# TROUBLE CALL ANALYSIS FOR SINGLE AND MULTIPLE OUTAGES IN RADIAL DISTRIBUTION FEEDERS

by

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# Abstract

Outage management describes system utilized by electric distribution utilities to help restore power in event of an outage. The complexity of outage management system employed by different utilities to determine the location of fault could differ. First step of outage management is to know where the problem is. Utilities typically depend on customers to call and inform them of the problem by entering their addresses.

After sufficient calls are received, the utility is able to pinpoint the location of the outage. This part of outage management is called trouble call analysis. In event of fault in a feeder of a radial distribution system, the upstream device or the device that serves to protect that particular zone activates and opens the circuit. This particular device is considered as the operated protective device. The knowledge of the activated protective device can help locate the fault. Repair crews could be sent to that particular location to carry out power restoration efforts. The main objective of this work is to study model of distribution system that could utilize the network topology and customer calls to predict the location of the operated protective device. Such prediction would be based on the knowledge of the least amount of variables i.e. network topology and customer calls. Radial distribution systems are modeled using the immune system algorithm and test cases with trouble calls are simulated in MATLAB to test the effectiveness of the proposed technique. Also, the proposed technique is tested on an actual feeder circuit with real call scenarios to verify against the known fault locations.

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# Chapter 1 - Power and Distribution System

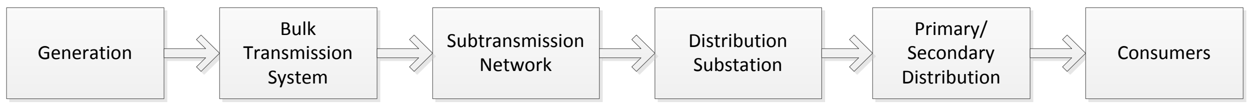
Electrical power in recent days has become an indispensable commodity in all aspects of our modern lives. More than luxury and a bare necessity, it has now become the backbone of present day's communication, transportation, finance, and healthcare infrastructures, among others. The electrical power network can widely be considered as the most complex and largest industry in the whole world [1].

## 1.1 Fundamental Electrical Power System

The electrical power network is a vast interconnected complex network that includes generation, transmission and distribution systems. The generation system includes the infrastructure that support the generation of electricity in real time. The generating plants convert energy from other forms to electrical energy. Most power plants operate within the principle of converting mechanical energy of the prime mover into electrical energy.

Transmission system is responsible for transmitting the generated power and comprises of thousands of miles of transmission lines carrying the bulk power. High voltage levels are utilized to minimize transmission losses over the lines. Transmission systems are always built with redundancies and follow loop configuration to ensure highest possible reliability. Distribution system is responsible for 'stepping down' high voltage to lower voltage level suitable for electricity distribution. Each system in itself includes a number of components working collectively to make sure uninterruptible power is transmitted from the generating site to its consuming end. These interdependent subcomponents collectively work together to deliver the power from generating site to consumer's home.

**Figure 1.1 Flow of power from generation to consumers**




## 1.2 Distribution System

Distribution system delivers power from the sub-transmission system converting the high voltages to lower levels and distributing it to the consumers. Distribution systems originate at the substations where they are usually fed by the sub-transmission lines. Utilizing power transformers, voltage is reduced to a level that is suitable for distribution. Distribution systems are different from transmission systems in that they usually follow a radial structure, have lower voltage levels and have a higher resistance-to-reactance (R/X) ratio. Another important attribute of distribution systems is unbalanced loads that are due to the fact that most of the loads are supplied through a single phase.

### *1.2.1 Primary Distribution System*

Primary distribution systems begin at the substation and transmit power to the distribution transformers. The lines coming off the substation called feeders are employed to serve this purpose. Feeders begin with feeder breaker at the substation and laterals that come off the main feeders serve the distribution transformers. These are also called taps or lateral taps. Laterals are single, two or three phases depending on the type of load connected, and are provided with fuses to help separate them from the main feeder in events of faults.

Distribution systems are designed with different configurations. The most common is the radial system. This system has a single path for power flow from the source to the consumers. All connected feeders are ‘radiating’ from the substation with a single feeder line. One definite advantage of this configuration is its simplicity and cost as it is cheaper than other options such as the loop configuration [2]. In order to improve reliability of the supply, radial configurations are provided with normally open tie points and sectionalizing switches that connect them to other circuits. In event of a fault, the faulted part of the system is isolated by disconnecting switches on two sides of the fault and power can be supplied to customers on the unfaulted section of the feeder through another circuit using the tie point. Scope of this work covers only radial configuration and the discussion would be limited to radial systems. Other types of configuration used are loop type primary feeder, and primary networks. More descriptions on these can be found in [2].

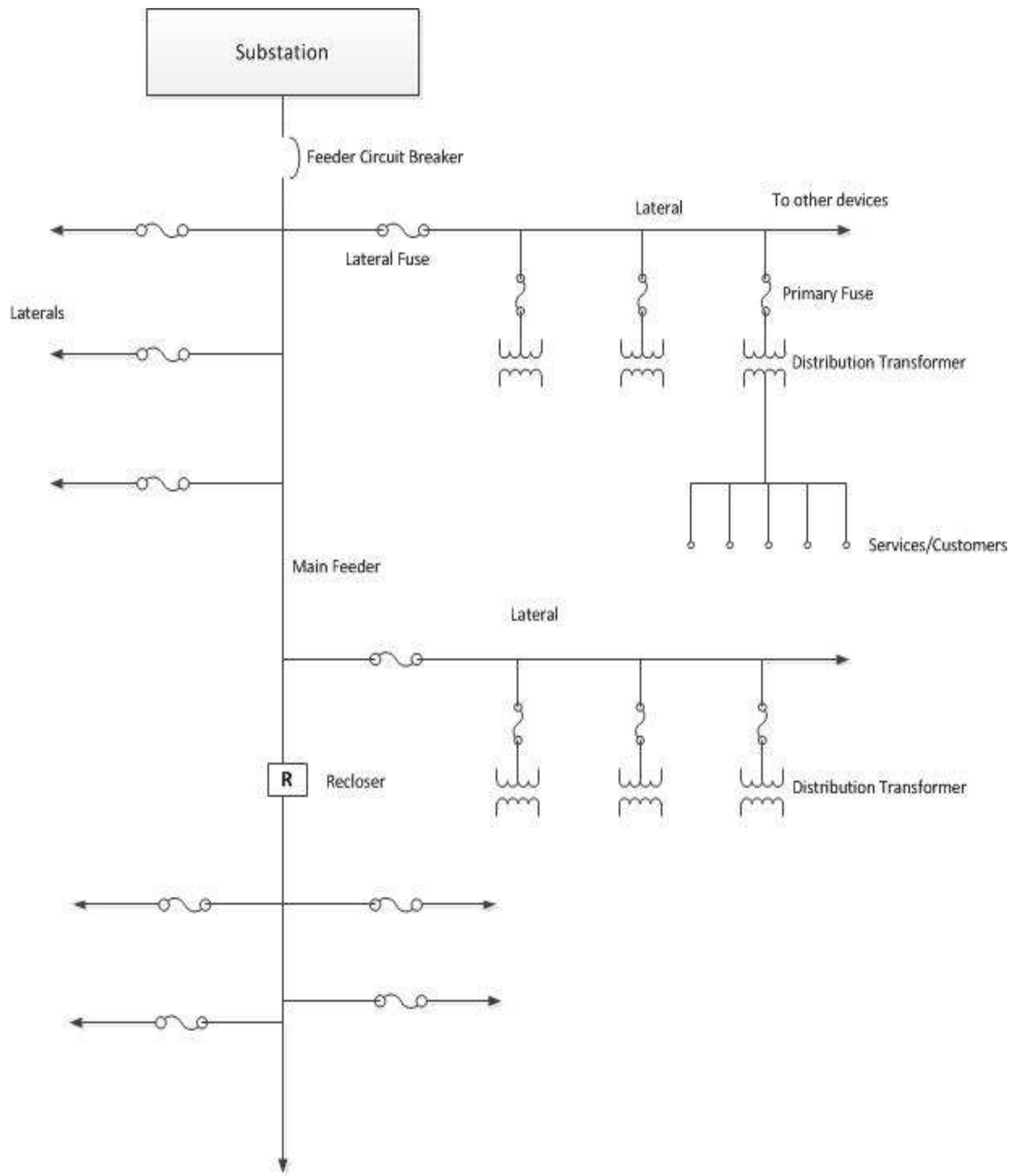
### *1.2.2 Secondary Distribution System*

Secondary distribution system extends from the distribution transformer to the load i.e. consumers. It consists of step down distribution transformers, secondary mains, services and meters at the consumer’s home. The consumers are connected to transformers through the service drops. In the United States, the standard voltage used for supplying single-phase residential loads is 120/240 V and is supplied through 1 phase 3 wire service [2]. The secondary distribution system could either be single phase or three phases depending on the type of load supplied.

## 1.3 Protection System

Faults in distribution system are primary causes of outages. The primary objective of distribution system protection is to reduce the duration of outage and to minimize the number of customers affected by it [2]. Faults in distribution system can be classified as temporary or permanent depending on the time duration of outage. Temporary faults are momentary and are usually cleared within a short period, thus, preventing any outages. Permanent type, which as its name suggests, is permanent in nature and requires attention of the repair crew to restore power. For this work, operation of protective equipment on distribution feeder circuit due to permanent faults is only considered. Figure 1.2 shows a typical radial distribution systems with protective equipment to illustrate the protection schemes within the distribution feeder.

**Figure 1.2 Typical radial distribution systems with protection scheme [2]**



Starting from lowest level in the distribution system, distribution transformer is provided with transformer fuse on its primary side. Most of the laterals connected to the primary (main) feeder are protected by lateral fuse or tap fuse. These are usually installed at the starting point of the lateral or branch. They help protect the circuit by clearing the faults that occur on the lateral. Above the laterals, circuit breakers or recloser are used to protect the feeder. Main circuit breaker is provided at the beginning of the feeder to provide backup protection.

## 1.4 Outage and Outage Management

This section will focus on outages in a distribution system and customer calls/trouble calls as well as the outage management techniques implemented in distribution system.

### *1.4.1 Outages*

Institute of Electrical and Electronics Engineers, Inc. defines outage as “the state of a component when it is not available to perform its intended function due to some event directly associated with that component” [3]. Outage in context of power distribution system is loss of power in distribution system due to expected or unexpected circumstances. Time duration of an outage could depend on number of factors such as the severity of the outage, identification of location of fault, and time taken by the service restoration crew to respond and solve the issue, among others.

### *1.4.2 Outages in Distribution System*

Primary objective of any utility company is to deliver uninterruptable power to its consumers in a reliable and cost effective way. Such uninterrupted power supply however cannot always be guaranteed. Different expected and unexpected circumstances result in loss of power in distribution system or a part of it. Not all the outages are unexpected. Utility might shed power to some feeder or a part of distribution system to conduct routine maintenance work or repairs. In these cases, utility would have a rough idea as to when the consumers can get the power back.

Failure of distribution system in supplying power to the consumers could be attributed to different factors. Pahwa [4] suggested three different reasons that cause outages in a distribution system- intrinsic factors, external factors and human errors. Intrinsic factors include those that are intrinsic in nature to any distribution system such as size of conductors or any manufacturing defects. External factors are those that adversely affect the distribution system externally. This could include weather related factors such as wind, lightning, ice or any external element that could come in contact with the distribution system such as animals and trees. The last factor attributes failure in distribution system to human error such as vandalism, accidents by utility or work crew and vehicular accidents.

### *1.4.3 Effects of Outages*

Electrical power drives both our critical and non-critical loads. As such, nobody appreciates when they are without power. More than inconvenience, there is an issue of environment and public safety at risk. Although critical infrastructures such as hospitals and telecommunications have backup power sources, effects of outage are more than just mere inconvenience. From the consumer's perspective, loss of electricity means the hardship of not having electricity at their home. Commercial and industrial customers might have to shut down their services if power is not restored within a short time. On the other hand, utilities have to face scrutiny from both the consumers and media during times of outages. They face the challenge of determining the location of problem and sending restoration crew to restore the power. In financial terms, utilities lose revenue due to the loss of loads. In addition, there is the added expenditure of repair crew, maintenance hours and equipment replacement. With increasing number of utility companies vying for stronger customer base, higher number of outages and longer restoration hours definitely does not look good for any utility's credentials.

### *1.4.4 Customer Calls/Trouble Calls*

Utility companies typically depend on customers that have been affected by outages to call and inform them of the outage. These trouble calls help in pinpointing the location of outage, and from there the problem can be identified. This part of outage management is called trouble call analysis.

The number of trouble calls that a utility might receive after an outage depends on a number of factors. The factors that could affect the number of incoming trouble calls are total number of customers for the particular feeder, time of the day and weather conditions. As calls come in, the biggest challenge is to determine sufficient number of calls before declaring the location of outage. A common assumption that can be made is that if a feeder supplies a large number of customers, customer calls to be received in event of a problem in the feeder, would also be large. Another factor could be the time of the day when the outage occurs. Less number of calls might be received if the outage occurs late at night when most people are asleep. Weather condition is also another factor that could determines the number of calls coming in. Storms could cause multiple outages in the distribution system [5]. The volume of calls encountered may be more than the typical under these circumstances.

### *1.4.5 Outage Management System*

Outage management system is a broad term that describes a system commonly utilized by electric distribution utilities that helps in management and power restoration during outage. The complexity of a particular outage handling system usually varies from utility to utility. Some could utilize manually intensive system that uses mapping methods to find common points based on escalation and experience of the utility personnel. Others could utilize more complex computerized methods that use improved automation, and automatically retrieve data from Automated Metering Infrastructure (AMI). Either way, the primary purpose of using such system remains the same - effectively aid in prediction of location of fault and restoration of power.

## 1.5 Thesis Motivation and Objective

It is essential that the utility company has a better understanding of the outage before they send in their crew for the restoration work. A system that could help utilities effectively predict outage locations would certainly be valuable. This is especially true in an event where calls coming in within the same timeframe are due to multiple faults within the same distribution circuit. A good call would save considerable amount of time and the power restoration process would be prompt. The complexity of outage management system employed by different utilities to determine the location of fault could differ. Several articles in the area of outage management are available in the literature. Some employ customer calls and network topology [5][6][7] while some employ calls, Automated Meter Reading (AMR) and distribution SCADA system[8].

The use of AMR and distribution SCADA has given utility companies higher level of monitoring and control. However, many energy providers are yet to implement them within their practice. They provide automation and control options at the distribution level and their functions in outage management can only be fringe benefit that can be achieved. Some of the traditional methods used for detecting the location of activated protective device in a radial distribution system such as the escalation method utilize the trouble calls from the customers to predict the location of the operated protective device in the circuit. However, these techniques are based on the premise that only one fault occurs at a part of a distribution feeder at a given time. Direct application would result into conflict especially in cases where outages are due to operation of multiple protective devices.

In a radial distribution system, whenever fault occurs in a part of feeder or lateral taps, the device that is upstream or the device that serves to protect that particular zone activates and opens the circuit. This particular device can be considered as the *operated protective device*. The knowledge of the activated protective device or the operated protective device can help determine the location of the fault. Repair crews could be sent to that particular location to carry out power restoration.

The main objective of this work is to study accurate methods which are automated to locate fault in a timely manner. This method would utilize network topology and customer calls to predict the location of the operated protective device in case of an outage. In other words, such prediction would be based on the knowledge of the least amount of variables i.e. network topology and customer calls. Immune system is used to model and simulate the distribution network because of its resemblance with the immune system. The calls are modeled as antigens and the protective devices are modeled as antibodies. Using differential equation that describes the dynamics of the immune system, operated protective device in the network is predicted. One important thing to note is that the modeling of the distribution network using this technique is independent of the number of customers calling. Thus, it takes into account the unreliability of the customer calls as all customers cannot be expected to make calls during outages. The proposed technique is tested with real distribution circuit and call scenarios. Also, a preprocessing technique is proposed to handle cases with more than a single operated device within the same circuit. This technique could help differentiate between single and multiple outages in the circuit within same time frame. Using the test cases, the technique is refined and verified.

# Chapter 2 - Review of Related Works

In the previous chapter, outages and outage management systems were discussed. Over the course of last twenty years much work has been carried out in the techniques and algorithms to detect location of faults in distribution system based on customer calls [5-10]. However, in terms of amount of research being carried out, this area still lags behind in competition to other areas in distribution systems which are being explored. With deregulation of power systems and number of energy distributors vying for a stronger customer base, efficient outage management techniques could help utilities establish a strong reputation for early restoration of power during outages.

## 2.1 Escalation Systems for Fault Identification

The common objects that are available for carrying out outage location studies are customer calls, AMR and distribution SCADA. Among these, the ones readily available are the calls that come in and the network topology of the distribution system in consideration. Customer calls have been widely used to predict the location of faults in the distribution system. In [6], Walter Scott provides an overview of the project developed to automate the outage restoration based on customer calls and connectivity of the distribution system. He also suggests stages of the restoration that could be automated such as answering calls, logging calls against protective devices, determining the device that is out and providing information to customers about restoration efforts.  Calls are processed using an upstream file containing data about customers, transformers and protective devices that are ordered from the end of the feeder to the substation. When calls come in, they are logged against the transformer that serves them and the upstream protective devices. The proposed method to determine which device is out is based on a downstream file, and the pattern of the calls coming in for a feeder is utilized in determining the device or devices that are out of service.

Martinez and Richards [7] have presented an expert system called Distribution Dispatcher's Expert Assistant (DDEA) that can observe the system on a real time basis, help in diagnosing loss of load in a feeder, analyze the customer calls and provide the operator with the location of the operated protective device. The system utilizes feeder database that includes the feeder's number, primary voltage, map coordinates of all the protective devices in the feeder, transformer's KVA rating, KVA demand of each transformers among others. Beside it also utilizes the SCADA database and the trouble call information. The expert system determines the operated protective device using the numeric module that finds the protective device whose downstream load approximately matches the amount of load lost. This system is designed to execute only when load drop above a certain level occurs. The threshold load drop has been fixed as 150 KVA. The sequence ran by the numeric module starts at the level of distribution transformer corresponding to the trouble call and checks if the load at the call location can be accounted for the amount of load lost. If not, the routine proceeds to the next protection level and so on. This process is repeated until the protective device is found whose downstream load approximately matches the amount of the load lost. It should also be mentioned that the system is designed to work one outage at a time and also assume that two or more different outages would not occur at the same instant on a single feeder.

A common technique used for detecting the location of activated protective device in a radial distribution system is the escalation method. This method is based on the upstream tracing of the distribution circuit starting from the location of the caller. The first common device identified during such upstream tracing is designated as the outage device. The underlying basis for this algorithm is that if calls coming in from customers at different locations share the same upstream device, then the problem could be attributed to the common upstream device. The knowledge of electrical connectivity of the distribution system is essential for implementing this algorithm. As almost all the utilities have this information or can get this, this technique can be combined with customer calls to predict the location of the outage. However, this method has its limitation. The biggest weakness of this method is the assumption that one device outage occurs at a time. This means that during a multiple fault case the algorithm is invalidated and a fault at the service level could possibly be escalated to the feeder breaker.

In [5], Laverty and Schulz modified the escalation algorithm to develop an improved algorithm that provides more accurate estimation about the outage device during a heat storm. This is achieved by defining different rules for escalation based on the type of device that is common to the outage reports. This essentially prevents over escalation of the outage reports. For a distribution transformer two rules have been defined that would determine if the call from a customer connected to it will escalate to transformer or stay at the service level. The first one states that the outage report will escalate to the transformer level only upon receiving a second outage report from a customer connected downstream to the transformer and all subsequent calls below the transformer will be attached to this report itself. The second rule states that for a transformer serving only one customer, the call automatically escalates to the transformer level upon receiving an outage report. Similarly, rules have been defined for lateral fuse or distribution switch and feeder breaker. These rules escalate the outage report to the device in question only when the specified conditions have been satisfied. This basically prevents different outage reports to be treated as a single outage and over escalation.

## 2.2 Use of Knowledge Based Approach, Statistical Methods and Artificial Intelligence

Liu and Schulz [8] have proposed a knowledge based system that locates outages in distribution system using data from customer calls, AMR and distribution SCADA. The proposed technique involves two major steps. The first step includes using traditional outage detecting algorithms or escalation methods to predict the device in question. The method utilized is similar to the one described earlier in this chapter where outages are searched for common point of connectivity to determine the device in question. The second step includes confirmation of these devices by utilizing on demand meter polling that employs the AMR system. A meter polling scheme has also been proposed to determine the procedure of polling the meters and verifying the outages.

In [9], Balakrishnan and Pahwa have proposed a knowledge based approach to evaluate outages related to storms in a distribution system. The proposed Computer Assisted Intelligent Storm Outage Evaluator (CAISOE) depends on placement of binary on-off real time voltage sensors at the distribution feeder and laterals. The number of voltage sensors to be placed in the network depends on the desired resolution of the fault. The voltage sensors transmit the real time voltage symptoms and the semantic network model of faults and the symptoms serve as the knowledge base for the CAISOE system.

Statistical methods have also been implemented in determining the location of outages and restoration times in distribution system. In [10], Rodrigo and Pahwa have presented an outage location methodology based on statistical hypothesis testing. The input measurement consists of the time of outage at customer's end that could be transmitted through devices installed at consumer's home. Noisy data on the time of the outage is used and by utilizing a statistical inference routine, the outage location and the type of the fault is predicted.

Time of outage restoration is the estimated time that would elapse before the utility could restore circuit from the outage and customers would get the power back. It is crucial for utility to keep their customers knowledgeable about the ongoing restoration effort and be able to give them a time frame it would take do get the power back, when asked. Chow et al.[11] have proposed a method to determine the time of outage restoration using statistical methods. They present an approach that utilizes statistical techniques to analyze the time of restoration data with respect to several factors that could determine the restoration time such as time, weather conditions, cause of outage, protection device activated etc.

Similarly, Artificial Intelligence (AI) has also been used to solve outage problems in distribution system. Lu et al.[12] have proposed a system that helps in diagnosing faults in distribution system utilizing customer trouble calls by implementing neural network approach. Their approach uses pattern of trouble calls to determine the device out or devices out if more than one device caused the outage. They employ a three level neural network model utilizing the back propagation method to carry out the training.

# Chapter 3 - Modeling of Distribution System

This chapter discusses immune system modeling technique that is experimented for modeling the outages and determining the location of the operated protective devices in the distribution system.

## 3.1 Defining Outages and Points of Interests

Initial modeling of distribution system required clear definition of outages in order to distinguish the level at which it occurred. Outage is defined as a condition where all electrical power beyond a particular point would be lost. A radial distribution system follows a tree structure with all load ends having the same source of power that could be traced to a single point upstream in the circuit. Starting from the lowest level in the distribution circuit, the first point of concern would be the service level i.e. the customer. A single call in itself could well represent a service level problem i.e. problem within customer's house, and not have anything to do with fault in the distribution system. A distribution transformer that supplies power to consumer can feed any potential number of homes. This number could range from a single consumer to any other fixed number that the utility thought would be technically feasible. This portion of the distribution circuit is called the secondary distribution system and extends from the distribution transformer to the consumer's home. Whenever a customer loses power and calls the utility company, they are typically linked with the distribution transformer that serves them. One important factor to consider is that during an outage not all of the customers affected by the fault can be expected to call. It could be very well possible that nobody is at home to make the call or the outage could have occurred at early morning hour, or the customer assumed that the utility knows about the outage. Whatever the case maybe, expecting many people to call during such incidence is impractical. To account for this, all customer calls are associated with the distribution transformer that serves them. This means that rather than treating each customer call as separate, calls from customers will be linked to the distribution transformer that serves them. This creates no practical problems for the field crew because since the services are close to the distribution transformer, the utility employee would be able to locate the problem from there. Distribution transformers are protected on the primary side by a fuse. Any problem on the secondary distribution system would have operated the fuse on the transformer. On tracing upstream, other points of concern would be lateral fuses, circuit breaker and recloser.

## 3.2 Immune System

Immune system is a highly complex system. The scope of this work is to only use the general model of the immune system. Hence, detailed technicality of the algorithm and the principals governing biological system would be excluded. Firstly, a general overview of how the immune system works is discussed.

The human immune system is a complex biological system that primarily functions to recognize and eliminate foreign materials. It constitutes of a network of cells and molecules that interact with each other and recognizes foreign elements [13]. Foreign elements that enter the human body are called antigens. The components of the immune system that are responsible for detecting the antigens are called antibodies.

The antibodies do not recognize the antigen as a whole object but recognize small regions of the antigen called epitopes. For an antibody to recognize an antigen it must bind with the epitope of the antigen through its binding region called paratope. Not only can antibodies recognize antigens but they are also able to recognize antibodies with the right epitope. This epitope property of antibody is called idiotope [13].

## 3.3 Immune System Algorithm

There are many equations that explain the dynamics of the immune system. Farmer et al. [14] describe the dynamics of an idiotypic immune system by the following set of differential equations:

$$\frac{dx_i}{dt} = c\left[\sum_{j=1}^{N} m_{ji} x_i x_j - k_1 \sum_{j=1}^{N} m_{ij} x_i x_j + \sum_{j=1}^{n} n_{ji} x_i y_j\right] - k_2 x_i \tag{3.1}$$

In the above equation, $N$ represents the number of antibodies with concentrations $\{x_1, x_2, \ldots, x_N\}$, $n$ represents the number of antigens each with concentrations $\{y_1, y_2, \ldots, y_n\}$ and C is the rate constant. The first term in the above equation describes the stimulation of the paratope of an antibody *i by* the epitope of antibody of type *j.* Similarly, the second term represents the suppression of antibody of type *i* when its epitope is recognized by the paratope of antibody *j.* The term $K_1$ represents the possible inequality between stimulation and suppression. The third term models the stimulation provided by the recognition of the antigen *j* having concentration of $y_j$ by the antibody of type *i* having concentration of $x_i$ . The last term models the death rate in absence of any interaction. The term $K_2$ defines the death rate.

## 3.4 Modeling Distribution System

The goal of this work is to model the distribution system in a simple way such that it is possible to determine the location of the outage device using the least available data. As mentioned earlier, circuit topology and customer trouble calls are the data that is readily available to the utility company. This factor is considered for modeling of the distribution system.

### *3.4.1 Modeling Protective Devices*

Protection of a distribution system is done by different protective devices. The protective devices that are considered for this work are reclosers, circuit breakers, lateral (tap) fuses and distribution transformer fuses. The protective devices are modeled as antibodies. They are analogous to the antibodies within the immune system as they essentially protect the distribution circuit from fault conditions. As the goal of this work is to determine the operated protective device during fault condition, only protective devices will be taken into consideration.

The protective devices have been designated different levels based on their location within the distribution system. All primary feeder circuit breaker and recloser are designated as first level devices. The fuses connected to the primary side of the secondary distribution transformer are designated as third level devices. Consequently, all the protective devices that operate between these two levels are designated as second level devices. This generally includes the lateral (tap) fuses serving the laterals.

### *3.4.2 Modeling Customer Calls*

Whenever a utility company gets a trouble call from one of its customers, it signifies a loss of power at some part of the distribution system. From the perspective of utility company, a single customer call could mean problem at the service level or it could be the first call of a large number of calls to follow. In either case, it represents an aberration from the normal supply of power.

The customer calls are modeled as antigens that stimulate the protective device in their zones within the distribution network. In other words, they are modeled as foreign elements within the system that activate the protective devices that lie upstream of them in the network.

### *3.4.3 Modified Algorithm*

As discussed in Section 3.3, the differential equation that describes the dynamics of idiotypic network takes into accounts the stimulation of paratope of antibody of type *i* by the epitope of antibody *j*. In this modeling, suppression of antibody when it is recognized by another antibody and the stimulation provided by the recognition of antigens by the antibodies is only taken into consideration. Hence, the term that accounts for the stimulation of paratope of the antibody by epitiope of another antibody is disregarded and using Equation 3.1, Equation 3.2 is obtained. Equation 3.3 shows the general representation of Equation 3.2.

$$\frac{dx_i}{dt} = c\left[ -k_1 \sum_{j=1}^{N} m_{ij} x_i x_j \; + \sum_{j=1}^{n} n_{ji} x_i y_j \right] - k_2 x_i \tag{3.2}$$

$$= c\left[ -(Suppression) \; + \; (\; Stimulation) \right] - (Death\ rate) \tag{3.3}$$

The left side of the Equation 3.2 describes the change in the concentration of the $i^{th}$ protective device with time. It is a function of the stimulation provided by the customer calls coming in and the net suppression effect from the protective devices within the network. This is used to determine the problematic device in the network by observing the concentration of a particular device after calls are received.

### *3.3.4 Stimulation Matrix*

The stimulation term in Equation 3.3 is based on the stimulation provided by the recognition of customer calls by the protective devices. The stimulation provided to a protective device is determined by the stimulation matrix $n_{ji}$. The stimulation provided to a protective device is based on the customer calls coming in. This is implemented through the stimulation matrix. In order to establish the elements of the matrix, it should be first defined how much stimulation a device receives based on the number of calls coming in.

The stimulation received by any $i^{th}$ protective device upstream is defined as a function of the number of devices in between the device and the call-originating customer. Equation 3.4 describes the stimulation matrix elements.

$$n_{ji} = \frac{\alpha}{\beta^{p}} \tag{3.4}$$

In Equation 3.4, $p$ is the number of devices between device $i$ and call originating device $j$. The maximum stimulation that can be provided to any device is $\alpha$ and is provided when the denominator is equal to one i.e. $p = 0$. What this means is whenever a call registers, the maximum stimulation is provided to the first fuse upstream of the call-originating customer. For all the other upstream protective devices, the stimulation is decreased by a factor of denominator $\beta$ depending on its device distance from the call-registering device.

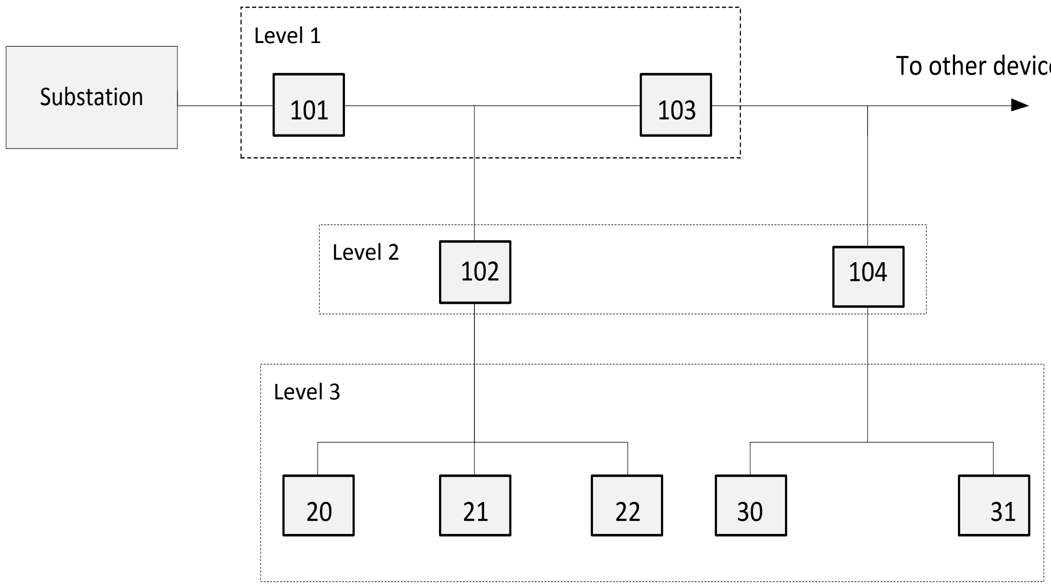
The value of $\alpha$ depends on the maximum value of stimulation desired. A value of 2 is considered as the maximum stimulation to be provided to any protective device. As the stimulation of the other protective devices is decreased by a factor of the denominator, the value of $\alpha$ can be chosen as other values as well depending on the value of the maximum stimulation desired. A large value of $\beta$ will decrease the stimulation provided to the upstream devices by a higher factor while a value less than 1 will cause the upstream devices to receive more stimulation than the first upstream device of the call-originating customer. On experimenting with different values, the optimum value of $\beta$ is found to be 1.1 from the test cases. Using this value, the stimulation provided to the second upstream device is around 90% of the maximum stimulation. Similarly, the stimulation provided to the third upstream device is around 80% of the maximum value.

### *3.3.5 Suppression Matrix*

The suppression term in Equation 3.2 represents the suppression of a protective device by another protective device. The amount of suppression any particular protective device receives is determined by the other protective devices in the network that recognize the outage call. This is implemented through the use of suppression matrix $m_{ij}$ which defines the suppression between devices *i* and *j*. As with the stimulation factor, the level of suppression between any two protective devices within a network needs to be defined first. The suppression between two devices is considered to be a function of difference in levels between those two. Each protective device has been designated a device level based on its type and functionality within the distribution network.

This is explained more clearly in Figure 3.1. The primary purpose of keeping suppression as a function of difference in levels is to make sure that devices at the same level suppress other level devices with equal strength, and not just based on their location within the network. In sample circuit given in Figure 3.1, device 30 will suppress device 21 with suppression equal to that of its suppression of device 31.

**Figure 3.1 Sample circuit showing different level devices**




The suppression term between two protective devices is determined by the Equation 3.5.

$$m_{ij} = \frac{\gamma}{\delta^q} \qquad (3.5)$$

In Equation 3.5, $q$ represents the difference in levels between devices $i$ and $j$. The maximum suppression that a device provides is $\gamma$ and it is provided to the devices that are in the same level as it is. For any device that is immediately one level up, the suppression provided is decreased by a factor of $\delta$. A large value of $\delta$ will decrease the suppression for the different level devices by a large factor. The value of $\gamma$ depends on the maximum suppression that is desired. For the test simulation cases, this is assumed to be 1. The optimum value of $\delta$ is found to be 2 from the test cases.

## 3.4 Data Files

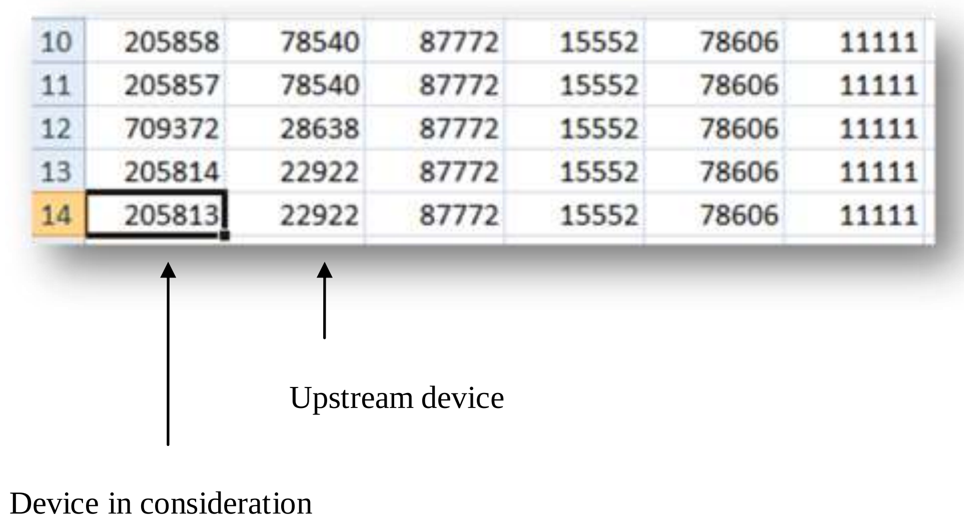
The test data was obtained from Westar Energy. The distribution circuit configuration was obtained for one of their feeder in Manhattan, Kansas. In addition, a record for customer calls that came in for two years along with the details of the operated protective device that was discovered by the field restoration crew was obtained. One of the biggest challenges would be to utilize the available data that employs ease of addition of new devices and removal of old devices in circuit and to maximize search speeds. A six-digit number represents the names of the level three devices. Similarly, the names of the level two and level one devices are designated by a five-digit number. Data was stored in a Microsoft Excel format that could be easily accessed from MATLAB.

The data files were kept in .xlsx (Microsoft Office Excel) format. Altogether, there were four data files that were created for the initial algorithm and simulation.

### *3.4.1 Circuit Configuration*

This file contains the circuit topology of the feeder in consideration. As the scope of this work is limited to radial distribution system, an approach has been followed that will allow us to easily document a particular device and allow flexibility to add or remove any devices with ease. Each individual level one device is allocated a single row in the data file. The first column represents the device in consideration. It is followed by its upstream protective device in the next right column and so on. Hence, the maximum width of this data file represents the device depth of the system. One major advantage of this approach is that any addition of new customers would not affect the data table. An example is shown in Figure 3.2. The highlighted device represents the device in consideration. The device number 22922 on the adjacent column to the right on the same row represents the upstream device of the device in consideration. Similarly, numbers on the following columns of the same row represent the following upstream devices.

**Figure 3.2 Circuit Configuration datafile**



| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 205858 | 78540 | 87772 | 15552 | 78606 | 11111 |
| 11 | 205857 | 78540 | 87772 | 15552 | 78606 | 11111 |
| 12 | 709372 | 28638 | 87772 | 15552 | 78606 | 11111 |
| 13 | 205814 | 22922 | 87772 | 15552 | 78606 | 11111 |
| 14 | 205813 | 22922 | 87772 | 15552 | 78606 | 11111 |



### *3.4.2 Device Level*

This file specifies the levels of all the devices within the distribution network. It also gives the comprehensive list of devices in the system. Addition of new devices and removal of any old devices can be done easily. Figure 3.3 shows an example of the file. The first column contains the device name and the second column contains its designated level.

**Figure 3.3 Device Level datafile**

| | | |
|---|---|---|
| 24 | 22878 | 2 |
| 25 | 22920 | 2 |
| 26 | 22922 | 2 |
| 27 | 23140 | 2 |
| 28 | 23141 | 2 |

Device name Designated level

### *3.4.3 Device Number*

This file specifies the number of devices directly beneath a particular device. This file is utilized while determining the state of any device based on the calls received.

**Figure 3.4 Device Number datafile**

| | | |
|---|---|---|
| 19 | 22808 | 2 |
| 20 | 22809 | 6 |
| 21 | 22870 | 5 |
| 22 | 22876 | 2 |
| 23 | 22877 | 2 |

Device name Number of devices directly beneath

## 3.5 Simulation

The simulation is done using MATLAB. The call record data was used to build a number of test cases. The calls were considered for a period of one and a half hour. What it essentially means is that a consecutive call coming in within a one and half hour time frame would be considered in the processing, and any call after that would be disregarded for that particular case. In cases where calls are received after the problem has been fixed, they are considered as separate instances. Outages in which the operated protective devices were identified by the field crew were only considered.

In this chapter, two cases are presented for illustration, and to identify and remedy a potential problem with the proposed method. Figure 3.5 below shows the part of the distribution feeder in consideration and the call scenario for the case. Figure 3.5 includes only the protective devices associated with this case excluding any other devices that may be present in the same part of the distribution network. Device number used for identification purpose is mentioned alongside the device with number of devices directly beneath it inside the parenthesis. The call symbol represents the number and location of the placed calls.

**Figure 3.5 Circuit diagram and call scenario for 06/18/2010**

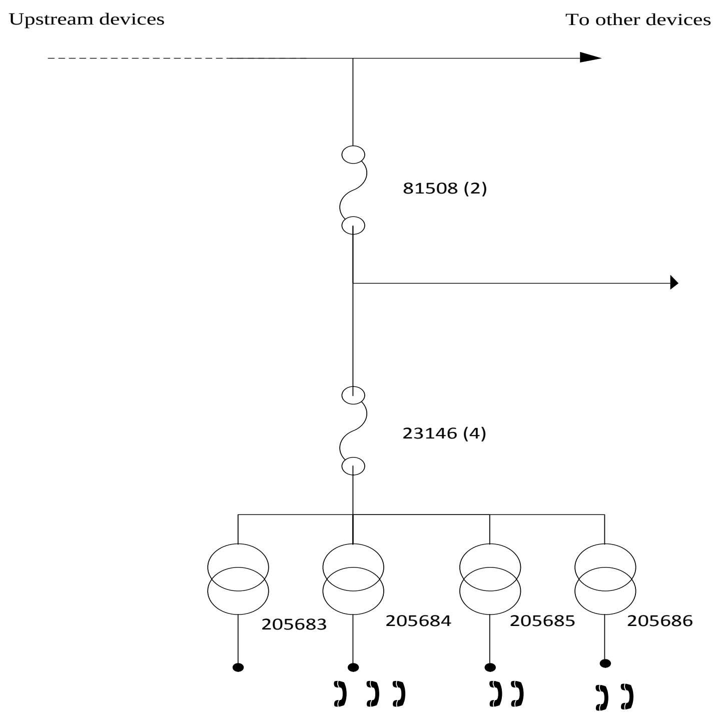


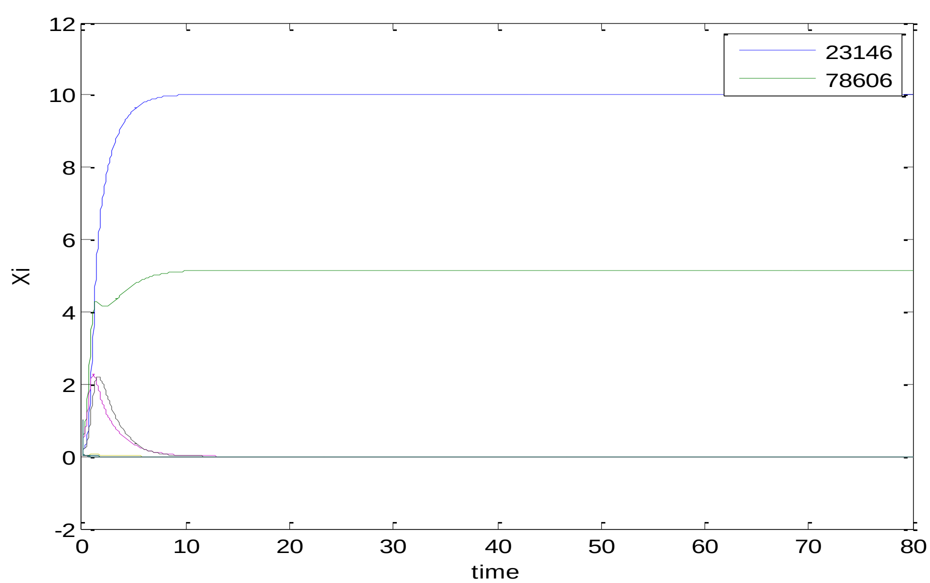

**Table 3.1 Events of 06/18/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205684 | 6/18/10 8:19 |
| 205684 | 6/18/10 8:20 |
| 205684 | 6/18/10 8:25 |
| 205686 | 6/18/10 8:26 |
| 205686 | 6/18/10 8:28 |
| 205685 | 6/18/10 8:33 |
| 205685 | 6/18/10 8:35 |

The call symbol next to the transformer denotes that call was placed from a customer supplied by that particular distribution transformer. Total number of symbols represents the total number of calls received. From the field data, the operated protective device was found to be device **23146**.

For simulation, initial parameter values of Equation 3.2 were defined first. In addition, the change is simulation result on varying these parameters is studied. Initial value of the rate constant $C$ is considered as 0.5. Also, the value of inequality between suppression and stimulation ( $K_1$ ) is taken as 1 assuming equal suppression and stimulation. The value of the death rate $K_2$ is also initialized as 0.7. The differential equation is solved using Runge-Kutta method using MATLAB's inbuilt function ODE 45. The simulation result in Figure 3.6 shows the concentration of different devices plotted against time after solving the differential Equation 3.2. The concentration of all the protective devices in the circuit is initially considered to be 1. Changes in concentration levels upon receiving the calls are observed. The final concentration at the end of the time step is checked to see which device has the highest value. Only top two devices that have the highest values have been labeled in Figure 3.6.

**Figure 3.6 Simulation result for 06/18/2010**

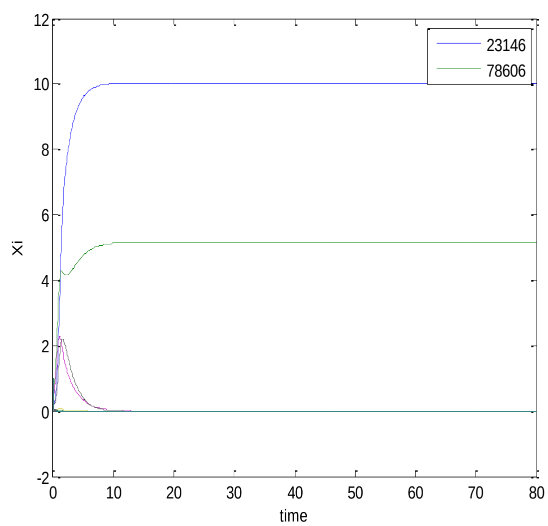


The simulation result shows that the device with the highest concentration is device **23146** which is also the operated protective device as determined from the field reports.

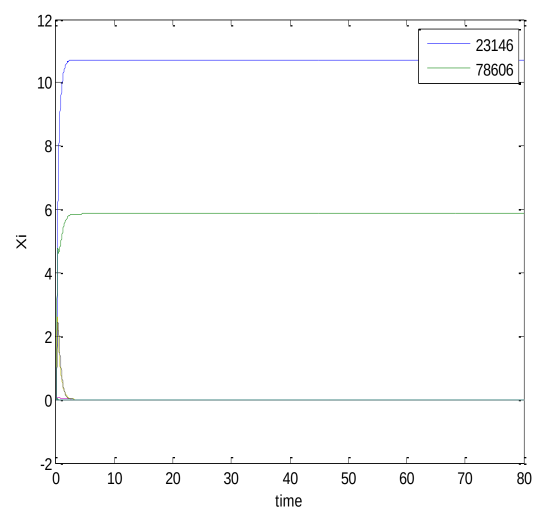
It was essential to see how different values of parameters in Equation 3.2 would affect the simulation result. The previously mentioned values were selected after testing the simulation results with different parameters. Figure 3.7 shows the variation in simulation result on changing the rate constant *C* while keeping other parameters constant.  It is observed that the variation only has effect on the transient portion of the curve while still giving the same results.

**Figure 3.7 Simulation results for varying rate constant**

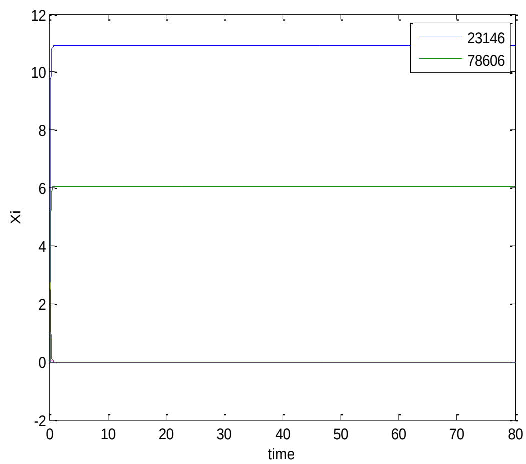
*C*=0.5



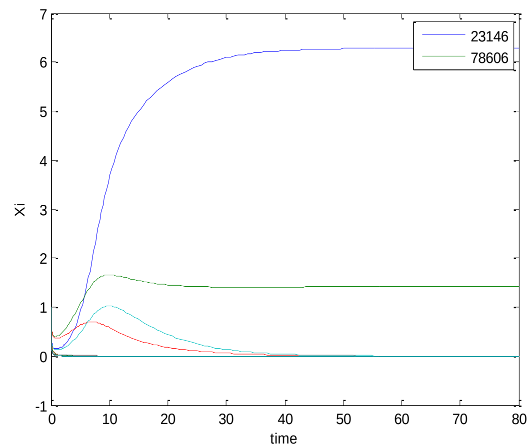

*C*=2



*C*=10



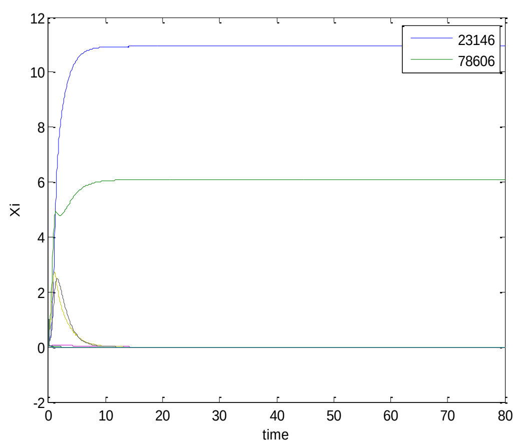

*C*=0.1



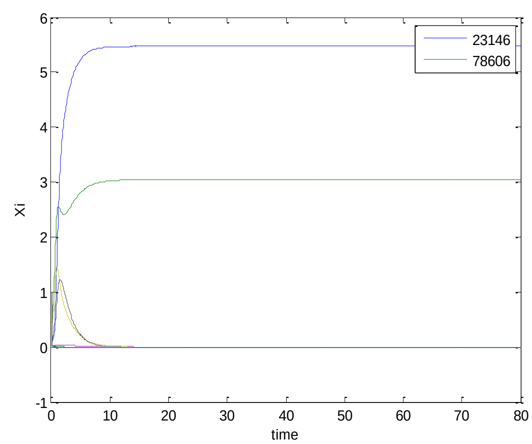

Similarly, the values of constant $K_1$ and $K_2$ were changed to observe changes in the simulation results, if any. Although there was variation in the nature and magnitude of the curves, the predicted result was same in each case. Figure 3.8 and Figure 3.9 show the variation in the values of $K_1$ and $K_2$ and obtained simulation results. All the additional simulations are done with $C$ = 0.5, $K_1$ = 1 and $K_2$ = 0.7.

**Figure 3.8 Simulation results for varying $K_1$**

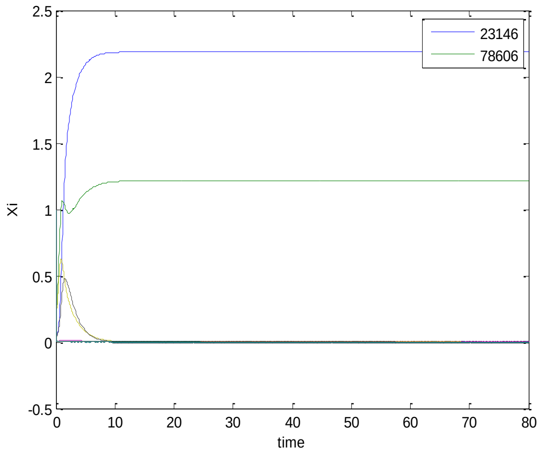
$K_1$=1




$K_1$=2



$K_1$=5




$K_1$= 0.2

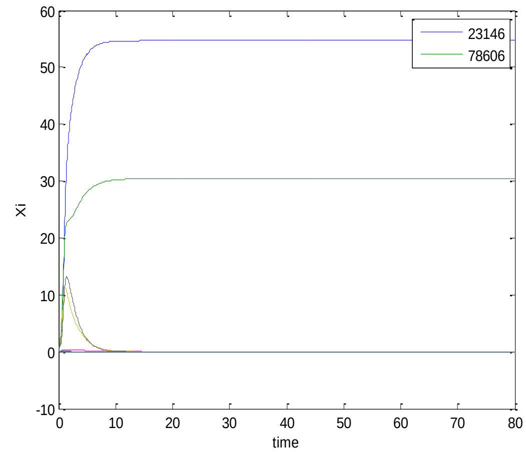
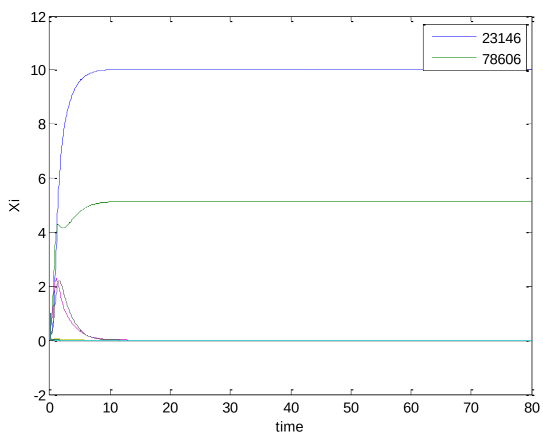
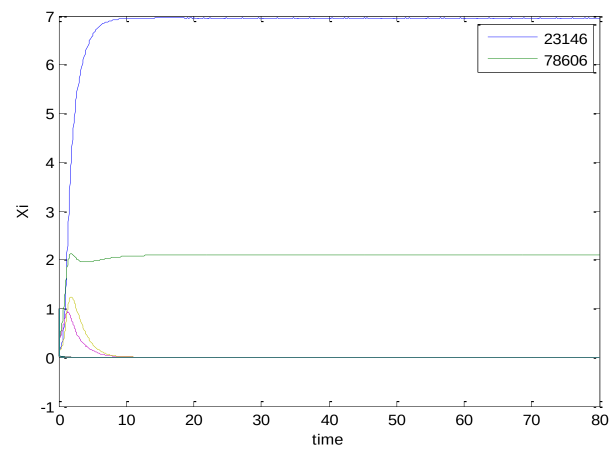



**Figure 3.9 Simulation results for varying $K_2$**

$K_2$= 0.7

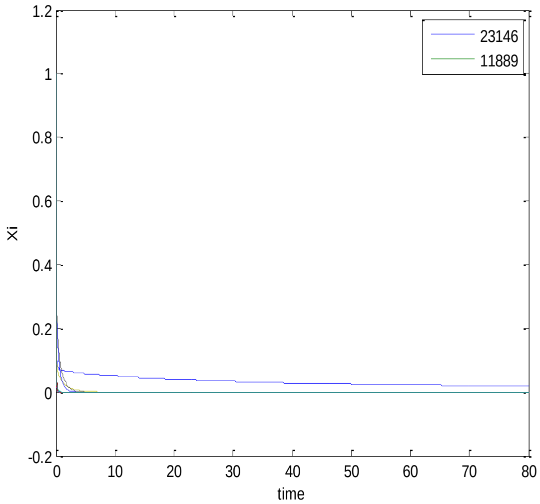


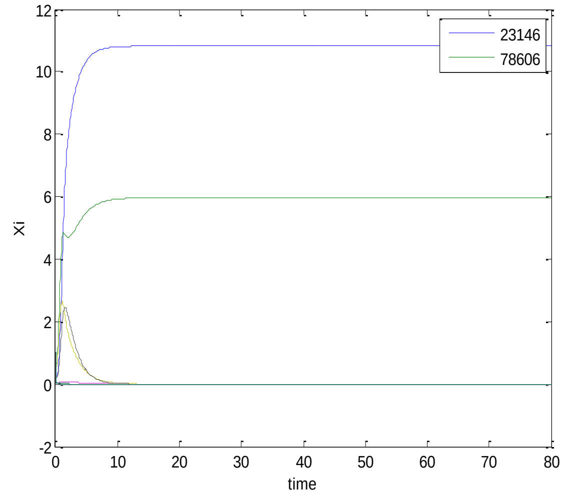

$K_2$= 3



$K_2$= 7

$K_2$=0.1




In some cases, customer calls coming in could signal single or multiple outages within the same distribution system. It was found that the direct application of this method results in conflict in resolving cases with multiple outages that occurred within the same time frame in the same distribution circuit. Figure 3.10 shows one such case. There are two different outages in the same distribution circuit within the same time frame.

**Figure 3.10  Circuit diagram and call scenario for 07/03/2009**

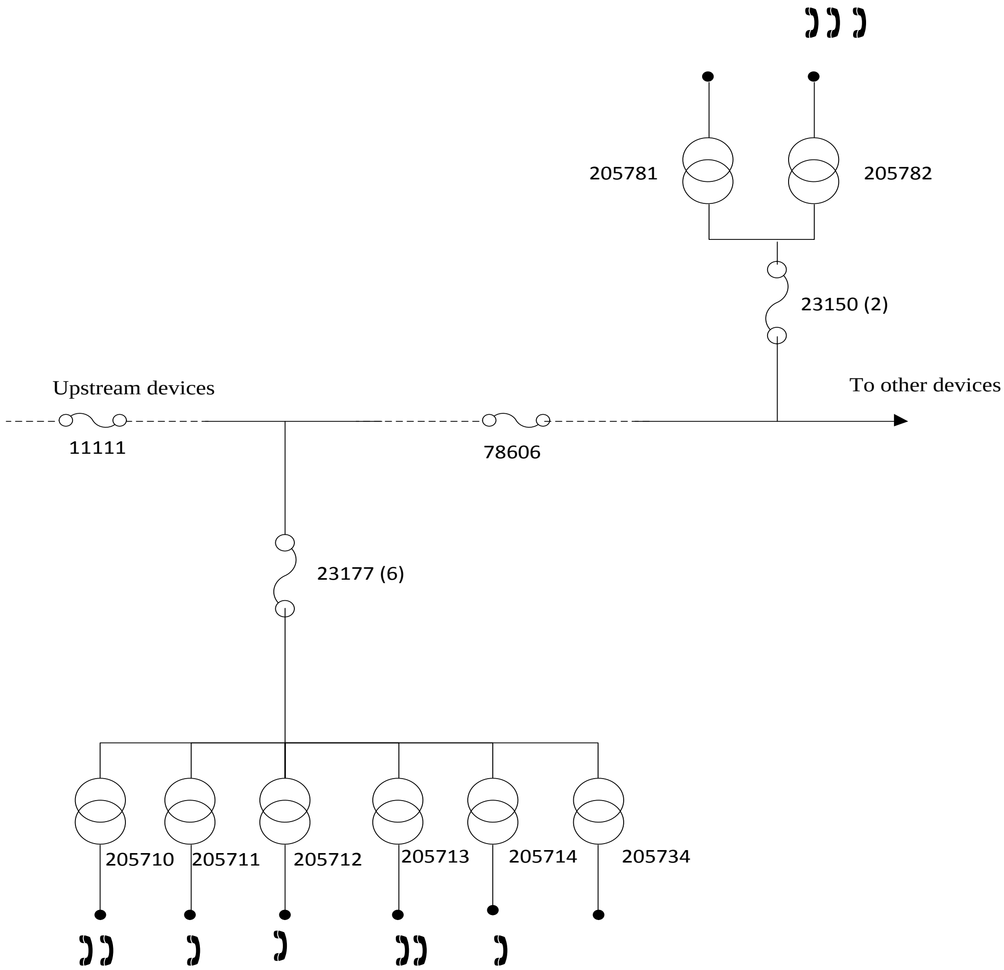
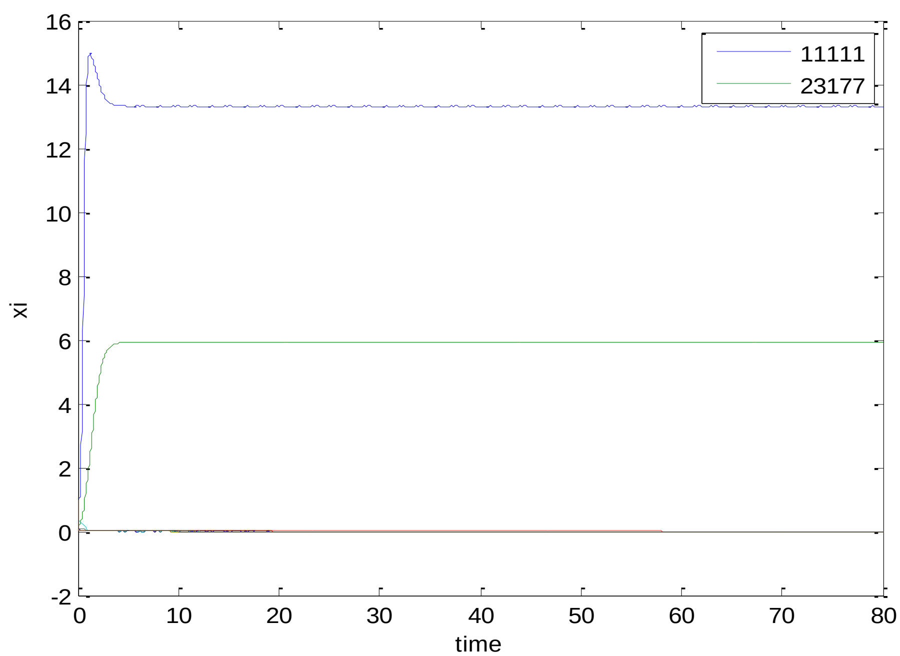



**Table 3.2 Events of 07/03/2009**

| Device ID | Date/Time of the Call |
|---|---|
| 205782 | 7/3/09 21:48 |
| 205782 | 7/3/09 21:49 |
| 205713 | 7/3/09 21:56 |
| 205710 | 7/3/09 22:00 |
| 205713 | 7/3/09 22:01 |
| 205712 | 7/3/09 22:12 |
| 205714 | 7/3/09 22:12 |
| 205711 | 7/3/09 22:27 |
| 205782 | 7/3/09 23:09 |
| 205710 | 7/3/09 23:54 |

From Table 3.2, it is hard to distinguish if the calls coming in are due to single or multiple outages. The two operated devices identified in the field report were device **23177** and device **205782**. However, direct application of the proposed method results in conflicting device showing up as the problematic device in call scenarios like the one mentioned in Figure 3.10 where calls coming in are due to multiple outages within the same time frame in same circuit. The simulation results are shown in Figure 3.8 where device 11111 (an upstream device) has been reported as the problematic device.

**Figure 3.11 Conflicting simulation result for 07/03/2009**




Therefore, a pre-processing technique was developed to separate the calls due to multiple outages. This processing technique is described in the Chapter 4.

# Chapter 4 - Call Analysis

From the perspective of utility companies and energy providers, calls coming in could be anything- a single outage or a multiple one. Storms are infamous for causing multiple outage problems in a distribution system. In this chapter, a simple yet efficient way to assist utility in differentiating sources of outages i.e. single or multiple is devised. This would definitely allow the utility to get a better view of the problem and then proceed from there onwards.

## 4.1 Defining Level and State of Operated Protective Devices

Operated protective devices are the protective devices that are opened due to fault or abnormal condition in some section of the distribution system. Based on the location of fault, they could be any protective device from a tap fuse to a feeder breaker. Determining the operated protective device can help utility personals to predict the location of faults in the distribution system. One method of determining if incoming calls are due to single or multiple outages is to group calls. However, care must be taken with such approach because classifying a single outage as multiple and vice versa could lead to added confusion and prolonged restoration efforts.

In order to classify the incoming calls, it is essential to define the state of the protective device in the distribution network. The protective device under consideration in the network could either be in a ‘0’ state for a normal device or in a ‘1’ state if a device is suspected to have operated. The terms 0 and 1 were used in order to explain the approach in a more lucid way and can be substituted with any other suitable terms. The state of all the protective devices in the distribution feeder is assumed to be ‘0’ initially.

### *4.1.1 Level One Devices*

All of the feeder circuit breaker and recloser are considered as level one device. Their state is initially set as ‘0’. The state of level one device is changed to ‘1’ if the percentage of devices connected directly beneath it with a state ‘1’ exceeds the defined threshold.

### *4.1.2 Level Two Devices*

Level two devices are the intermediate devices between level one and level three and include the lateral fuses. As with level one device their state is initially set as ‘0’. Their state changes to ‘1’ only if the percentage of devices connected directly beneath it with a state of ‘1’ exceeds the specified threshold.

### *4.1.3 Level Three Devices*

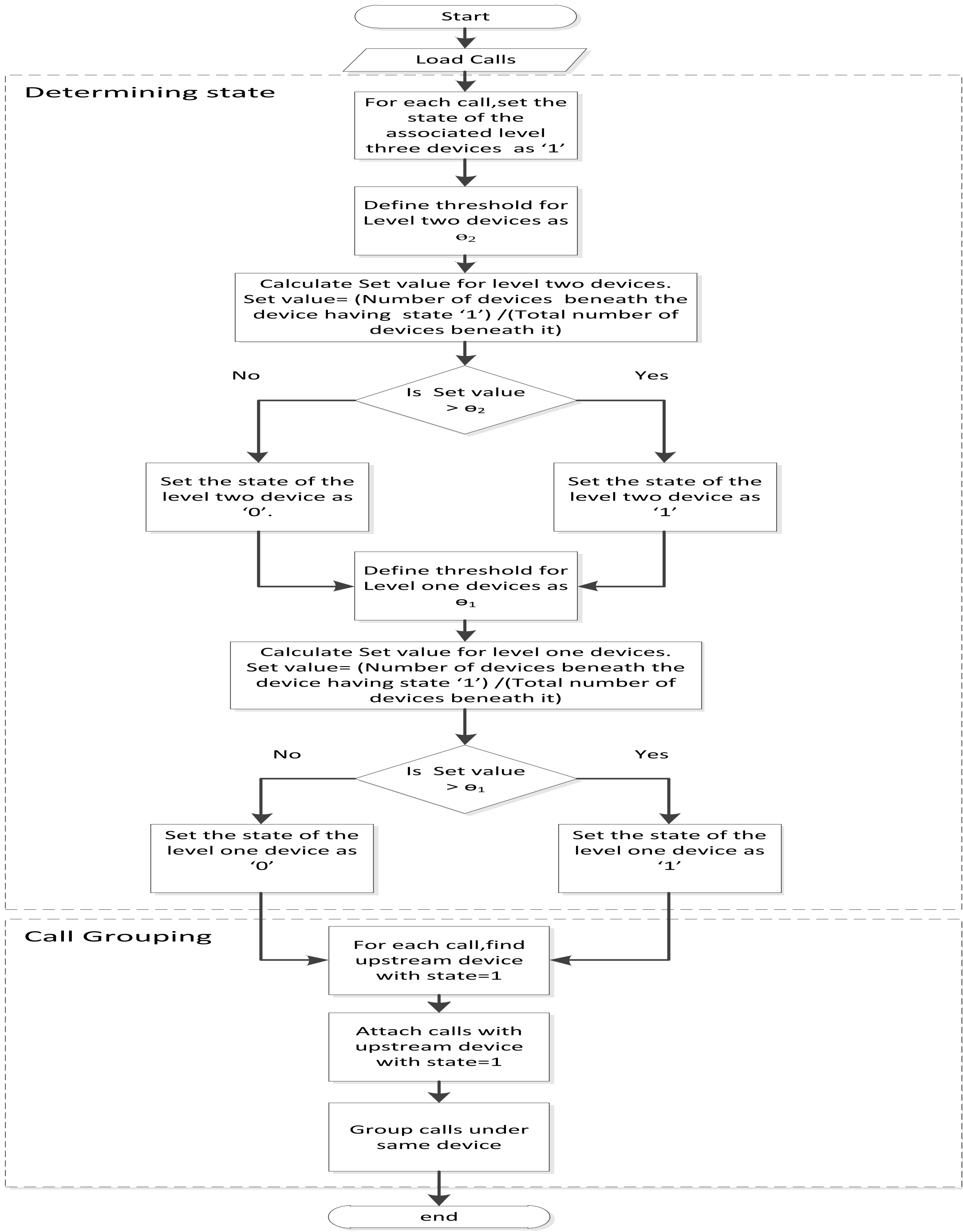
Level three devices are the distribution level transformer fuses that are linked with the customer calls. Initial state of these devices is ‘0’. However, a single call from a customer served by it changes its state to ‘1’.

## 4.2 Call Grouping Algorithm

Call grouping algorithm is a simple approach that helps sort the calls that come in from different location within the same considered period. It essentially allows us to differentiate the incoming calls based on the outages. The process starts off by setting the state of level three device that are associated with the calls as ‘1’. As previously mentioned, a single call from a customer is sufficient to change the status of level three devices to state ‘1’. Any subsequent calls that get reported from customers served by the same device will not affect the state.  Once all calls that have been registered have been processed, the next step is to determine the state of the level two devices.

The state of all level two devices is initially set to state ‘0’ and would only be changed to state ‘1’ when certain percentage of the devices beneath it have been registered to be in a state ‘1’. The threshold criteria that gets used acts as a controller for preventing over escalation or under escalation. If  large number is used as a threshold, a single outage could be grouped as multiple outages, and similarly, if too small a number were used then  multiple outages could be grouped as a single outage. Similar approach is followed for level one devices as well. After all the state of the devices have been determined, calls are grouped based on the state of the upstream device. The flow chart in Figure 4.1 explains the process.

**Figure 4.1 Call Grouping Algorithm flowchart**



## 4.3 Results

Utilizing the outage data from Westar Energy, sixteen test cases were constructed. The initial objective of utilizing the cases is to see what threshold percentage would help in classifying the calls correctly for level one and level two devices. The number of test cases is kept to sixteen because other cases replicated the same configuration and classification as these cases.

In this section, test carried out with calls from outage of 07/03/2009 with multiple operated devices is presented to demonstrate this approach. This test case was selected because two different outages were caused within the same time frame in the same distribution circuit. The threshold level for level one and two devices was set as 50% and 20% respectively. The algorithm successfully helped in classifying the calls into two different groups as shown in Figure 4.2.

**Figure 4.2 Call grouping for 07/03/2009**

| *Device ID* | *Date/Time of the Call* |
|---|---|
| 205782 | 7/3/09 21:48 |
| 205782 | 7/3/09 21:49 |
| 205713 | 7/3/09 21:56 |
| 205710 | 7/3/09 22:00 |
| 205713 | 7/3/09 22:01 |
| 205712 | 7/3/09 22:12 |
| 205714 | 7/3/09 22:12 |
| 205711 | 7/3/09 22:27 |
| 205782 | 7/3/09 23:09 |
| 205710 | 7/3/09 23:54 |

| *Device ID* | *Date/Time of the Call* |
|---|---|
| 205713 | 7/3/09 21:56 |
| 205710 | 7/3/09 22:00 |
| 205713 | 7/3/09 22:01 |
| 205712 | 7/3/09 22:12 |
| 205714 | 7/3/09 22:12 |
| 205711 | 7/3/09 22:27 |
| 205710 | 7/3/09 23:54 |

| *Device ID* | *Date/Time of the Call* |
|---|---|
| 205782 | 7/3/09 21:48 |
| 205782 | 7/3/09 21:49 |
| 205782 | 7/3/09 23:09 |

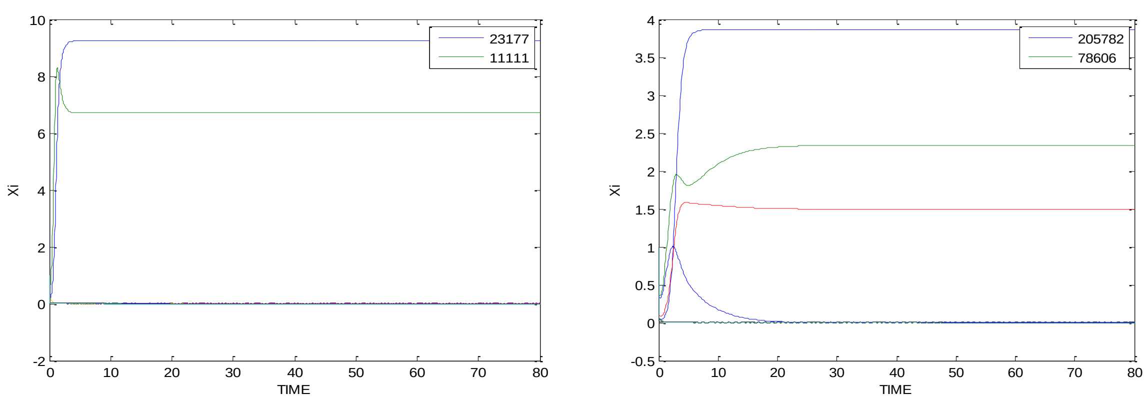
The state of all devices is considered to be ‘0’ in the beginning. Table 4.1 shows how the state of the different devices changes with each incoming call. The calls in Table 3.1 have been numbered from 1 to 10. For level three devices, states change from ‘0’ to ‘1’ as calls are registered. For level two and level one devices, state changes from ‘0’ to ‘1’ only when threshold limit is reached. The highlighted cell shows the change in state from ‘0’ to ‘1’ for that particular device.

**Table 4.1 Variation of device state with incoming calls**

| Calls | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Device ID** | | | | | | | | | | | |
| **Level 3** | | | | | | | | | | | |
| 205710 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 205711 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 205712 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 205713 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 205714 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 205734 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205782 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 205781 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Level 2** | | | | | | | | | | | |
| 23177 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23150 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Level 1** | | | | | | | | | | | |
| 78606 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The two operated devices were then easily identified using the proposed technique.The devices were determined to be device **23177** and device **205782** as shown in Figure 4.3 that corresponds with the devices reported by the field report.

**Figure 4.3 Simulation results for 07/03/2009**



One important aspect of this approach is the selection of right number to use as threshold percentage for different level devices. It is kept in mind that even though there is an outage, not all customers can be relied to make the call.

### *4.3.1 Level Three Device Threshold*

Threshold limit does not need to set for level three device with previously mentioned assumption that a simple call associated with level three device is sufficient to change its state from state '0' to state '1'.

### *4.3.2 Level Two Device Threshold*

For level two device, using high number as threshold would mean that calls would not be grouped correctly and would be limited to a lower level. The information about the calls coming in for the sixteen cases, and whether they were single or multiple outages was available. The cases were tabulated with different threshold limit to check the values that gave the right classification. Threshold value for level two devices was determined first while keeping the threshold value of level one device at a fixed value. Table 4.2 shows the cases and classification used for determining the threshold value of level two devices and its correct or incorrect grouping based on the test results and field data. The optimum value of level two devices that worked for all sixteen cases was found to be 20%. What this basically means is for level two devices, 20% of the directly downstream devices should be in a state '1' for the state of level two device to change to state '1'.

**Table 4.2 Variation of threshold percentage for level two devices for different cases**

| Threshold(%) | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Case Number | | | | | | | | | | |
| 1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 4 | Incorrect | Incorrect | Incorrect | Incorrect | Incorrect | Incorrect | Correct | Correct | Correct | Correct |
| 5 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 8 | Incorrect | Incorrect | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 9 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 10 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 11 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 12 | Incorrect | Incorrect | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 13 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 14 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 15 | Incorrect | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 16 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 17 | Incorrect | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 18 | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |

### *4.3.3 Level One Device Threshold*

Level one devices include main feeder circuit breakers and reclosers and, as radial distribution feeder is being considered, has a large number of immediate downstream devices beneath it. There might be outage cases where fault is associated with the main feeder and one of the main feeder circuit breaker or recloser upstream is operated to clear the fault. In these cases, customers beneath the operated main feeder breaker will lose power. However, for the utility, these calls either could represent a single outage due to fault on the main feeder or could represent multiple outages. None of the test cases encountered had fault associated with a main feeder breaker or recloser. For the preprocessing technique described earlier, calls are grouped based on the state of the upstream devices. In event of an outage associated with level one device, it is required that the state of that particular level one device is changes from ‘0’ to ‘1’ in order to group the calls in a single group. As the state only changes from ‘0’ to ‘1’ when certain number of level two devices beneath it are in a state of ‘1’, it is important to properly estimate such threshold value. If this value is low, outages on only a few laterals could group the outages in a group and associate it to the main feeder. On the other hand, if it is high, outage on the main feeder could be considered as multiple outages on laterals. This number seems paradoxical, as it should be low as well as high. One important factor on which this threshold number could depend is weather conditions. Under normal weather conditions, the chance of more than one outage occurring within the same period is relatively low. Similarly, probability of more than two outages within same time period is even less. During such conditions, if calls that are associated with multiple devices come in, it is very likely that a main feeder circuit breaker upstream of the call origin could have operated. In such case, a lower threshold value for level one device would make it possible to classify incoming calls in a single group. On the other hand, during rough weather and storm conditions, the likelihood of fault increases resulting into higher probability of multiple outages. During such conditions, a relatively higher threshold value for level one device will ascertain that the calls are not classified into a single group.

A sample call scenario based on the test circuit is used to explain this in detail. Figure 4.3 shows a part of the test feeder with level one device 78606 that has 40 level three devices directly downstream. It is assumed that a fault associated with the main feeder causes it to trip to clear the fault and all the customers beneath this device experience the outage. Further, it is assumed that all incoming calls are classified correctly into a single group with a threshold of 10%. Calls associated with just 4 downstream level three devices are considered. The simulation result in Figure 4.4 shows that device 78606 being the operated device.

**Figure 4.3 Sample test case for level one device threshold**

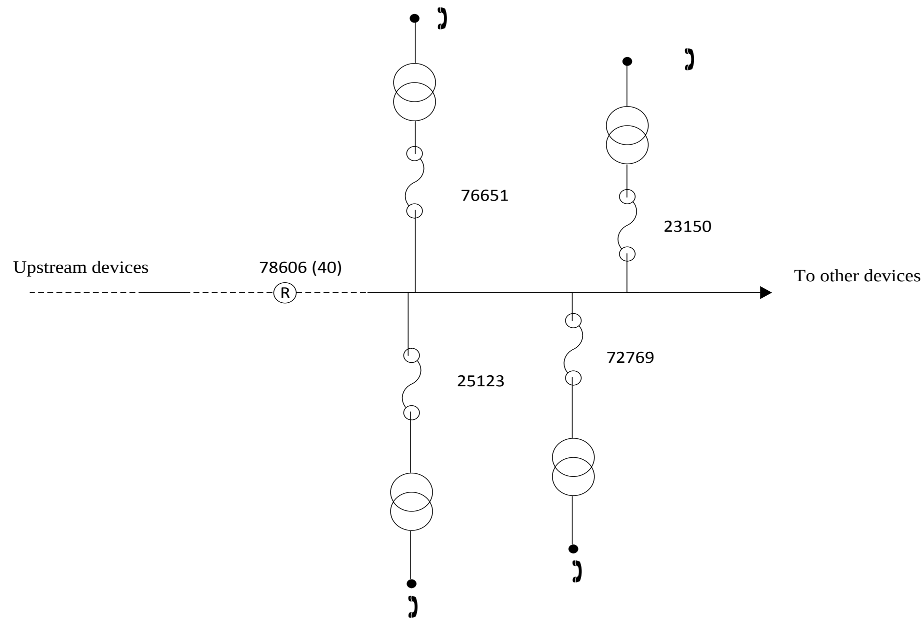
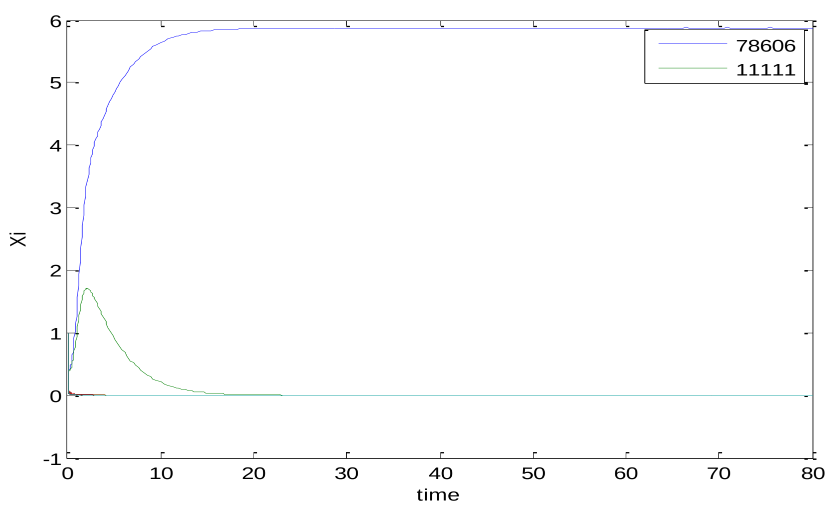



**Figure 4.4 Simulation result for sample test case**



From the sample case, it is seen that the even four calls out of the forty downstream devices are sufficient to predict the level one device 78606 as the operated protective device if the calls are classified in a single group. For the calls to classify into one group the threshold value for the level one device has to be at least 10%. However, during a rough weather, 10% would be low value for level one device. This would lead to conflicting results when determining the operated device using the proposed technique. A higher threshold value, on the other hand, makes sure that calls that originate at multiple points within the feeder does not easily change the state of the upstream device to state '1' and prevents from classifying multiple calls in a single group. Thus, the threshold value of level one device has to be chosen as a tradeoff between allowing multiple outages to classify into different group during rough weather conditions while also allowing calls associated with different devices to be grouped together during normal conditions. The best way to achieve this would be to set a variable threshold that is changed between a certain ranges depending on the weather conditions. All other simulations for this thesis were done repeatedly with a threshold value ranging from 20% to 90% for level one devices. The same results were obtained for all the threshold values.

# Chapter 5 - Implementation on Test Cases

In this chapter, different test cases to validate effectiveness of the proposed technique are presented. The first step included testing whether the calls would be grouped in a single group or a multiple group using threshold values from Chapter 4. Second step included using the proposed technique to predict the actual operated device. The grouping of the calls as obtained from the proposed preprocessing technique for each case is mentioned in the case description. First seven cases will be briefly discussed in the following section while the remaining cases, event details and simulation results for other cases are included in Appendix A.

## 5.1 Selected Test Cases

### *5.1.1 Case 1*

Case 1 presents the outage events for October 29, 2010. The circuit diagram for the origin of the calls is given in Figure 5.1. It should be noted that only the lateral from which calls have been reported and the considered protective devices has been shown excluding any adjacent laterals both upstream and downstream. Any immediate upstream device has also been shown along with the general downstream direction for the main feeder. There are four calls received with a period less than half an hour. Calls have been received only from three of the transformers out of the six associated with the outage as shown in Table 5.1. This bolsters the previous assumption that all of the customers cannot be expected to call even in an event of outage.

**Figure 5.1 Circuit diagram and call scenario for 10/29/2010**

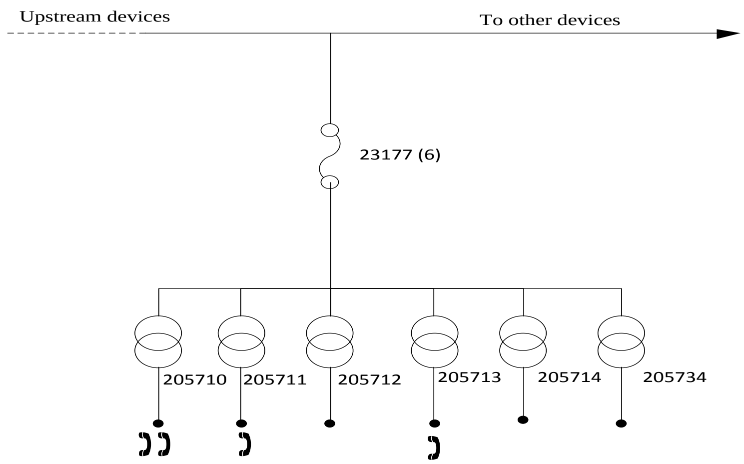
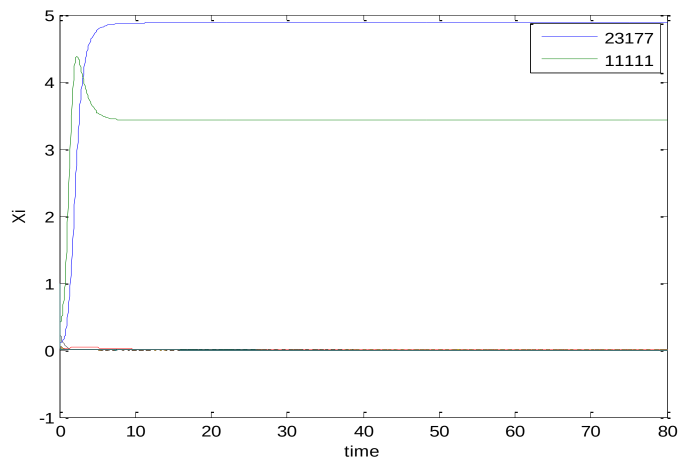



**Table 5.1 Events of 10/29/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205711 | 10/29/2010 10:17 |
| 205710 | 10/29/2010 10:20 |
| 205713 | 10/29/2010 10:27 |
| 205710 | 10/29/2010 10:34 |

Device **23177** has been predicted as the operated protective device by the simulation which is confirmed from the field data.

**Figure 5.2 Simulation result for 10/29/2010**



### *5.1.2 Case 2*

Case 2 shows the events for evening of July 29, 2011. The circuit layout for the call originating point in the circuit is shown in Figure 5.3 and the sequence of calls is shown in Table 5.2. It is seen that calls are originating from a single device 205634 that is directly beneath the upstream lateral fuse 23141. It is also noticeable that the calls originate at 19:16 PM and continue till 21:21 PM.

As mentioned previously, calls coming in within an hour and a half of separation are only considered to be processed together. However, the extra call coming in is mentioned to make call scenario much clearer. The predicted device from the simulation is the device **205634**. Even if the  extra call is not considered, the same result is obtained.

**Figure 5.3 Circuit diagram and call scenario for 7/29/2011**

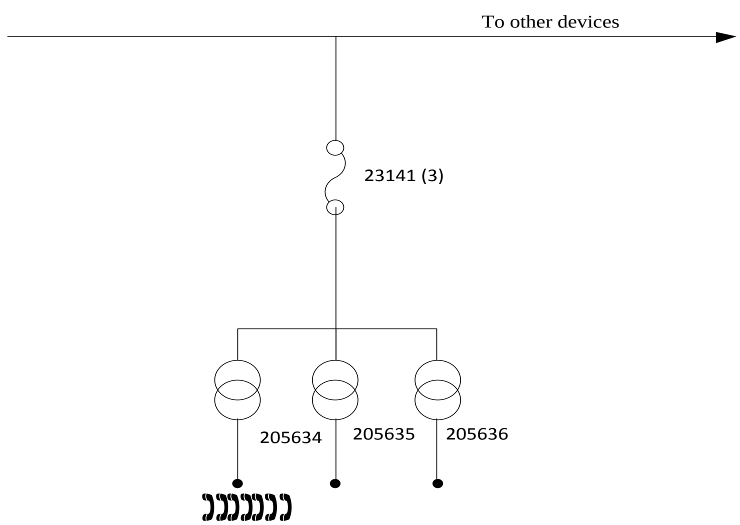
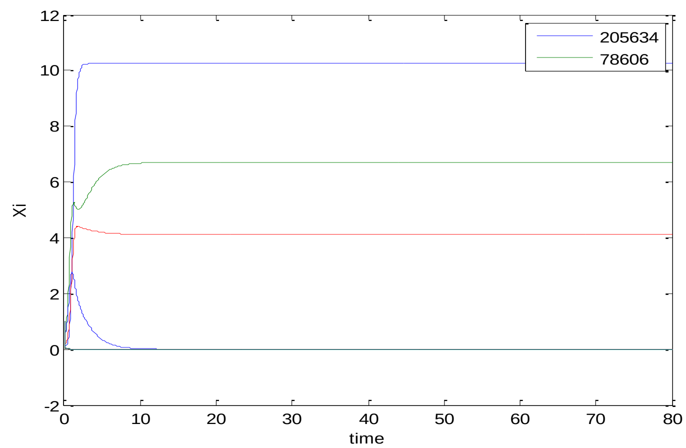


**Table 5.2 Events of 7/29/2011**

| Device ID | Date/Time of the Call |
|---|---|
| 205634 | 07/29/2011 19:16 |
| 205634 | 07/29/2011 19:24 |
| 205634 | 07/29/2011 19:27 |
| 205634 | 07/29/2011 19:34 |
| 205634 | 07/29/2011 19:36 |
| 205634 | 07/29/2011 20:44 |
| 205634 | 07/29/2011 21:21 |

**Figure 5.4 Simulation result for 7/29/2011**




### *5.1.3 Case 3*

Case 3 discusses the events of August 10, 2010. Figure 5.5 below shows the circuit portion at the call origin point in the distribution system along with the call scenario. The circuit layout for this case is different from the previous two cases. The lateral coming off from the main feeder is further branched out into number of other smaller laterals each with and without its own lateral fuses. In total, four such branches have their own distribution transformer. There are also a distribution transformers whose primary back up device is the main lateral fuses. The events for this case are given in Table 5.3.

On examining the events and the circuit, it is seen that the calls are concentrated on the branch lateral 78540. Simulation results predict the operated device to be device **78540** that corresponds to the field data.

**Figure 5.5 Circuit diagram and call scenario for 8/10/2010**

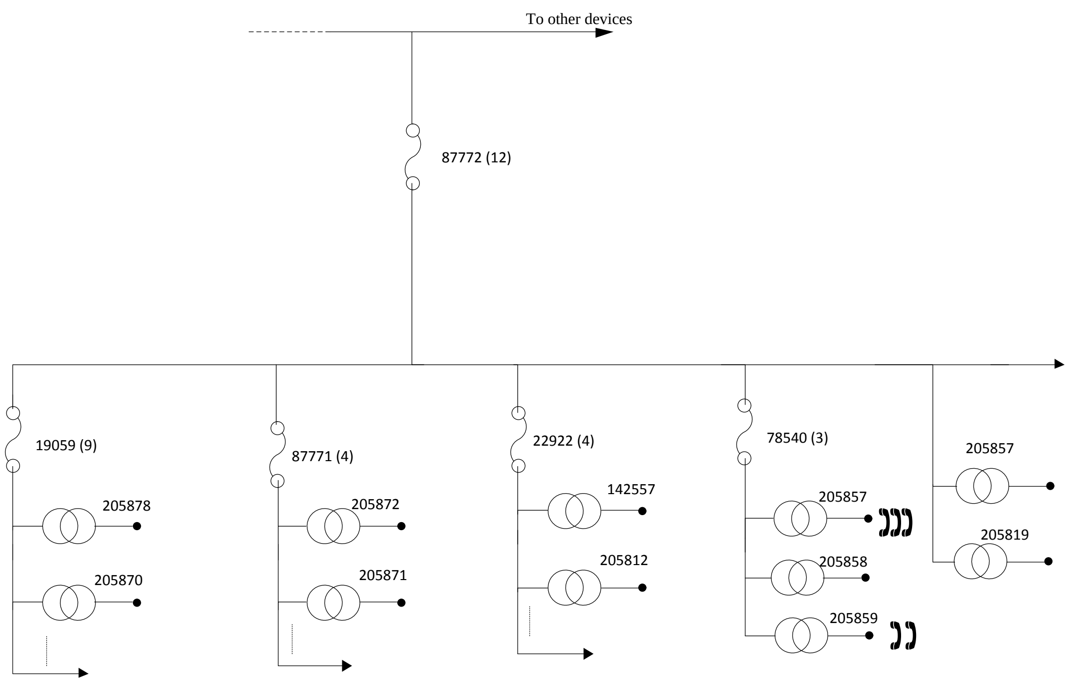
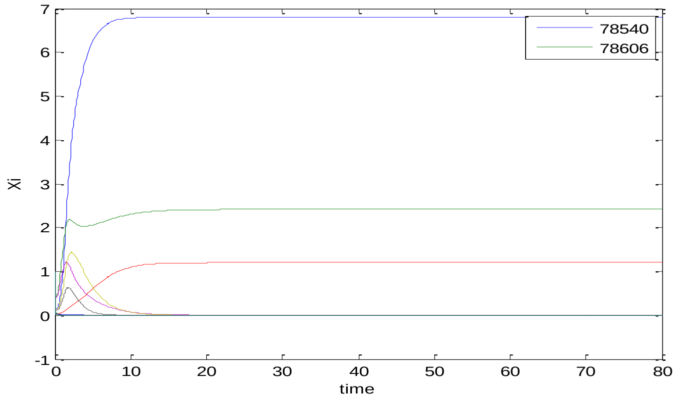



**Table 5.3 Events of 8/10/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205857 | 8/10/10 7:46 |
| 205859 | 8/10/10 7:46 |
| 205857 | 8/10/10 7:54 |
| 205857 | 8/10/10 7:56 |
| 205859 | 8/10/10 9:13 |

**Figure 5.6 Simulation result for 8/10/2010**




### *5.1.4 Case 4*

Case 4 is similar to Case 3 in sense that the outage occurs within the same lateral as Case 3 but the operated protective device is different. The first call comes in at 13:05 PM and is followed by a spate of calls. It is clearly seen on observing the calls scenario in Table 5.4 and Figure 5.7 that the outage is more spread with calls originating from a number of devices than Case 3. The simulation predicts device **87772** as the operated protective device that is verified from the field data.

**Figure 5.7 Circuit diagram and call scenario for 3/25/2010**

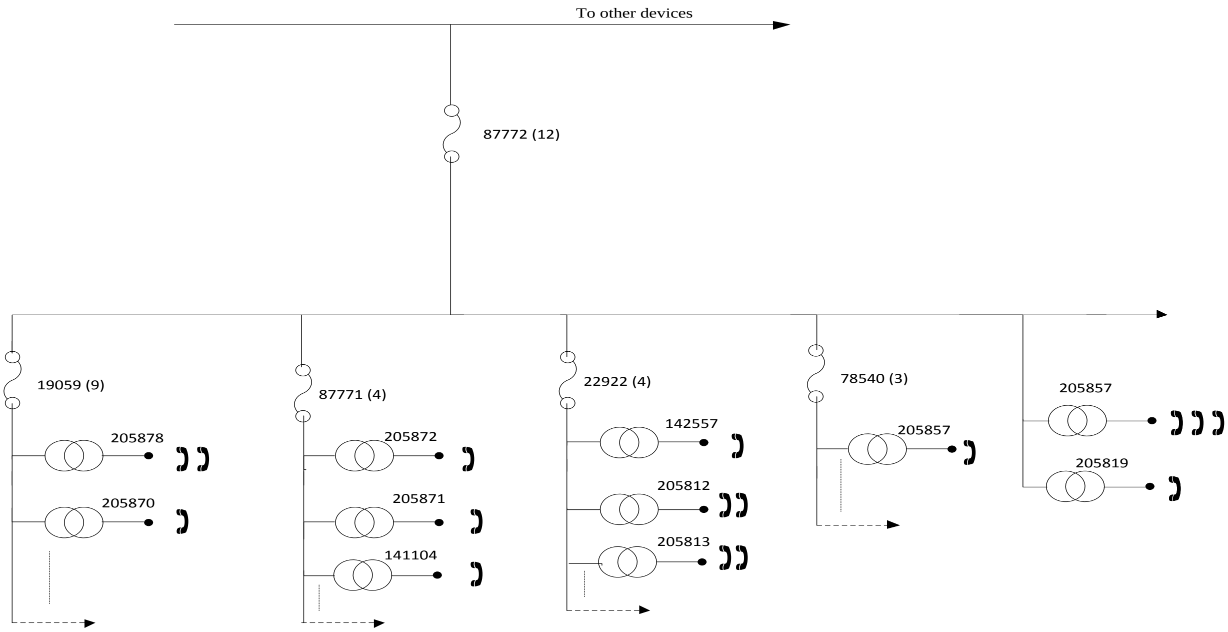
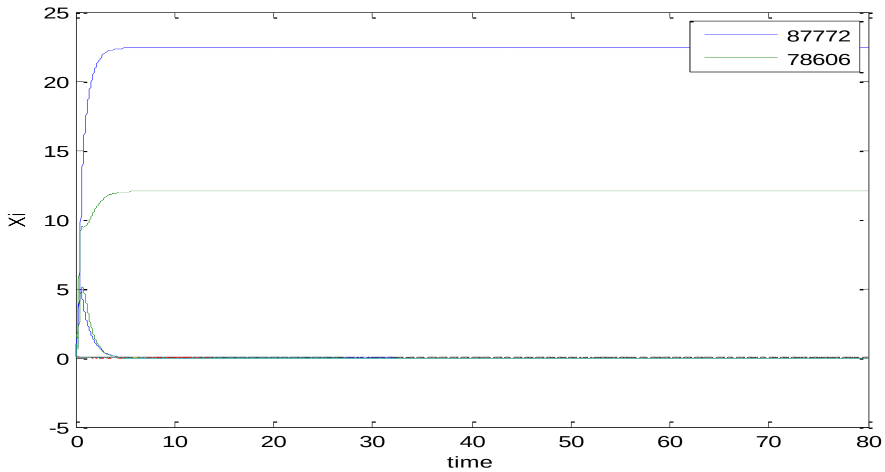



**Table 5.4 Events of 3/25/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205878 | 3/25/10 13:05 |
| 142557 | 3/25/10 13:05 |
| 205872 | 3/25/10 13:08 |
| 205812 | 3/25/10 13:14 |
| 205878 | 3/25/10 13:16 |
| 141104 | 3/25/10 13:16 |
| 205813 | 3/25/10 13:17 |
| 205870 | 3/25/10 13:18 |
| 205813 | 3/25/10 13:22 |
| 205812 | 3/25/10 13:34 |
| 205871 | 3/25/10 13:40 |
| 205856 | 3/25/10 13:41 |
| 205856 | 3/25/10 13:46 |
| 205856 | 3/25/10 13:47 |
| 205819 | 3/25/10 14:10 |
| 205857 | 3/25/10 14:23 |

**Figure 5.8 Simulation result for 3/25/2010**




### *5.1.5 Case 5*

Case 5 presents the call scenarios for August 17, 2010. The first call originates at 09:18 and all the other calls are within a time range of one hour. The lateral fuse 71361 has a number of devices directly beneath it. It is also seen that six out of the total eight calls received were from downstream of device 25039. Despite high number of calls coming in the device it is not reported as the operated protective device by the simulation. The device **71361** is reported as the operated protective device by the simulation which matches the field reports.

**Figure 5.9 Circuit diagram and call scenario for 8/17/2010**

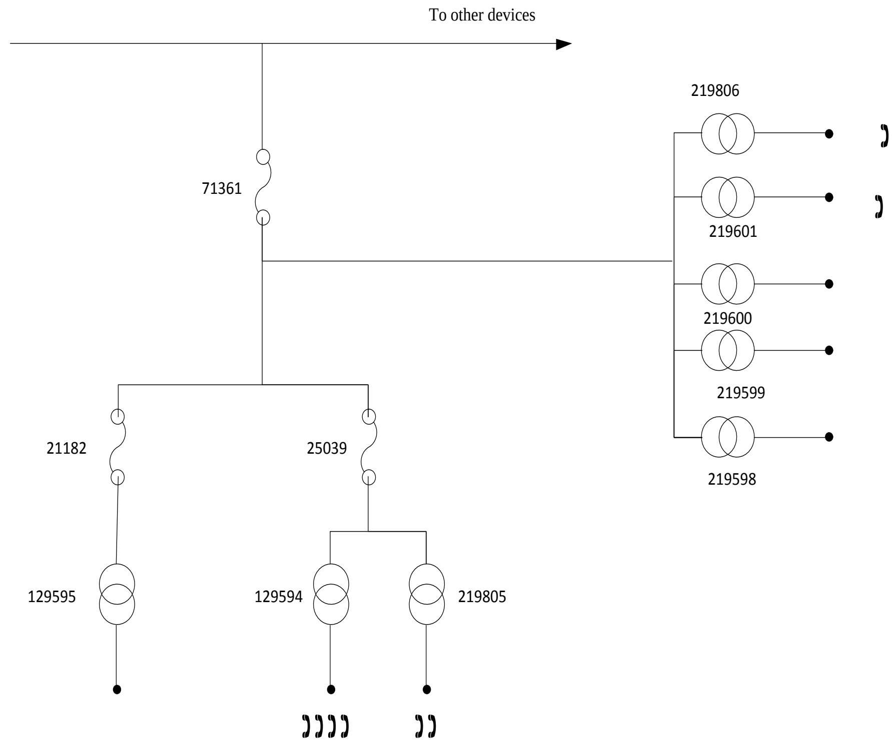
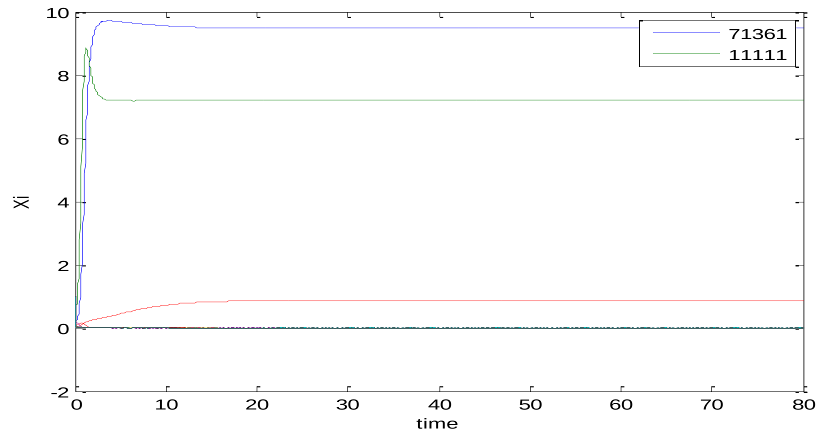



**Table 5.5 Events of 8/17/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 129594 | 8/17/10 9:18 |
| 129594 | 8/17/10 9:19 |
| 129594 | 8/17/10 9:20 |
| 219805 | 8/17/10 9:26 |
| 129594 | 8/17/10 9:39 |
| 219601 | 8/17/10 9:47 |
| 219806 | 8/17/10 9:49 |
| 219805 | 8/17/10 10:04 |

**Figure 5.10 Simulation result for 8/17/2010**




### *5.1.6 Case 6*

This case shows an excellent example of the trouble calls originating due to the operation of multiple protective devices within the same period. As previously mentioned, time duration of one and half hours is considered as period for analysis purpose. Hence, even though more calls follow, only calls coming in during that time period are included in Figure 5.11 and Table 5.6. The calls are processed with previously determined threshold percentages of 20% for level two device and 50% for level one device. The calls were grouped into four groups as shown in Table 5.7. On processing the three major groups, devices **22878**, **23177** and **71361** were determined to be the operated protective devices. These devices were confirmed with the field data. The fourth group includes a single call from a device that was registered at the end of the period. It was a single call received for an outage associated with other devices which are not shown in the figure. Since no further calls were registered in the analysis period, it is disregarded.

**Figure 5.11 Circuit diagram and call scenario for 07/12/2009**

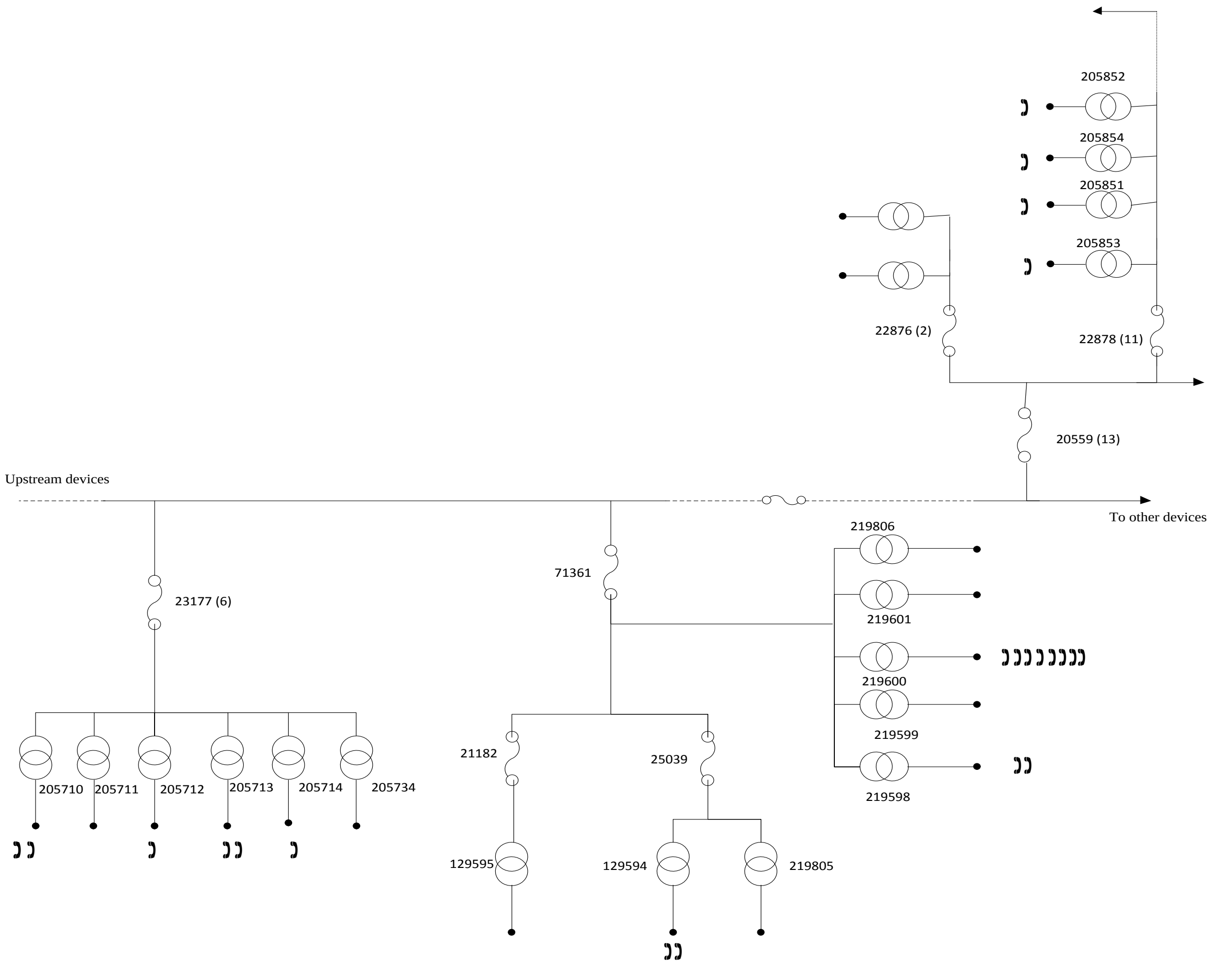


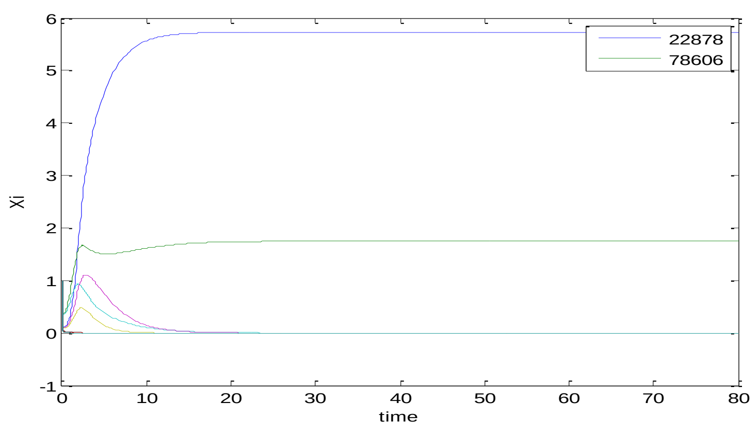

**Table 5.6 Events of 07/12/2009**

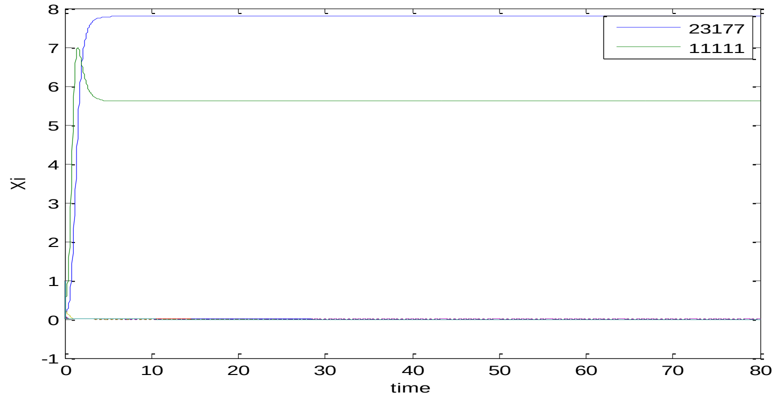
| Device ID | Date/Time of the Call | Device ID | Date/Time of the Call |
|---|---|---|---|
| 219600 | 7/12/09 6:06 | 219600 | 7/12/09 6:31 |
| 205710 | 7/12/09 6:07 | 205854 | 7/12/09 6:45 |
| 219600 | 7/12/09 6:10 | 219598 | 7/12/09 6:46 |
| 205713 | 7/12/09 6:10 | 205713 | 7/12/09 6:49 |
| 205853 | 7/12/09 6:11 | 205851 | 7/12/09 6:53 |
| 219600 | 7/12/09 6:14 | 219598 | 7/12/09 6:56 |
| 205852 | 7/12/09 6:15 | 219600 | 7/12/09 7:11 |
| 205710 | 7/12/09 6:15 | 205712 | 7/12/09 7:19 |
| 205714 | 7/12/09 6:21 | 219600 | 7/12/09 7:19 |
| 129594 | 7/12/09 6:24 | 205650 | 7/12/09 7:30 |
| 129594 | 7/12/09 6:28 | 219600 | 7/12/09 7:35 |
| 219600 | 7/12/09 6:30 | | |

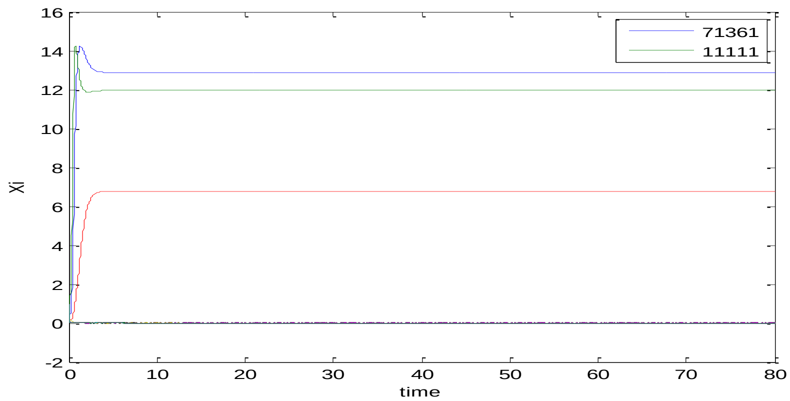
**Table 5.7 Call groups for 07/12/2009**

| Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|
| 205853 | 205710 | 219600 | 205650 |
| 205852 | 205713 | 219600 | |
| 205854 | 205710 | 219600 | |
| 205851 | 205714 | 129594 | |
| | 205713 | 129594 | |
| | 205712 | 219600 | |
| | | 219600 | |
| | | 219598 | |
| | | 219598 | |
| | | 219600 | |
| | | 219600 | |
| | | 219600 | |

**Figure 5.12 Simulation results for 07/12/2009**






### *5.1.7 Case 7*

This case also shows an example of the trouble calls originating due to the operation of multiple protective devices within the same period. Only calls coming in during that period are included in Figure 5.13 and Table 5.8. Due to the large number of calls associated, the protective devices are shown in simplified form without including the downstream devices for the concerned protective devices. The calls are processed with previously determined threshold percentages of 20% for level two devices and 50% for level one devices. The calls were grouped into four major groups as shown in Table 5.9. On processing the four major groups, devices **22878**, **23177** and **71362** and **25121** were determined to be the operated protective devices. These devices were confirmed with the field data. Apart from the four major groups, the calls registered in that time period included four ungrouped calls that included a single transformer outage call and single call received for outage associated with other devices. Since no further calls were registered in the analysis period, they were disregarded.

**Figure 5.13 Circuit diagram and call scenario for 08/13/2010**

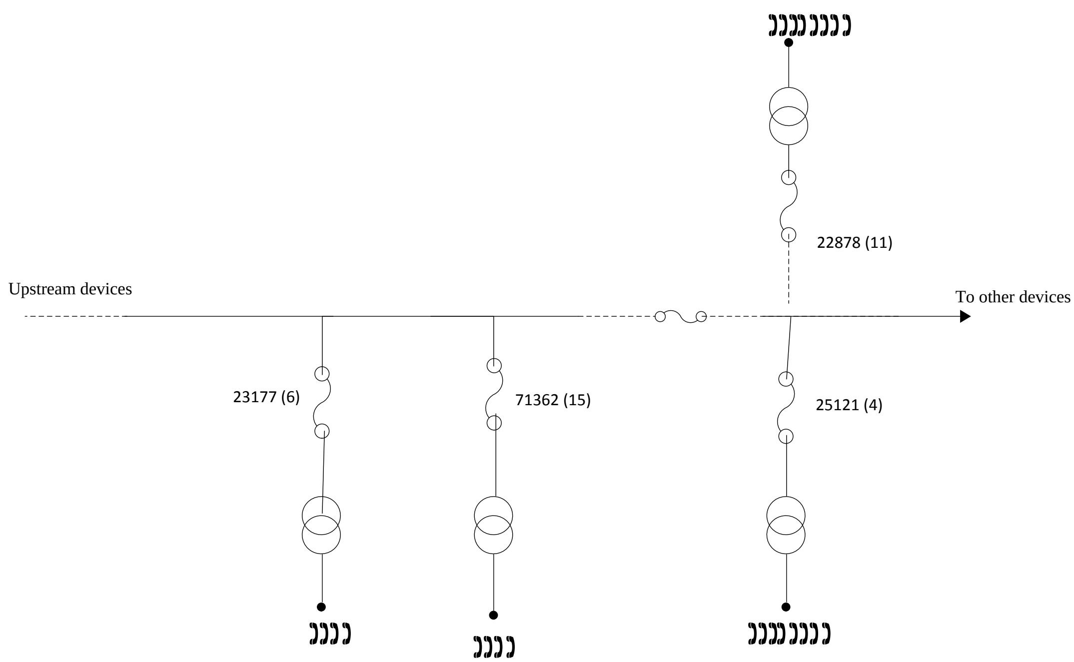



**Table 5.8 Events of 08/13/2010**

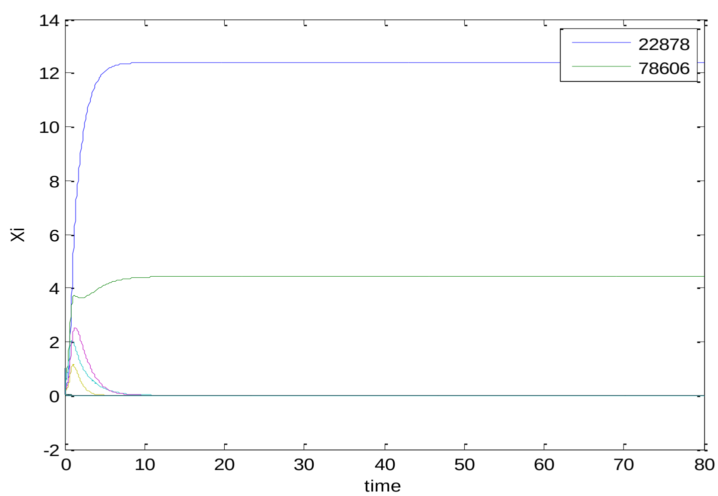
| Device ID | Date/Time of the Call | Device ID | Date/Time of the Call |
|---|---|---|---|
| 205769 | 8/13/10 16:30 | 205577 | 8/13/10 17:00 |
| 205762 | 8/13/10 16:33 | 205847 | 8/13/10 17:05 |
| 205582 | 8/13/10 16:34 | 205710 | 8/13/10 17:14 |
| 205759 | 8/13/10 16:37 | 205742 | 8/13/10 17:18 |
| 205845 | 8/13/10 16:37 | 205711 | 8/13/10 17:19 |
| 205581 | 8/13/10 16:37 | 205848 | 8/13/10 17:22 |
| 205854 | 8/13/10 16:39 | 142557 | 8/13/10 17:31 |
| 205587 | 8/13/10 16:39 | 205762 | 8/13/10 17:33 |
| 204005 | 8/13/10 16:40 | 219600 | 8/13/10 17:35 |
| 205710 | 8/13/10 16:41 | 205848 | 8/13/10 17:35 |
| 205582 | 8/13/10 16:47 | 205855 | 8/13/10 17:41 |
| 205713 | 8/13/10 16:50 | 205854 | 8/13/10 17:48 |

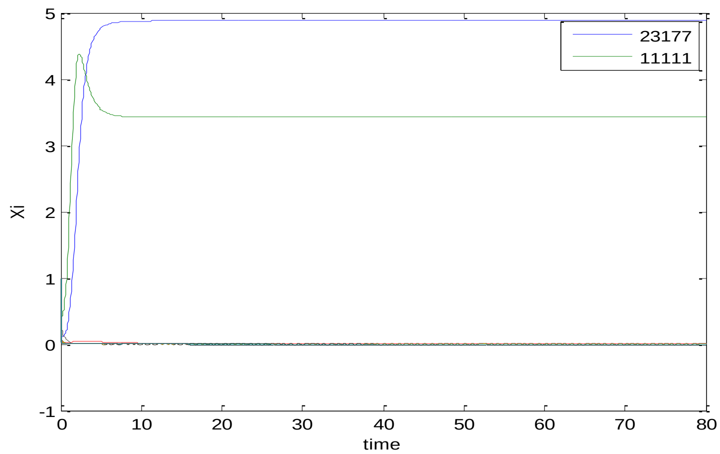
| | | | |
|---|---|---|---|
| 205588 | 8/13/10 16:55 | 205838 | 8/13/10 17:49 |
| 205581 | 8/13/10 16:58 | 205855 | 8/13/10 17:49 |

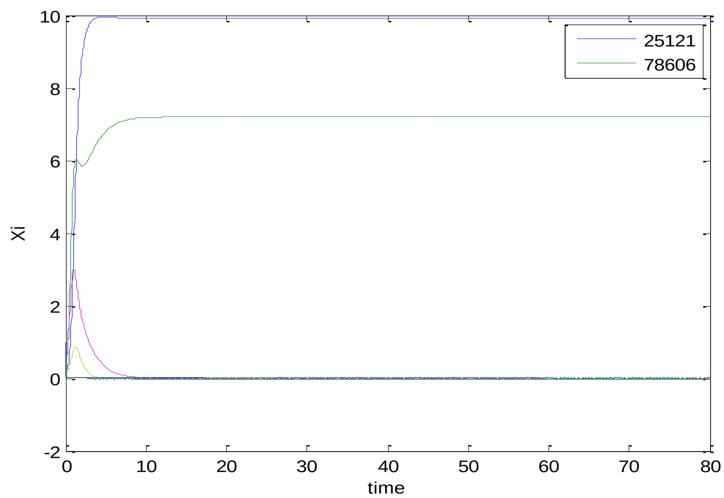
**Table 5.9 Call groups for 08/13/2010**

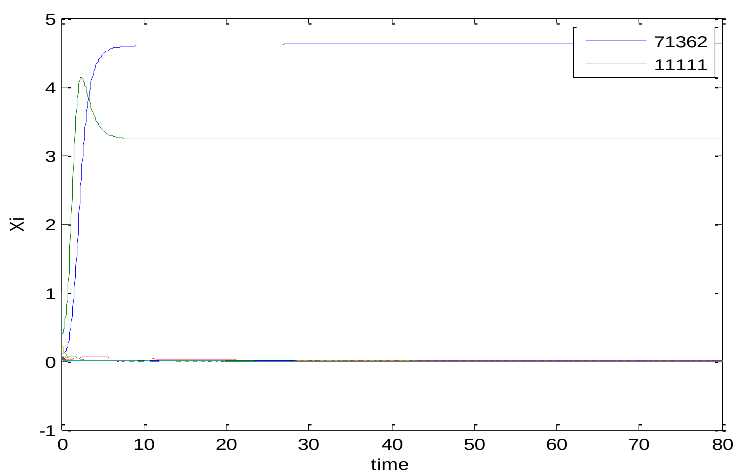
| Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|
| 205845 | 205710 | 205582 | 205769 |
| 205854 | 205713 | 205581 | 205762 |
| 205847 | 205710 | 205587 | 205759 |
| 205848 | 205711 | 204005 | 205762 |
| 205848 | | 205582 | |
| 205855 | | 205588 | |
| 205854 | | 205581 | |
| 205855 | | 205577 | |

**Figure 5.14 Simulation results for 08/13/2010**




5
4
3
2
1
0
-1
Xi
0
10
20
30
40
50
60
70
80
time
23177
11111


10
8
6
4
2
0
-2
Xi
0
10
20
30
40
50
60
70
80
time
25121
78606


5
4
3
2
1
0
-1
Xi
0
10
20
30
40
50
60
70
80
time
71362
11111

# Chapter 6 - Discussion and Conclusion

An alternative approach utilizing the immune system modeling was designed, developed and tested for determining the operated protective device in a radial distribution circuit based on customer calls. The only utilized resources were the circuit data and the call information which are one of the commonly available information for utility company. The distribution system has been modeled in a way that would allow the prediction of the operated protective devices easily. Due to its resemblance with the distribution system, immune system was selected to model the circuit. One important thing to note is that the modeling of the distribution network using this technique is not completely dependent on the number of customers calling. This gives a distinct advantage in the sense that the number of calls received do not have to be weighed against the number of customers supplied by a particular transformer and further takes into account the unpredictability of such calls during outages.

The test feeder used in the test cases all are in radial configuration that includes a main feeder with a number of laterals. Due to this reason, most of the laterals have similar configuration to each other. On observing test cases as well, it is seen that some test cases have similar configuration to each other with similar call scenario. In addition, some test cases utilize the same circuit for a problem that occurred on a different date.

During test cases, incidence with multiple outages and operated protective devices were also encountered. Direct application of the proposed technique resulted in conflicting device showing up as the operated protective device. This is clearly because the proposed approach handles one fault scenario at a time. Hence, when calls resulting from two different outages that occurred within the same period are processed together the algorithm loses its functionality. A call processing technique was thus proposed that utilizes threshold limits to group calls together based on their origin. In a radial system, a device downstream tripping can cause outage to a lower number of customers compared to when a device upstream is tripped. In addition, calls coming in from different points within the same circuit would only originate from the same outage, only if a device upstream is operated. Based on simple principles, the technique is effective in radial systems. This is especially useful during storms which can cause multiple outages resulting in confusion and delayed outage restoration.

It was observed that a very low value of threshold for level one device would classify calls in a single group even in cases of multiple outages. This would lead to conflicting results when the operated device is determined using the proposed technique. The optimum value of level two devices that worked for all sixteen cases was found to be 20%. For level one devices, threshold values between 20% and 90% gave correct results. However, this value should be selected carefully based on conditions to prevent classifications of multiple outages into one group.

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# Appendix A - Test Cases

## Case 8

**Figure A.1 Circuit diagram and call scenario for 08/26/2009**

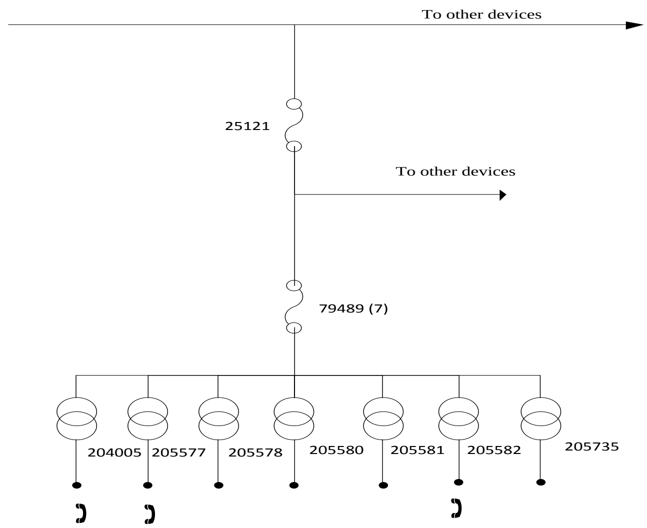
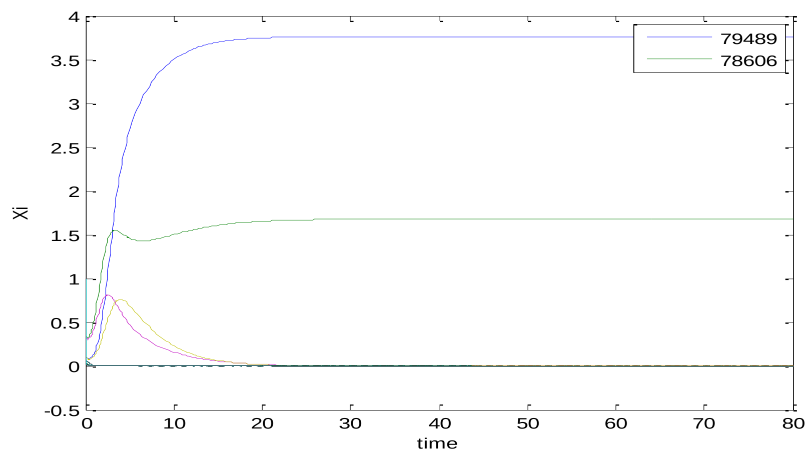



**Table A.1 Events of 08/26/2009**

| Device ID | Date/Time of the Call |
|---|---|
| 205582 | 8/26/09 6:51 |
| 205577 | 8/26/09 7:00 |
| 204005 | 8/26/09 7:40 |

Device reported by the Utility: 79489

**Figure A.2 Simulation result for 08/26/2009**




## Case 9

**Figure A.3 Circuit diagram and call scenario for 10/09/2009**

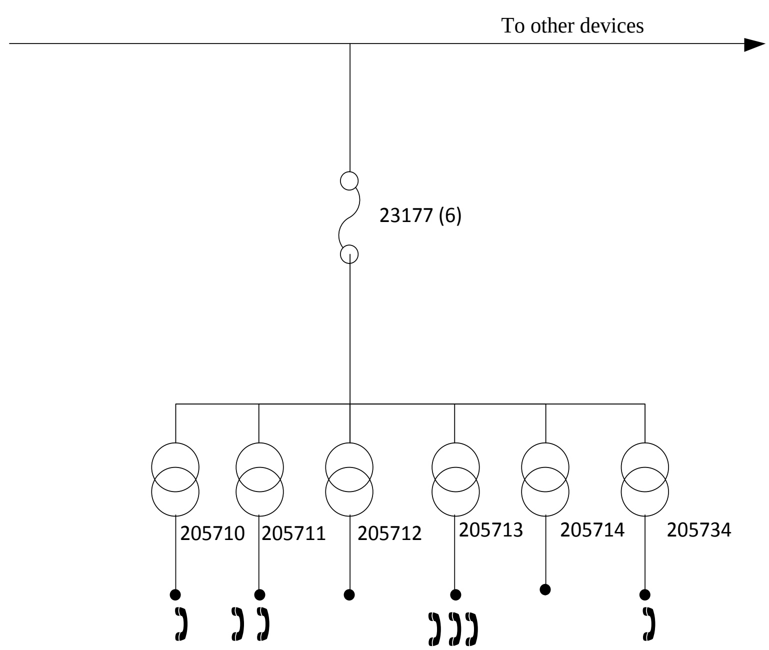
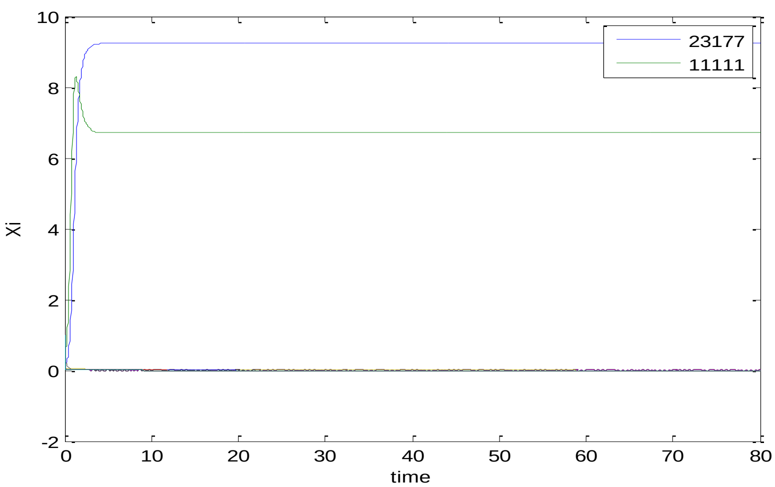


**Table A.2 Events of 10/09/2009**

| Device ID | Date/Time of the Call |
|---|---|
| 205713 | 10/9/09 17:09 |
| 205711 | 10/9/09 17:09 |
| 205734 | 10/9/09 17:09 |
| 205713 | 10/9/09 17:09 |
| 205710 | 10/9/09 17:13 |
| 205711 | 10/9/09 17:15 |
| 205713 | 10/9/09 17:18 |

Device reported by the Utility: 23177

**Figure A.4 Simulation result for 10/09/2009**



## Case 10

**Figure A.5 Circuit diagram and call scenario for 4/24/2010**

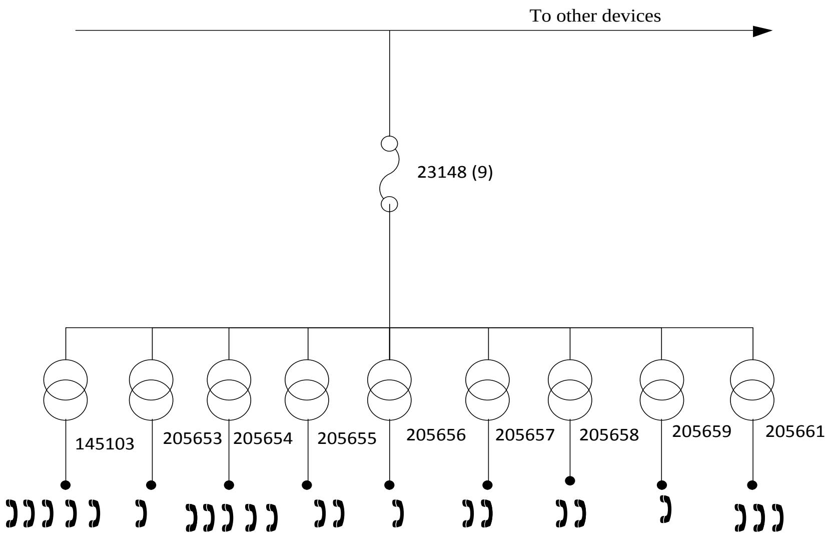
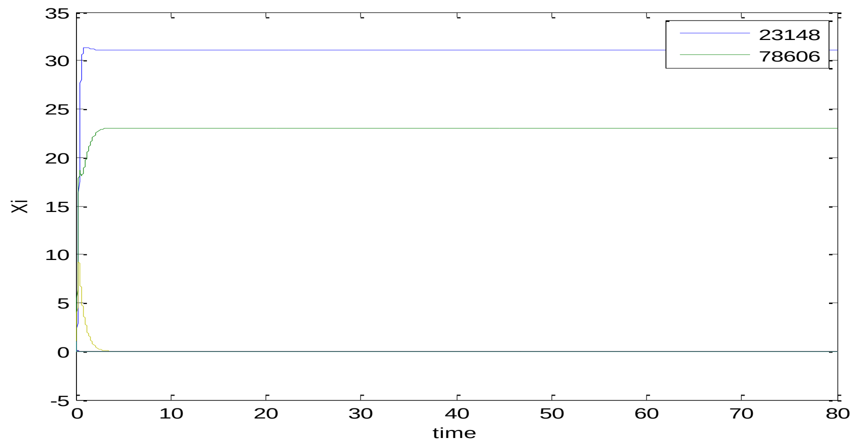



**Table A.3 Events of 4/24/2010**

| Device ID | Date/Time of the Call | Device ID | Date/Time of the Call |
|---|---|---|---|
| 145103 | 4/24/2010 8:01 | 205656 | 4/24/2010 8:20 |
| 205654 | 4/24/2010 8:04 | 205661 | 4/24/2010 8:24 |
| 145103 | 4/24/2010 8:05 | 205661 | 4/24/2010 8:28 |
| 145103 | 4/24/2010 8:05 | 145103 | 4/24/2010 8:32 |
| 205658 | 4/24/2010 8:05 | 205655 | 4/24/2010 8:34 |
| 205655 | 4/24/2010 8:06 | 145103 | 4/24/2010 8:37 |
| 205653 | 4/24/2010 8:06 | 205659 | 4/24/2010 8:47 |
| 205657 | 4/24/2010 8:08 | | |
| 205657 | 4/24/2010 8:09 | | |
| 205658 | 4/24/2010 8:09 | | |
| 205654 | 4/24/2010 8:11 | | |
| 205654 | 4/24/2010 8:12 | | |
| 205654 | 4/24/2010 8:16 | | |
| 205661 | 4/24/2010 8:18 | | |
| 205654 | 4/24/2010 8:18 | | |

Device reported by the Utility: 23148

**Figure A.6 Simulation result for 4/24/2010**




## Case 11

**Figure A.7 Circuit diagram and call scenario for 6/18/2010**

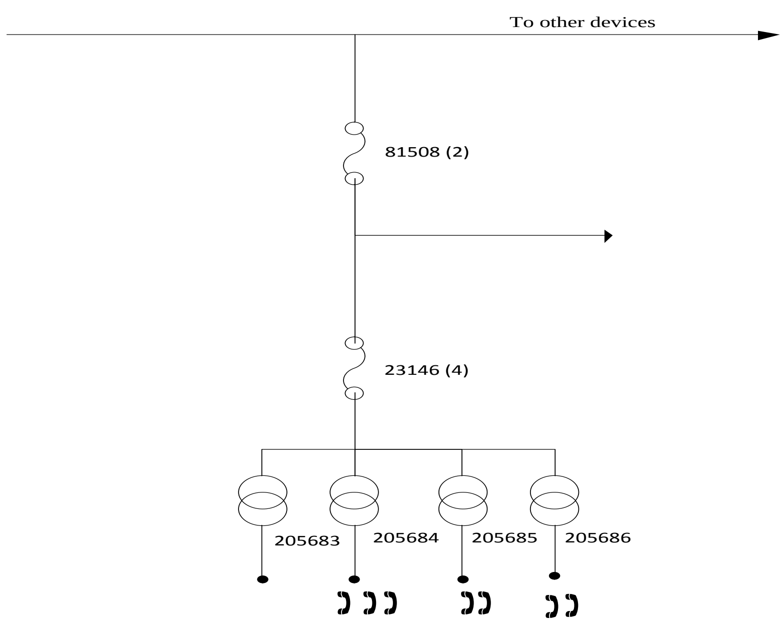
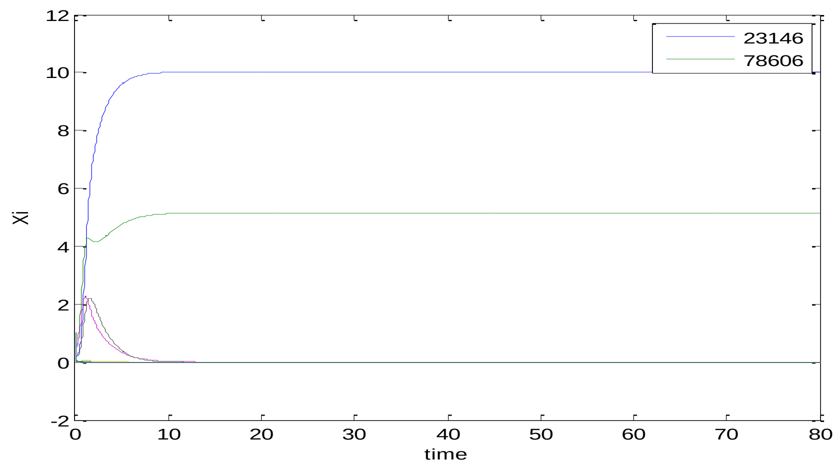


**Table A.4 Events of 6/18/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205684 | 6/18/10 8:19 |
| 205684 | 6/18/10 8:20 |
| 205684 | 6/18/10 8:25 |
| 205686 | 6/18/10 8:26 |
| 205686 | 6/18/10 8:28 |
| 205685 | 6/18/10 8:33 |
| 205685 | 6/18/10 8:35 |

Device reported by the Utility: 23146

**Figure A.8 Simulation result for 6/18/2010**



## Case 12

**Figure A.9 Circuit diagram and call scenario for 08/30/2010**

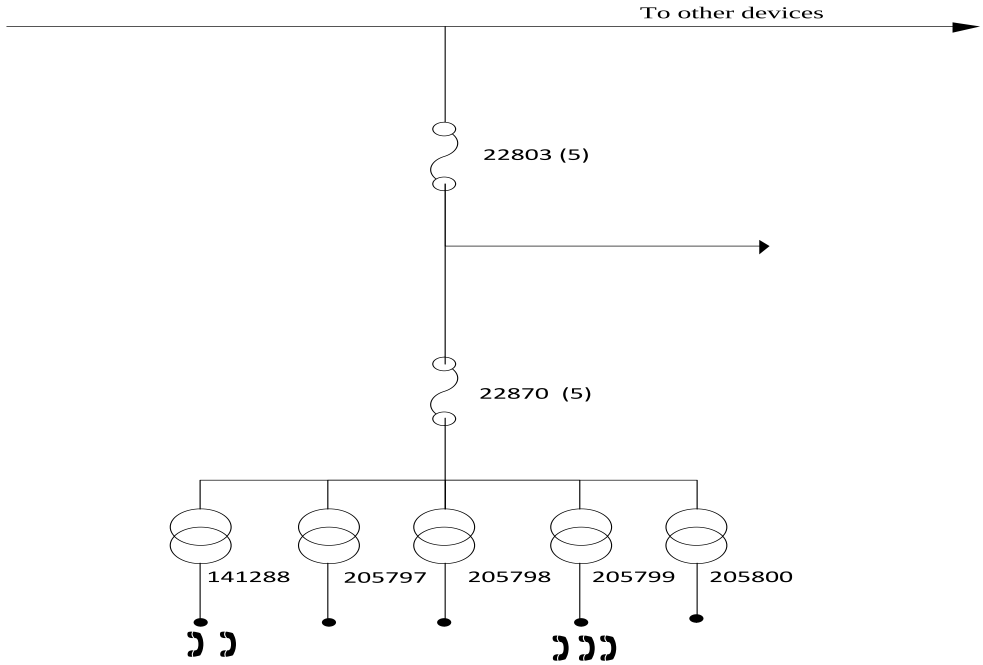
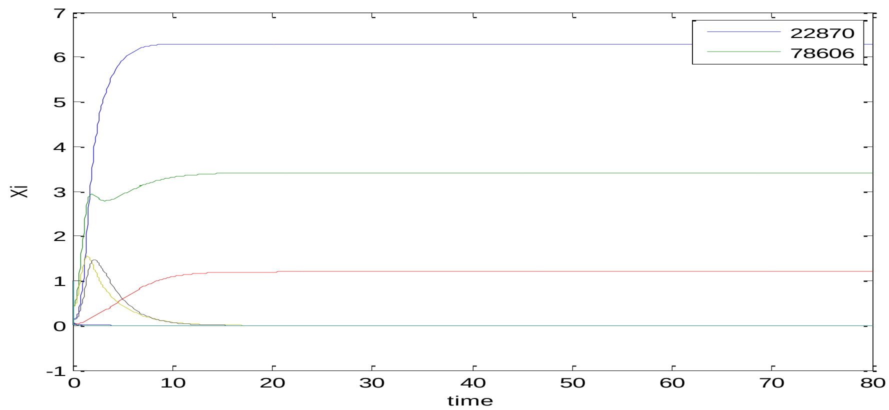



**Table A.5 Events of 08/30/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 141288 | 8/30/10 12:13 |
| 205799 | 8/30/10 12:20 |
| 141288 | 8/30/10 12:22 |
| 205799 | 8/30/10 12:22 |
| 205799 | 8/30/10 12:23 |

Device reported by the Utility: 22870

**Figure A.10 Simulation result for 08/30/2010**




## Case 13

**Figure A.11 Circuit diagram and call scenario for 09/02/2010**

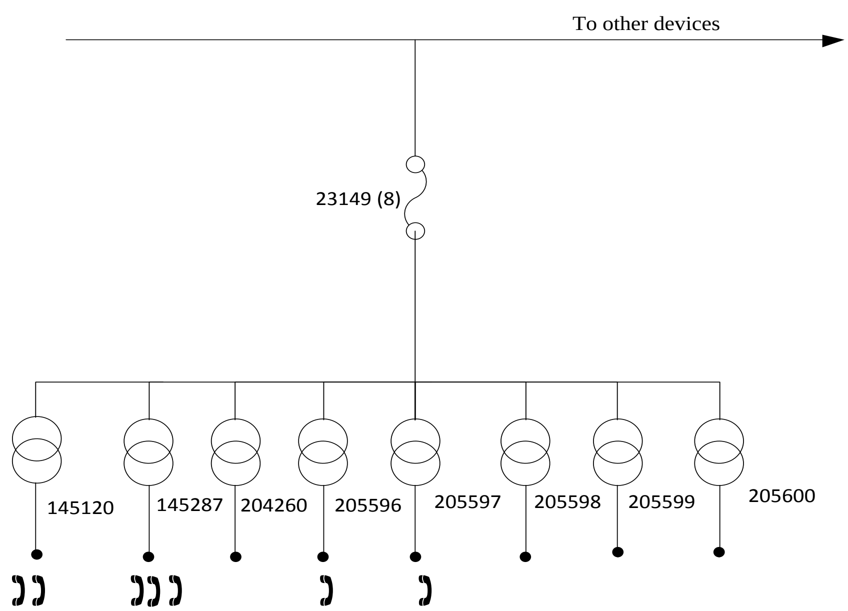
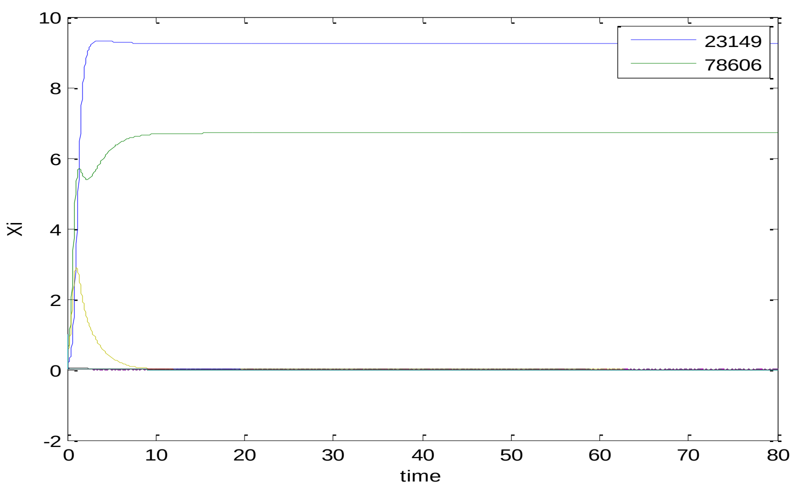


**Table A.6 Events of 09/02/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205596 | 9/2/10 14:32 |
| 145287 | 9/2/10 14:32 |
| 145287 | 9/2/10 14:38 |
| 205597 | 9/2/10 14:43 |
| 145120 | 9/2/10 14:53 |
| 145287 | 9/2/10 15:10 |
| 145120 | 9/2/10 15:19 |

Device reported by the Utility: 23149

**Figure A.12 Simulation result for 09/02/2010**



## Case 14

**Figure A.13 Circuit diagram and call scenario for 11/14/2010**

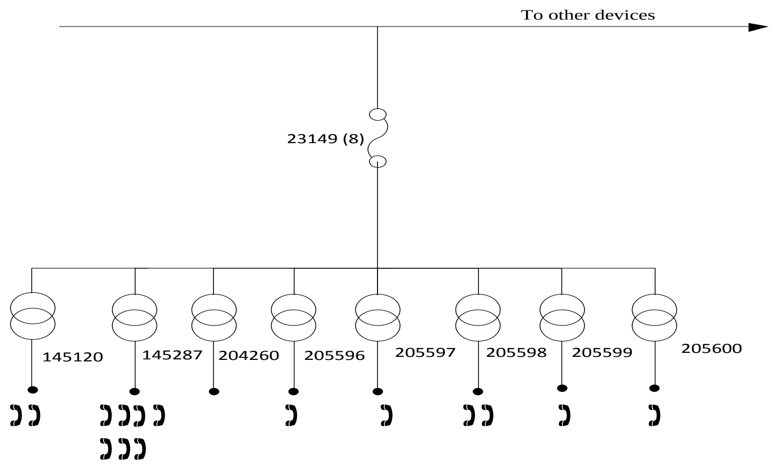
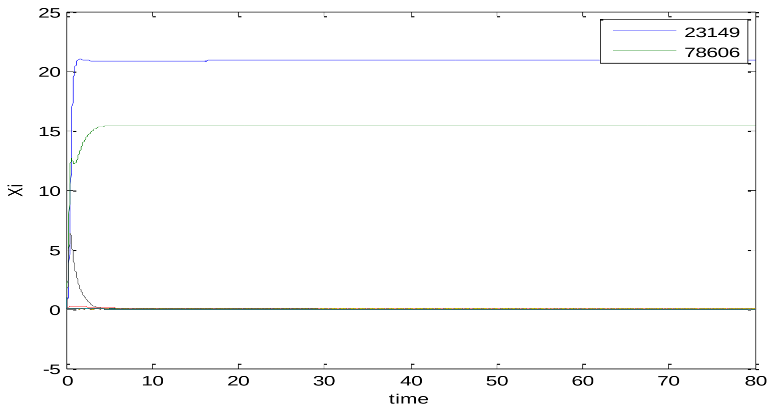



**Table A.7 Events of 11/14/2010**

| Device ID | Date/Time of the Call |
|---|---|
| 205598 | 11/14/2010 10:26 |
| 205597 | 11/14/2010 10:27 |
| 145287 | 11/14/2010 10:28 |
| 205596 | 11/14/2010 10:28 |
| 205598 | 11/14/2010 10:29 |
| 145287 | 11/14/2010 10:29 |
| 145287 | 11/14/2010 10:34 |
| 145287 | 11/14/2010 10:34 |
| 145287 | 11/14/2010 10:40 |
| 205600 | 11/14/2010 10:42 |
| 205599 | 11/14/2010 10:42 |
| 145287 | 11/14/2010 10:47 |
| 145120 | 11/14/2010 10:47 |
| 145120 | 11/14/2010 10:53 |
| 145287 | 11/14/2010 11:04 |

Device reported by the Utility: 23149

**Figure A.14 Simulation result for 11/14/2010**




## Case 15

**Figure A.15 Circuit diagram and call scenario for 03/13/2011**

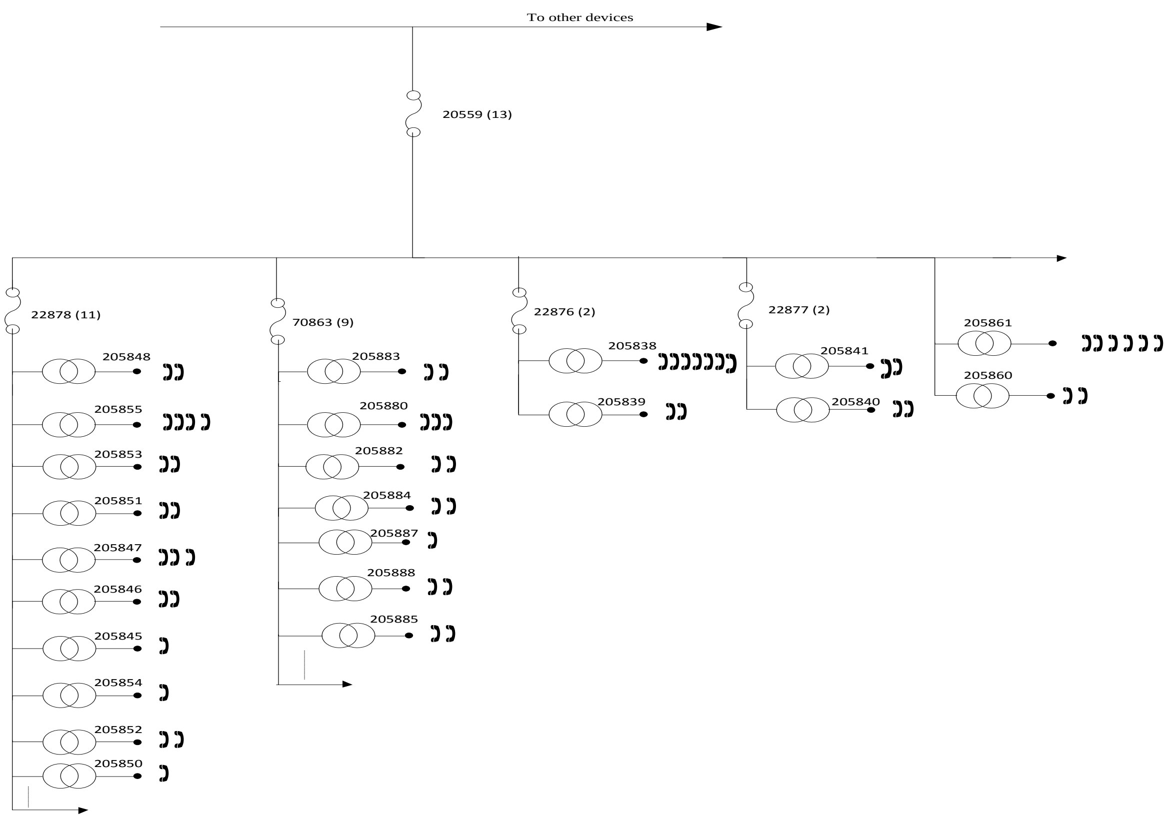
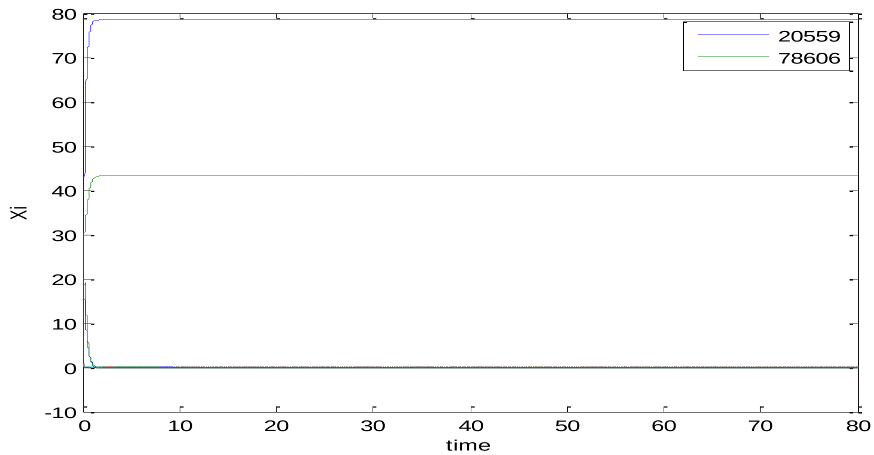


**Table A.8 Events of 03/13/2011**

| Device ID | Date/Time of the Call | Device ID | Date/Time of the Call |
|---|---|---|---|
| 205848 | 03/13/2011 22:14 | 205847 | 03/13/2011 22:27 |
| 205855 | 03/13/2011 22:15 | 205838 | 03/13/2011 22:28 |
| 205853 | 03/13/2011 22:16 | 205841 | 03/13/2011 22:29 |
| 205861 | 03/13/2011 22:16 | 205854 | 03/13/2011 22:30 |
| 205883 | 03/13/2011 22:17 | 205841 | 03/13/2011 22:30 |
| 205880 | 03/13/2011 22:17 | 205839 | 03/13/2011 22:30 |
| 205861 | 03/13/2011 22:17 | 205880 | 03/13/2011 22:31 |
| 205846 | 03/13/2011 22:18 | 205855 | 03/13/2011 22:31 |
| 205861 | 03/13/2011 22:18 | 205855 | 03/13/2011 22:32 |
| 205880 | 03/13/2011 22:19 | 205855 | 03/13/2011 22:32 |
| 205883 | 03/13/2011 22:19 | 205847 | 03/13/2011 22:33 |
| 205861 | 03/13/2011 22:19 | 205888 | 03/13/2011 22:34 |
| 205860 | 03/13/2011 22:19 | 205861 | 03/13/2011 22:35 |
| 205882 | 03/13/2011 22:19 | 205885 | 03/13/2011 22:35 |
| 205882 | 03/13/2011 22:19 | 205885 | 03/13/2011 22:35 |
| 205861 | 03/13/2011 22:19 | 205840 | 03/13/2011 22:37 |
| 205848 | 03/13/2011 22:20 | 205852 | 03/13/2011 22:41 |
| 205884 | 03/13/2011 22:20 | 205838 | 03/13/2011 22:42 |
| 205853 | 03/13/2011 22:20 | 205838 | 03/13/2011 22:56 |
| 205839 | 03/13/2011 22:20 | 205847 | 03/13/2011 22:59 |
| 205845 | 03/13/2011 22:20 | 205846 | 03/13/2011 23:17 |
| 205884 | 03/13/2011 22:20 | 205838 | 03/13/2011 23:18 |
| 205851 | 03/13/2011 22:22 | 205850 | 03/13/2011 23:23 |
| 205887 | 03/13/2011 22:23 | 205838 | 03/13/2011 23:56 |
| 205860 | 03/13/2011 22:24 | 205838 | 03/13/2011 23:57 |
| 205888 | 03/13/2011 22:24 | 205838 | 03/14/2011 00:22 |
| 205840 | 03/13/2011 22:27 | 205852 | 03/14/2011 00:41 |
| 205880 | 03/13/2011 22:27 | | |

Device reported by the Utility: 20559

**Figure A.16 Simulation result for 03/13/2011**




# Case 16

**Figure A.17 Circuit diagram and call scenario for 04/13/2011**

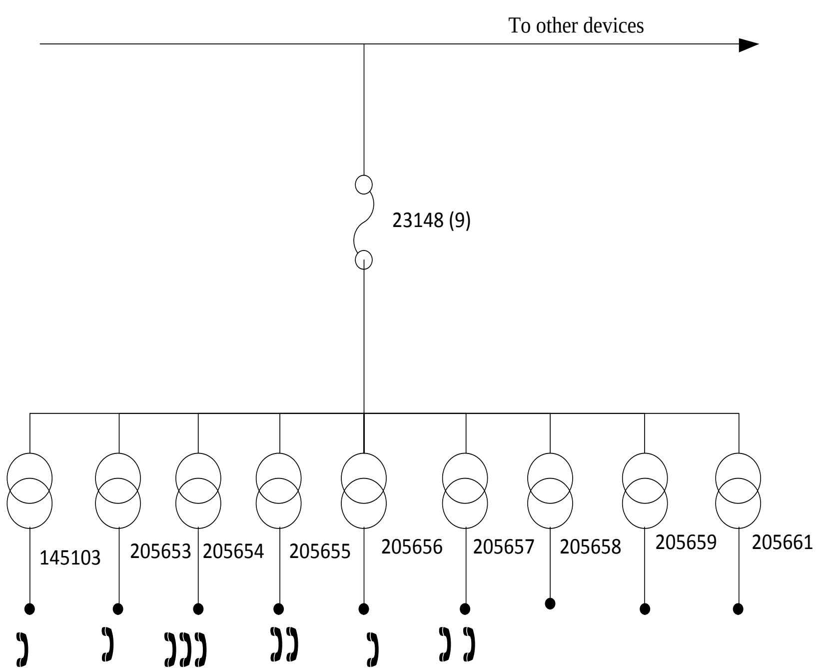
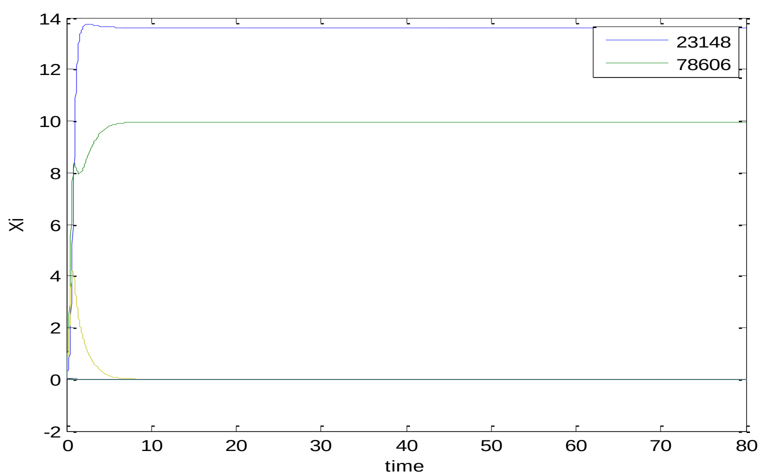


**Table A.9 Events of 04/13/2011**

| Device ID | Date/Time of the Call |
|---|---|
| 145103 | 04/13/2011 10:16 |
| 205653 | 04/13/2011 10:16 |
| 205654 | 04/13/2011 10:16 |
| 205654 | 04/13/2011 10:17 |
| 205655 | 04/13/2011 10:18 |
| 205657 | 04/13/2011 10:19 |
| 205655 | 04/13/2011 10:21 |
| 205657 | 04/13/2011 10:22 |
| 205656 | 04/13/2011 10:40 |
| 205654 | 04/13/2011 17:08 |

Device reported by the Utility: 23148

**Figure A.18 Simulation result for 04/13/2011**



# Case 17

**Figure A.19 Circuit diagram and call scenario for 8/1/2011**

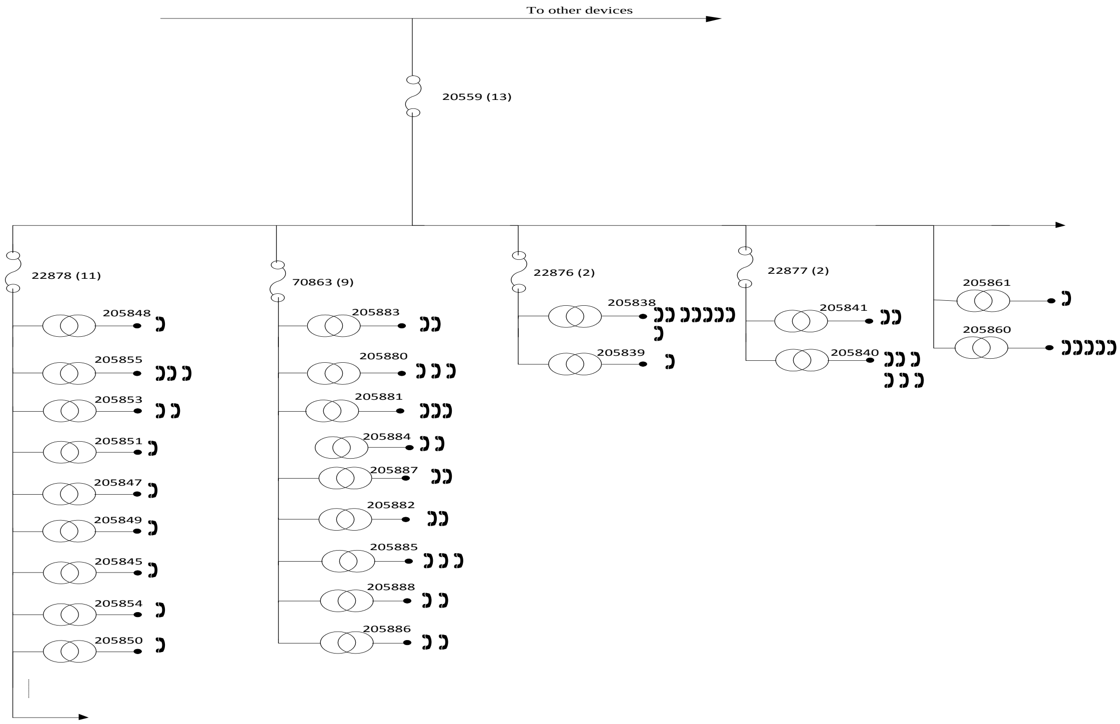


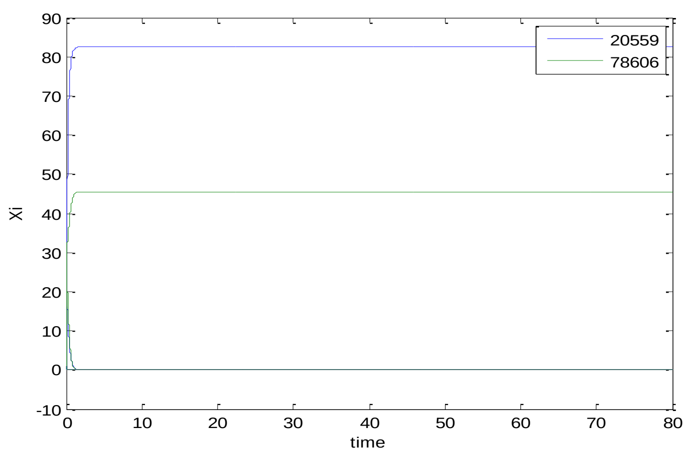

**Table A.10 Events of 8/1/2011**

| Device ID | Date/Time of the Call | Device ID | Date/Time of the Call |
|---|---|---|---|
| 205853 | 08/01/2011 17:50 | 205881 | 08/01/2011 18:05 |
| 205883 | 08/01/2011 17:50 | 205886 | 08/01/2011 18:05 |
| 205887 | 08/01/2011 17:50 | 205838 | 08/01/2011 18:06 |
| 205855 | 08/01/2011 17:51 | 205885 | 08/01/2011 18:07 |
| 205838 | 08/01/2011 17:52 | 205851 | 08/01/2011 18:09 |
| 205847 | 08/01/2011 17:52 | 205855 | 08/01/2011 18:10 |
| 205883 | 08/01/2011 17:53 | 205840 | 08/01/2011 18:12 |
| 205884 | 08/01/2011 17:53 | 205854 | 08/01/2011 18:12 |
| 205881 | 08/01/2011 17:53 | 205848 | 08/01/2011 18:13 |
| 205860 | 08/01/2011 17:53 | 205860 | 08/01/2011 18:14 |
| 205855 | 08/01/2011 17:53 | 205855 | 08/01/2011 18:14 |
| 205882 | 08/01/2011 17:54 | 205849 | 08/01/2011 18:16 |
| 205853 | 08/01/2011 17:54 | 205845 | 08/01/2011 18:21 |
| 205880 | 08/01/2011 17:55 | 205838 | 08/01/2011 18:21 |
| 205840 | 08/01/2011 17:55 | 205888 | 08/01/2011 18:22 |
| 205880 | 08/01/2011 17:56 | 205838 | 08/01/2011 18:22 |
| 205882 | 08/01/2011 17:56 | 205838 | 08/01/2011 18:24 |

| | | | |
|---|---|---|---|
| 205840 | 08/01/2011 17:56 | 205886 | 08/01/2011 18:25 |
| 205838 | 08/01/2011 17:56 | 205883 | 08/01/2011 18:27 |
| 205881 | 08/01/2011 17:57 | 205840 | 08/01/2011 18:28 |
| 205884 | 08/01/2011 17:58 | 205840 | 08/01/2011 18:28 |
| 205885 | 08/01/2011 17:58 | 205840 | 08/01/2011 18:30 |
| 205838 | 08/01/2011 17:59 | 205838 | 08/01/2011 18:32 |
| 205887 | 08/01/2011 17:59 | 205885 | 08/01/2011 18:32 |
| 205841 | 08/01/2011 17:59 | 205861 | 08/01/2011 18:32 |
| 205880 | 08/01/2011 18:01 | 205850 | 08/01/2011 18:32 |
| 205888 | 08/01/2011 18:04 | 205839 | 08/01/2011 18:34 |
| 205841 | 08/01/2011 18:04 | 205860 | 08/01/2011 19:20 |
| 205860 | 08/01/2011 18:05 | 205860 | 08/01/2011 19:21 |

Device reported by the Utility: 20559

**Figure A.20 Simulation result for 8/1/2011**



## Case 18

**Figure A.21 Circuit diagram and call scenario for 7/24/2011**

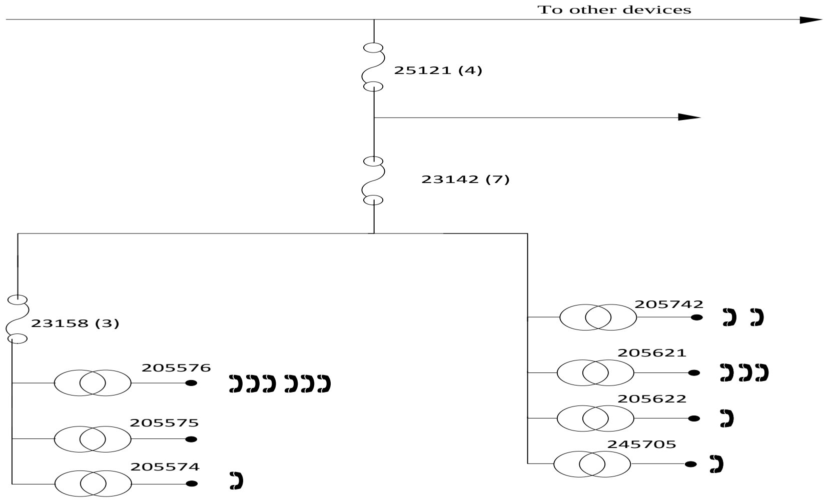



**Table A.11 Events of 7/29/2011**

| Device ID | Date/Time of the Call |
|---|---|
| 205742 | 07/24/2011 21:47 |
| 205621 | 07/24/2011 21:51 |
| 205622 | 07/24/2011 21:58 |
| 219596 | 07/24/2011 22:12 |
| 205576 | 07/24/2011 22:28 |
| 245705 | 07/24/2011 22:40 |
| 205621 | 07/24/2011 22:53 |
| 205576 | 07/24/2011 22:53 |
| 205576 | 07/24/2011 23:04 |
| 205574 | 07/24/2011 23:07 |
| 205576 | 07/24/2011 23:27 |
| 205576 | 07/24/2011 23:27 |
| 205621 | 07/24/2011 23:29 |
| 205576 | 07/24/2011 23:56 |
| 205742 | 07/25/2011 00:16 |

Device reported by the Utility: 23142

**Figure A.22 Simulation result for 7/29/2011**