 730. The power flow in zone2 after the fault at 730 is depicted in the Figure4-13. Also, the change in the phase angles of the positive sequence current of the lines L17 and L18 is opposite. The plot of the I_1 phase angles for the lines L17 and L18 shown in the Figure 4-12, confirms the current reversal as well. The fault is simulated at 0.007 seconds. The JADE output for this case is shown in the figure below:

```

C:\> Command Prompt - java jade.Boot Recloser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent2 ZA...
Nov 29, 2011 5:26:31 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 29, 2011 5:26:32 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParser
fImpl$JAXPSAXParser
Nov 29, 2011 5:26:32 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 29, 2011 5:26:32 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.

hey this is- ZA1 understand : recloserlockedoutFromRecloser
hey this is- ZA2 understand that recloserlockedoutFromRecloser
- Recloser received: will inform SwitchAgent to take actionFromZA1
hey this is- ZA3 understand recloserlockedoutFromRecloser
hey this is- SW1 i got the : Locate faultFromZA1
hey this is- SW2 i got the : Locate faultFromZA2
- Recloser received: will inform SwitchAgent to take actionFromZA2
The fault type is Three phase fault and the location is between"Line.117""Line.
118"
hey this is- SW3 i got the : Locate faultFromZA3
- Recloser received: will inform SwitchAgent to take actionFromZA3
hey this is- ZA2 understand : FaultLocation is node 730FromSW2

```

Figure 4-11: JADE Output for fault at 730 node

Figure 4-12: I1 phase angle reversal for fault at 730 node

Figure 4-13 Power flow in zone2 during fault at 730

4.5.4 Three phase to ground fault at node 708

In this test case, a 3LG fault is simulated at 708. Since this is a zone2 fault, SW2 acts will observe a violation of the positive sequence current magnitudes. L17, L18 and L20 violate the limits. For a 3LG fault in zone2, I_{1th} is 900A (Table 4-23) and the values of I_1 in all the lines in the test system for the 3LG fault at node 708 (zone2) can be seen from Table 4-17. The power flow in all the lines in the system after the fault is shown in Table 4-52. The power flow result shows that the real power flows in the same direction in the lines L17, L18 and L20. However, the flow in the line L22 will flow in the opposite direction of the line L20. Hence, the agent will decide that the faulty node is 708. The power flow in zone2 after the fault at 730 is depicted in the Figure4-17. Also, the change in the phase angles of the positive sequence current of the lines L20 and L22 will be opposite. The plot of the I_1 phase angles for the lines L20 and L22 shown in the Figure4-14 confirms this. The fault is simulated at 0.007 seconds.

Figure 4-14: I_1 phase angle reversal for fault at 708 node

The JADE output for this case is shown in the figure below:

```

C:\> Command Prompt - java jade.Boot Recloser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent2 ZA...
Nov 29, 2011 5:21:32 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 29, 2011 5:21:32 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParse
rImpl$JAXPSAXParser
Nov 29, 2011 5:21:32 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 29, 2011 5:21:32 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.

-----
hey this is- ZA1 understand : recloserlockedoutFromRecloser
hey this is- ZA3 understand recloserlockedoutFromRecloser
hey this is- ZA2 understand that recloserlockedoutFromRecloser
- Recloser received: will inform SwitchAgent to take actionFromZA1
hey this is- SW1 i got the : Locate faultFromZA1
hey this is- SW3 i got the : Locate faultFromZA3
- Recloser received: will inform SwitchAgent to take actionFromZA2
hey this is- SW2 i got the : Locate faultFromZA2
- Recloser received: will inform SwitchAgent to take actionFromZA3
The fault is a 3 phase to ground and its location is at the intersection"Line.12
@""Line.121""Line.122"
hey this is- ZA2 understand : FaultLocation is node 708FromSW2

```

Figure 4-15: JADE Output for fault at 708 Node

The message exchange between the agents from sniffer agent GUI for the fault location in zone2 is represented in Figure 4-16.

Figure 4-16: Agent Message exchange for Fault Location in zone2

Figure 4-17 Power flow in zone2 during fault at 730

4.5.5 Line to Line fault at node 738

In this test case, a LL fault is simulated at 738. The Switch Agents in all the zones start checking sequence current magnitudes and SW3 notices violation in I_{2th} of L27 and L28. For a LL fault in zone3, I_{2th} is 470A (Table 4-23) and the values of I_3 in all the lines in the test system for the LL fault at node 738 (zone3) can be seen from Table 4-22. The power flow in all the lines in the system after the fault is shown in Table 4-53. Then, the condition for current reversal for a line to line fault in L27 and L28 are checked. The current reversal for LL fault is determined by checking direction of real power in two phases of the distribution line. When there is a faulty node with generation sources on either side of it, the real power in at least two phases of the adjoining lines of it will be opposite. The power flow results clearly show that the real power will be opposite in phases 1 and 2 for the lines L28 and L29. Hence, the agent locates the fault to be between these lines at 738. The JADE output for this case is shown in the figure below:

```

Command Prompt - java jade.Boot Redoser:RecloserAgent ZA1:ZoneAgent1 ZA2:ZoneAgent2 ZA...
INFO: Service jade.core.event.Notification initialized
Nov 29, 2011 5:31:22 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 29, 2011 5:31:22 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParser
rImpl$JAXPSAXParser
Nov 29, 2011 5:31:22 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 29, 2011 5:31:22 PM jade.core.AgentContainerImpl joinPlatform
INFO: -----
Agent container Main-Container@arunalwala-PC is ready.

hey this is- ZA1 understand : recloserlockedoutFromRecloser
hey this is- ZA2 understand that recloserlockedoutFromRecloser
hey this is- ZA3 understand recloserlockedoutFromRecloser
hey this is- SW1 i got the : Locate faultFromZA1
- Recloser received: will inform SwitchAgent to take actionFromZA2
hey this is- SW3 i got the : Locate faultFromZA3
The fault type is line to line and the location is between"Line.128""Line.129"
hey this is- SW2 i got the : Locate faultFromZA2
hey this is- ZA3 understand : FaultLocation is 738FromSW3
- Recloser received: will inform SwitchAgent to take actionFromZA1
- Recloser received: will inform SwitchAgent to take actionFromZA3

```

Figure 4-18: JADE Output for fault at 738 Node

The message exchange between the agents from sniffer agent GUI for the fault location in zone3 is represented in Figure 4-19.

Figure 4-19: Agent Message exchange for Fault Location in Zone3

Table 4-51 Power flow for 3LG fault at node 730

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	739.23	647.62	702.39	656.20	670.60	687.08	0.00	0.00	-589.08	-147.40	-629.83	-157.52
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	530.46	91.60	533.67	99.77	508.08	117.23	-497.09	-62.65	-505.35	-70.02	-479.79	-82.24
Line.l2	-36.75	-6.00	-37.08	-8.55	-33.45	-8.23	37.10	6.10	37.44	8.66	33.74	8.34
Line.l3	-66.23	-11.92	-52.60	-23.97	-47.01	-7.21	66.78	12.22	52.99	24.17	47.26	7.38
Line.l4	600.07	80.56	595.03	102.55	560.24	97.67	-533.28	-22.24	-540.49	-45.22	-507.16	-31.73
Line.l5	-69.80	-13.92	-52.99	-24.17	-50.19	-5.68	70.66	14.38	53.55	24.46	50.59	5.96
Line.l6	-35.01	-3.87	-20.53	-18.66	-13.86	0.77	35.32	4.03	20.72	18.76	13.91	-0.74
Line.l7	0.00	-0.01	1.49	-0.88	1.44	0.87	0.00	0.00	-1.48	0.88	-1.44	-0.88
Line.l8	0.00	0.00	1.48	-0.88	1.44	0.88	0.00	0.00	-1.48	0.88	-1.44	-0.88
Line.l9	-38.46	-5.79	-22.21	-17.87	-18.35	1.63	39.28	6.04	22.65	18.00	18.54	-1.55
Line.l10	2.81	1.55	18.05	-10.73	20.04	9.20	-2.81	-1.56	-18.02	10.74	-20.00	-9.19
Line.l11	-42.10	-7.60	-40.70	-7.27	-38.58	-7.64	42.90	7.84	41.45	7.48	39.27	7.89
Line.l12	-35.66	-10.52	-33.02	-5.80	-36.73	-6.73	35.73	10.54	33.07	5.81	36.80	6.76
Line.l13	-37.93	-9.30	-37.90	-5.48	-39.40	-8.32	38.42	9.45	38.36	5.62	39.91	8.50
Line.l14	3.03	1.71	0.00	0.00	2.94	-1.71	-3.03	-1.71	0.00	0.00	-2.94	1.71
Line.l15	-40.13	-7.81	-37.44	-8.66	-36.68	-6.63	40.46	7.91	37.73	8.74	36.96	6.73
Line.l16	-29.27	-7.51	-30.77	-1.11	-34.96	-5.15	29.45	7.57	30.95	1.16	35.19	5.23
Line.l17	562.55	29.75	571.26	46.33	542.11	36.87	-479.38	14.51	-492.37	-5.48	-472.89	9.56
Line.l18	-69.39	-15.41	-76.66	5.48	-92.11	-8.66	70.01	15.74	77.30	-5.15	93.01	9.24
Line.l19	-34.05	-2.60	-32.95	-3.69	-33.09	-1.18	34.46	2.82	33.30	3.87	33.42	1.40
Line.l20	-35.96	-13.13	-44.36	8.84	-59.93	-8.06	36.25	13.29	44.70	-8.66	60.53	8.45
Line.l21	0.86	0.51	0.00	0.00	0.88	-0.51	-0.86	-0.51	0.00	0.00	-0.88	0.51
Line.l22	-37.11	-13.79	-44.70	8.66	-61.42	-7.94	37.41	13.96	45.05	-8.48	62.04	8.33

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l23	-30.60	-8.24	-30.95	-1.16	-36.33	-4.56	30.72	8.30	31.05	1.21	36.48	4.66
Line.l24	-34.23	-7.62	-34.62	-1.89	-38.79	-4.66	34.51	7.70	34.87	1.97	39.12	4.78
Line.l25	2.34	-0.01	2.37	0.00	2.31	0.00	-2.33	0.01	-2.37	0.00	-2.31	0.00
Line.l26	-45.59	-9.10	-53.39	3.62	-62.04	-8.33	46.30	9.47	54.23	-3.19	63.12	9.02
Line.l27	-13.18	-8.87	-18.99	6.60	-30.21	-5.82	13.28	8.92	19.13	-6.54	30.50	6.00
Line.l28	-27.03	-0.67	-33.09	-1.71	-30.50	-6.00	27.19	0.75	33.31	1.82	30.68	6.11
Line.l29	-29.94	0.90	-36.10	-3.47	-30.68	-6.11	30.13	-0.80	36.36	3.60	30.85	6.23
Line.l30	-32.05	-0.32	-36.36	-3.60	-32.84	-5.10	32.27	0.44	36.62	3.73	33.03	5.23
Line.l31	1.92	1.12	0.00	0.00	1.99	-1.12	-1.92	-1.12	0.00	0.00	-1.98	1.12
Line.l32	-34.02	-1.14	-35.23	-3.41	-33.85	-2.67	34.65	1.33	35.87	3.60	34.41	2.87
Line.l33	-36.56	-2.45	-35.87	-3.60	-36.37	-1.75	38.29	2.98	37.44	4.06	37.90	2.31
Line.l34	1.91	1.12	0.00	0.00	1.96	-1.12	-1.91	-1.12	0.00	0.00	-1.96	1.12

Table 4-52 Power flow 3LG fault 708

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	770.88	638.18	738.78	646.25	700.62	679.17	0.00	0.00	-625.73	-153.61	-676.47	-170.07
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	571.19	106.76	577.36	112.95	543.73	134.04	-539.38	-79.17	-550.21	-84.43	-516.67	-100.57
Line.l2	-39.78	-8.05	-40.40	-11.02	-35.56	-10.79	40.12	8.15	40.76	11.12	35.84	10.89
Line.l3	-75.67	-20.46	-61.27	-33.51	-53.83	-15.57	76.27	20.78	61.72	33.75	54.11	15.77
Line.l4	654.83	107.68	651.87	128.96	606.06	126.94	-590.23	-51.32	-598.67	-73.02	-554.60	-62.99
Line.l5	-80.01	-22.88	-61.72	-33.75	-57.70	-13.67	80.96	23.39	62.38	34.09	58.16	13.99
Line.l6	-42.38	-10.01	-26.52	-26.52	-18.29	-4.95	42.77	10.21	26.80	26.66	18.36	5.00
Line.l7	0.00	-0.01	1.84	-1.09	1.77	1.08	0.00	0.00	-1.84	1.09	-1.77	-1.08
Line.l8	0.00	0.00	1.84	-1.09	1.77	1.08	0.00	0.00	-1.83	1.08	-1.77	-1.08

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l9	-46.66	-12.38	-28.64	-25.57	-23.81	-3.90	47.68	12.69	29.29	25.76	24.07	4.00
Line.l10	3.14	1.73	20.13	-11.96	22.17	10.25	-3.14	-1.73	-20.10	11.97	-22.14	-10.24
Line.l11	-50.82	-14.42	-49.42	-13.80	-46.24	-14.25	51.81	14.72	50.35	14.07	47.10	14.56
Line.l12	-38.58	-13.38	-35.86	-7.56	-39.87	-9.04	38.65	13.40	35.91	7.58	39.93	9.06
Line.l13	-41.11	-12.03	-41.29	-7.21	-42.80	-10.80	41.58	12.17	41.73	7.33	43.30	10.98
Line.l14	3.74	2.10	0.00	0.00	3.60	-2.10	-3.74	-2.10	0.00	0.00	-3.59	2.10
Line.l15	-43.86	-10.25	-40.76	-11.12	-39.44	-8.79	44.19	10.35	41.04	11.20	39.70	8.89
Line.l16	-35.99	-14.33	-38.08	-6.70	-42.16	-11.81	36.22	14.40	38.30	6.77	42.45	11.91
Line.l17	626.21	65.64	636.75	79.72	596.76	74.79	-544.61	-22.25	-558.73	-39.31	-528.57	-29.11
Line.l18	542.64	21.09	558.73	39.31	526.60	30.27	-515.64	-6.74	-532.73	-25.83	-504.05	-15.16
Line.l20	552.12	11.62	568.06	31.60	539.07	18.37	-502.58	14.73	-520.71	-7.07	-497.76	9.31
Line.l22	-37.01	-15.22	-44.74	7.07	-60.95	-8.82	37.34	15.39	45.09	-6.89	61.60	9.23
Line.l21	0.81	0.48	0	-0.00	0.83	-0.48	-0.81	-0.48	0	0	-0.83	0.48
Line.l19	-36.48	-4.87	-35.33	-5.76	-35.02	-3.21	36.89	5.09	35.68	5.94	35.35	3.43
Line.l23	-37.68	-15.24	-38.30	-6.77	-43.87	-11.07	37.84	15.32	38.43	6.83	44.05	11.19
Line.l24	-42.32	-14.45	-42.95	-7.70	-46.93	-11.19	42.67	14.56	43.28	7.79	47.33	11.33
Line.l25	2.98	-0.01	3.01	0.01	2.88	0.01	-2.98	0.01	-3.01	-0.01	-2.88	-0.01
Line.l26	-45.32	-10.66	-53.31	2.15	-61.60	-9.23	46.06	11.05	54.17	-1.71	62.73	9.96
Line.l27	-13.31	-9.52	-19.09	5.72	-30.02	-6.27	13.42	9.58	19.23	-5.66	30.33	6.45
Line.l28	-26.85	-1.53	-33.00	-2.39	-30.33	-6.45	27.02	1.61	33.23	2.51	30.52	6.57
Line.l29	-29.66	-0.03	-35.93	-4.09	-30.52	-6.57	29.86	0.13	36.20	4.22	30.70	6.69
Line.l30	-31.68	-1.21	-36.20	-4.22	-32.58	-5.61	31.90	1.33	36.47	4.36	32.79	5.75
Line.l31	1.82	1.08	0.00	0.00	1.89	-1.08	-1.82	-1.08	0.00	0.00	-1.88	1.08
Line.l32	-33.61	-2.05	-35.08	-4.01	-33.59	-3.18	34.26	2.24	35.73	4.20	34.17	3.39
Line.l33	-36.07	-3.31	-35.73	-4.20	-36.03	-2.32	37.84	3.86	37.35	4.67	37.61	2.89
Line.l34	1.81	1.07	0.00	0.00	1.86	-1.07	-1.81	-1.07	0.00	0.00	-1.86	1.07

Table 4-53 Power flow for LL fault at 738

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Subxf	1270.85	194.87	-26.27	928.27	335.40	211.13	0.00	0.00	-1212.62	196.59	111.02	-695.82
Xfm1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Line.l1	1118.85	-216.60	-125.18	607.59	304.80	187.40	-1096.96	238.63	141.60	-590.36	-303.87	-185.76
Line.l2	-83.50	32.22	34.93	-49.28	39.09	28.89	83.78	-32.15	-34.55	49.38	-39.05	-28.92
Line.l3	-155.58	49.41	91.55	-107.06	142.87	43.90	156.00	-49.19	-90.61	107.54	-142.68	-43.85
Line.l4	1336.04	-320.27	-268.08	746.69	121.91	112.97	-1291.86	365.99	306.64	-706.19	-121.80	-112.33
Line.l5	-188.61	42.78	90.61	-107.54	95.38	50.25	189.47	-42.31	-89.25	108.24	-95.23	-50.25
Line.l6	-86.09	25.46	64.70	-71.74	126.32	19.05	86.36	-25.35	-63.70	72.24	-126.03	-18.98
Line.l7	0.00	-0.04	6.99	-3.27	18.64	3.19	0.00	0.01	-6.99	3.27	-18.63	-3.24
Line.l8	0.00	-0.01	6.99	-3.27	18.63	3.24	0.00	0.00	-6.98	3.26	-18.63	-3.26
Line.l9	-119.15	18.85	56.71	-68.97	60.31	22.34	120.30	-18.52	-54.80	69.52	-60.14	-22.37
Line.l10	8.01	1.60	27.90	-13.56	86.67	11.97	-8.01	-1.61	-27.87	13.57	-86.63	-11.96
Line.l11	-128.31	16.91	26.90	-55.96	-26.52	10.41	129.40	-16.59	-26.12	56.17	26.55	-10.45
Line.l12	-103.37	16.85	24.55	-36.50	-31.09	31.20	103.45	-16.83	-24.51	36.51	31.10	-31.21
Line.l13	-108.77	20.64	20.30	-38.36	-42.47	29.25	109.33	-20.47	-20.05	38.43	42.53	-29.26
Line.l14	32.64	6.39	0.00	0.00	47.33	-6.40	-32.61	-6.39	0.00	0.00	-47.30	6.39
Line.l15	-116.41	25.75	34.55	-49.38	-8.28	35.32	116.81	-25.64	-34.25	49.46	8.30	-35.34
Line.l16	-81.71	11.01	36.50	-39.70	18.83	7.81	81.86	-10.97	-36.31	39.75	-18.83	-7.83
Line.l17	1373.57	-376.99	-343.14	745.89	102.97	104.52	-1315.43	409.84	399.94	-716.48	-102.94	-104.21
Line.l18	1288.04	-414.10	-399.94	716.48	61.17	108.47	-1269.38	424.64	418.87	-706.68	-61.18	-108.42
Line.l19	-121.21	31.24	48.87	-44.18	-12.21	38.07	121.69	-30.98	-48.50	44.36	12.24	-38.12
Line.l20	1390.59	-455.88	-467.74	750.87	73.39	70.34	-1354.92	476.10	502.87	-732.68	-73.42	-70.25
Line.l21	14.44	1.98	0.00	0.00	22.63	-2.01	-14.43	-1.99	0.00	0.00	-22.62	1.99
Line.l22	1340.48	-478.08	-502.87	732.68	50.79	72.26	-1305.47	497.91	538.00	-714.50	-50.84	-72.21
Line.l23	-97.55	8.24	36.31	-39.75	-4.34	10.56	97.67	-8.18	-36.20	39.81	4.34	-10.59

Element	kW1_1	kvar1_1	kW2_1	kvar2_1	kW3_1	kvar3_1	kW1_2	kvar1	kW2_2	kvar2_2	kW3_2	kvar3_2
Line.l24	-121.20	10.95	29.99	-42.55	-46.34	10.57	121.58	-10.83	-29.78	42.60	46.37	-10.58
Line.l25	19.61	-0.02	6.62	-0.01	42.00	0.01	-19.61	0.01	-6.62	0.01	-41.98	-0.02
Line.l26	1281.68	-480.83	-530.21	697.41	50.84	72.21	-1222.87	514.15	589.20	-666.88	-50.91	-72.12
Line.l27	1301.39	-554.57	-533.72	702.51	15.43	37.87	-1225.12	597.93	722.09	-662.46	-15.51	-37.89
Line.l28	1186.81	-574.22	-700.17	638.75	15.51	37.89	-1142.22	599.56	745.43	-615.34	-15.56	-37.90
Line.l29	-77.42	40.68	60.06	-24.91	15.56	37.90	77.62	-40.58	-59.85	25.01	-15.54	-37.94
Line.l30	-103.11	39.16	59.85	-25.00	-28.66	39.37	103.44	-38.98	-59.65	25.10	28.69	-39.39
Line.l31	25.50	1.42	0.00	0.00	44.20	-1.43	-25.48	-1.42	0.00	0.00	-44.19	1.42
Line.l32	-92.08	39.02	-55.48	-35.63	13.22	35.65	92.67	-38.84	-55.90	35.79	-13.18	-35.68
Line.l33	-120.27	35.93	54.90	-35.79	-31.89	38.60	122.58	-35.21	-53.45	36.20	32.04	-38.64
Line.l34	27.59	2.91	0.00	0.00	45.06	-2.92	-27.57	-2.91	0.00	0.00	-45.05	2.91

4.6 Fault Zone Location Scenario

From an implementation point of view, the algorithm discussed in section 4.3 might not be practical because measurements like sequence current components, phase angles and power flow, for every line in the system might not be available. But, with limited measurements it can be really difficult to ascertain the precise location of the fault. Taking both these perspectives into consideration, this section describes an algorithm for locating the fault zone by using measurements only at the switches shown in the Figure 4-6. The IEEE 37 bus system described in section 4.2 with a Distributed Generation penetration of 25% is used as the test system for this scenario. The agent architecture, the fault location algorithm and test cases for the fault zone location scenario are described in the subsequent sections.

4.6.1 Agent Architecture

The proposed Multi Agent system architecture for Fault Zone Location consists of two categories of agents available.

- Global Agent
- Switch Agents.

Recloser agent (RA) is a Global agent which keeps track of the status of the recloser at the substation and informs the Switch Agent when the recloser locks out. These Switch Agents then communicate among themselves to locate the fault zone.

Each of the Switch Agents represents a switch shown in Figure 4-6. The only information that switches have in this scenario is the magnitude of the positive sequence current.

The main responsibility of each agent has been described below:

- Recloser Agent (RA): This agent keeps track of the status of the recloser at the substation and informs the SwitchAgent1 when the recloser locks out. After the lock out, the tripping off action of the recloser has been implemented by opening the substation transformer in test system.

- SwitchAgent (SW): These agents represent the switches separating each of the zones. These agents communicate among themselves in order to come up with the faulty zone. It is the most important entity in this agent architecture since it locates the faulted zone. The fault zone location algorithm is discussed in section 4.5.2

4.6.2 Fault Location Algorithm

The basic concept in the fault zone location algorithm is that during a fault, the power generating sources will tend to feed the fault as a result the current flowing through the switches associated with each of the zones (Switch1, 2, 3 for Zone 1, 2, 3 respectively) will be high. Since the majority of the power (75%) is coming from the substation, a large amount of current flows through the switches in the upper zones for fault occurring in the zones below them.

Since, the only measurement available at the switches is the magnitude of positive sequence current, the thresholds for fault detection at each of the switches have been set in terms of this measurement. In order to give the thresholds for each of the switches of the various zones, a detailed short circuit study has been conducted by simulating different kinds of fault at various locations in the test system. The faults considered are three phase (3LG), line to line (LL) and single phase to ground (SLG) fault. The results of short circuit study for all these fault types have been shown in the section 4.7.

For a fault in a particular zone, the associated Switch Agent will see a violation in positive sequence current threshold but it will only confirm the fault in its zone only after receiving the threshold status from the Switch Agent of the zone below it. The main reason for taking the decision after getting the threshold status from the other switch agent is because the majority power is coming from the substation and if a fault occurs in a lower zone, the threshold at the switches in the upper zone might be violated. So, to accurately isolate the fault zone the information about threshold status of the other Switch is essential. The test cases for fault zone isolation have been presented in section 4.8

4.7 Short Circuit Study

In this section, the results of the short circuit analysis for all the fault types considered in this work (LL, SLG and 3LG) have been tabulated. The values of I1 for 3LG, SLG LL fault at the switches separating each of the zones in the test system have been tabulated. Based on these values I1th for each of switches have been determined. The resistance of the fault is 0.5 ohm .

Table 4-54: I1 value for 3LG fault

Zone Number	Faulty Node	SW1	SW2	SW3
Zone1	702	728.08	80.82	27.84
Zone1	705	714.60	76.14	25.96
Zone1	713	719.55	78.48	27.04
Zone1	704	707.61	75.31	26.05
Zone1	714	705.02	74.43	25.71
Zone1	720	689.54	70.62	24.69
Zone1	706	676.68	67.31	23.79
Zone1	707	661.23	61.22	21.23
Zone1	722	657.56	60.02	20.81
Zone1	724	640.20	54.44	18.93
Zone1	725	668.14	64.41	22.70
Zone1	712	706.38	73.34	24.85
Zone2	744	697.02	683.42	26.75
Zone2	727	703.20	690.46	27.28
Zone2	709	693.60	679.93	28.96
Zone2	708	686.59	671.97	29.18
Zone3	734	668.28	651.20	698.05
Zone3	737	653.44	633.65	677.46
Zone3	710	655.24	636.39	680.98
Zone3	738	647.63	627.73	670.99
Zone3	711	640.25	619.35	661.32

Table 4-55: I1 value for SLG fault

Zone Number	Faulty Node	SW1	SW2	SW3
Zone1	702	251.524	78.369	49.493
Zone1	705	252.14	77.7276	49.0665
Zone1	713	251.381	78.1568	49.2897
Zone1	704	251.211	77.8656	49.1436
Zone1	714	251.312	77.7496	49.0848
Zone1	720	251.04	77.3548	48.8961
Zone1	706	250.936	76.9309	48.7008
Zone1	707	251.747	76.3847	48.4139
Zone1	722	251.803	76.2655	48.3589
Zone1	724	251.856	75.8491	48.1607
Zone1	725	251.169	76.6225	48.5373
Zone1	712	252.462	77.3314	48.866
Zone2	744	249.752	194.632	49.174
Zone2	727	249.819	195.254	49.2806
Zone2	730	248.68	194.159	49.5792
Zone2	709	248.413	193.638	49.6061
Zone2	708	248.007	192.655	49.6225
Zone3	734	247.006	190.344	181.688
Zone3	737	246.446	188.588	179.01
Zone3	710	247.525	189.395	179.605
Zone3	738	246.197	187.667	177.498
Zone3	711	246.012	186.891	176.114

Table 4-56: I1 value for LL fault

Zone Number	Faulty Node	SW1	SW2	SW3
Zone1	702	449.777	33.0217	19.58
Zone1	705	444.831	35.0288	21.8093
Zone1	713	446.288	35.3765	21.4536
Zone1	704	441.329	37.7279	23.4264
Zone1	714	440.346	37.8606	23.679
Zone1	720	433.716	40.0773	25.5893
Zone1	706	428.059	41.293	26.8234
Zone1	707	422.199	40.8372	27.4348
Zone1	722	421.006	40.9574	27.6649

Zone Number	Faulty Node	SW1	SW2	SW3
Zone1	724	413.616	41.7424	28.8132
Zone1	725	424.689	41.334	27.2941
Zone1	712	441.743	35.7172	22.7897
Zone2	744	435.748	403.789	22.1544
Zone2	727	438.417	407.346	20.9148
Zone2	730	435.553	404.149	19.4697
Zone2	709	433.657	401.683	19.5203
Zone2	708	430.536	397.548	19.6897
Zone3	734	422.392	386.79	395.115
Zone3	737	416.516	378.985	386.029
Zone3	710	416.565	378.156	384.689
Zone3	738	413.196	374.618	413.196
Zone3	711	409.953	370.298	375.852

Table 4-57: I1th value

Switch #	I1th
SW1	240
SW2	180
SW3	175

4.8 Fault Zone Location Test cases

In this section, the test cases for the fault location in the zones have been described. The simulation is started by simulating the fault on the test system in OpenDss and the values of positive sequence current magnitude are written to an excel file. The agents read the appropriate value to take decisions. The test cases for this scenario are presented in sections 4.8.1, 4.8.2 and 4.8.3.

4.8.1 Zone1 Fault

Consider a LL fault simulated at 705 (zone1) in OpenDss. The values of positive sequence current at the switches at the instant before opening substation transformer are written to an excel file. Table 4-56 provides I_1 values at the various switches for a LL fault and I_{1th} values are available in Table4-57. First, the Recloser agent informs of its locking out action to Switch Agent1 (SW1). Since the LL fault is in Zone1, the

SwitchAgent1 (SW1) will observe a violation in the value of I_{1th} (240A) and on observing this, it asks Switch Agent2 (SW2) if its value of I_{1th} (180A) has been violated or not. As seen from the Table 4-56, SW2 will not see a violation and informs the SW1 the same, upon which SW1 will confirm that the faulty zone is zone1. The JADE output for this case is shown in the Figure 4-20 and the message exchange between the agents detected by the sniffer agent is shown in Figure 4-21.

```

C:\> java jade.Boot -gui Recloser:RecloserAgent1 SW1:SwitchAgent1a SW2:Switch...

INFO: Service jade.core.management.AgentManagement initialized
Nov 10, 2011 2:54:51 PM jade.core.BaseService init
INFO: Service jade.core.messaging.Messaging initialized
Nov 10, 2011 2:54:51 PM jade.core.BaseService init
INFO: Service jade.core.mobility.AgentMobility initialized
Nov 10, 2011 2:54:51 PM jade.core.BaseService init
INFO: Service jade.core.event.Notification initialized
Nov 10, 2011 2:54:51 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 10, 2011 2:54:51 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParse
rImpl$JAXPSAXParser
Nov 10, 2011 2:54:51 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 10, 2011 2:54:51 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.

-----
hey this is- SW1 i got the : Recloser Lock Out SignalFromRecloser
- Recloser received: will take actionFromSW1
hey this is- SW2 i got the : Do you see current violationFromSW1
hey this is- SW1 i got the : No violationFromSW2
The faulty Zone is Zone1
  
```

Figure 4-20: JADE Output for fault in Zone1

Figure 4-21: Agent Message exchange for Zone1 Fault

4.8.2 Zone2 Fault

Consider that a 3LG fault simulated at node 709 (Zone2) in OpenDss. Table 4-54 provides I_1 values at the various switches for a 3LG fault and I_{1th} values are available in Table4-57. First, the Recloser agent informs of its locking out action to Switch Agent1 (SW1). SwitchAgent1 (SW1) will observe a violation in the value of I_{1th} (240A) and on observing this it asks Switch Agent2 (SW2), if value of its I_{1th} (180A) has been violated or not. As seen from the Table 4-54, SW2 will see a violation and informs the SW1 about the same, upon which SW1 will not take any action and SW2 will communicate with SwitchAgent3 (SW3) and enquire about its threshold status. SW3 informs SW2 that it doesn't see a violation in its I_{1th} (175A), upon which SW2 will decide the Zone2 is the faulty zone. The JADE output for this case is shown in the Figure 4-22 and the message exchange between the agents detected by the sniffer agent is shown in Figure 4-23.

```
Command Prompt - java jade.Boot -gui Recloser:RecloserAgent1 SW1:SwitchAgent1a SW2:Switch...
INFO: Service jade.core.messaging.Messaging initialized
Nov 10, 2011 3:21:48 PM jade.core.BaseService init
INFO: Service jade.core.mobility.AgentMobility initialized
Nov 10, 2011 3:21:48 PM jade.core.BaseService init
INFO: Service jade.core.event.Notification initialized
Nov 10, 2011 3:21:48 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 10, 2011 3:21:48 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MIP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParser
rImpl$JAXPSAXParser
Nov 10, 2011 3:21:48 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 10, 2011 3:21:48 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.

hey this is- SW1 i got the : Recloser Lock Out SignalFromRecloser
- Recloser received: will take actionFromSW1
hey this is- SW2 i got the : Do you see current violationFromSW1
hey this is- SW3 i got the : Do you see current violationFromSW2
hey this is- SW1 i got the : violationFromSW2
hey this is- SW2 i got the : no violationFromSW3
The faulty Zone is Zone2
```

Figure 4-22: JADE Output for fault for Zone2 Fault

Figure 4-23: Agent Message exchange for Zone2&Zone3 Fault

4.8.3 Zone3 Fault

Consider that a SLG fault simulated at node 734 (Zone3) in OpenDss. Table 4-55 provides I_1 values at the various switches for a SLG fault and I_{1th} values are available in Table4-57. First, the Recloser agent informs of its locking out action to Switch Agent1 (SW1). SwitchAgent1 (SW1) will observe a violation in the value of I_{1th} (240A) and on observing this it asks Switch Agent2 (SW2), if value of its I_{1th} (180A) has been violated or not. As seen from the Table 4-55, SW2 will see a violation and informs the SW1 about the same, upon which SW1 will not take any action and SW2 will communicate with SwitchAgent3 (SW3) and enquire about its threshold status. SW3 informs SW2 that it has a violation in its I_{1th} (175A), upon which SW2 will not take any action. SW3 after receiving the message from SW2 and knowing of its violation will decide that Zone 3 is faulted. The message exchange between the agents detected by the sniffer agent is shown in Figure 4-23 and the JADE output for this case is shown in the Figure 4-24.

```
Command Prompt - java jade.Boot -gui Recloser:RecloserAgent1 SW1:SwitchAgent1a SW2:Switch...
INFO: Service jade.core.messaging.Messaging initialized
Nov 10, 2011 3:54:03 PM jade.core.BaseService init
INFO: Service jade.core.mobility.AgentMobility initialized
Nov 10, 2011 3:54:03 PM jade.core.BaseService init
INFO: Service jade.core.event.Notification initialized
Nov 10, 2011 3:54:03 PM jade.core.messaging.MessagingService clearCachedSlice
INFO: Clearing cache
Nov 10, 2011 3:54:03 PM jade.mtp.http.HTTPServer <init>
INFO: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParserImpl$JAXPSAXParser
Nov 10, 2011 3:54:03 PM jade.core.messaging.MessagingService boot
INFO: MTP addresses:
http://arunalwala-PC:7778/acc
Nov 10, 2011 3:54:03 PM jade.core.AgentContainerImpl joinPlatform
INFO:
Agent container Main-Container@arunalwala-PC is ready.

hey this is- SW1 i got the : Recloser Lock Out SignalFromRecloser
- Recloser received: will take actionFromSW1
hey this is- SW2 i got the : Do you see current violationFromSW1
hey this is- SW1 i got the : violationFromSW2
hey this is- SW3 i got the : Do you see current violationFromSW2
The fault Zone is Zone3
hey this is- SW2 i got the : violationFromSW3
```

Figure 4-24: JADE Output for Zone3 Fault

CHAPTER 5

CONCLUSION AND FUTURE WORK

The present electric grid is in the transition stage to evolve into a smart grid. One of the leading technologies capable of inducing intelligence into electric grid is the agent technology. Multi agent systems are autonomous, intelligent, distributed and provide faster solutions which are in line with many of the smart grid objectives. Their wide applications in field of power system engineering are ample proof of their capability and their real time deployment on the field would yield really promising results.

5.1 Conclusion

In this thesis a Multi agent system model has been implemented in order to determine the fault location in MicroGrid system. The proposed Multi-agent system makes use of a Hierarchical model in which fault detection is done at the top level while the fault location is done at the zonal level. The Microgrid system is developed by adding solar PV model Distributed Generation at various nodes of a benchmark IEEE37 bus system .The proposed model of the Multi Agent system has been implemented on this modified IEEE 37 bus benchmark distribution network. Different fault types like Single line to ground, Line to Line and Three Phase to ground faults have been successfully located by this agent system.

The Multi agent system architecture for fault location for different kinds of faults has been designed and developed using JADE software. All the possible fault cases for different Distributed Generation penetration level in the Microgrid were considered and the results are promising.

5.2 Future Work

The MicroGrid is being looked at as one of the alternatives to increase the robustness and reliability of electric power system. Some of the future extensions to the work cited in this thesis are listed below:

- The next stage of the work shall be focused on the development of an agent system to achieve optimal energy management of the island MicroGrid that will be formed because of the fault isolation at some locations on the IEEE37 bus system considered.
- The work uses a lot of information measurements like sequence current magnitudes and phase angles in all the lines in the system. These kinds of measurements might not be always available and even if available might not be synchronized. So, there is need for work that just takes limited measurements and implements fault location.
- In this work for the implementation of MicroGrid simple steady state model of solar PV generation available in OpenDss software have been used. In order to obtain better results a more dynamic model of the PV model that can be used in the Microgrid can be developed.
- In this work only low impedance faults have been considered but not high impedance faults. So, future work has to focus on the fault location for a high impedance fault.
- This work does not take in to account the scenario where there is a communication failure during message exchange between the agents.
- Future work shall also focus on determining the location of the zonal agent in each of the zones of the test system.

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