

OPEN MAIN DETECTION IN UNDERGROUND DISTRIBUTION NETWORK  
USING STATISTICAL APPROACHES

by

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## ABSTRACT

### OPEN MAIN DETECTION IN UNDERGROUND DISTRIBUTION NETWORK USING STATISTICAL APPROACHES

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The continuous increase for people dependency on electrical energy to run most of their industrial, commercial and residential activities makes it necessary to regularly improve the distribution systems. This Improvement does not involve served area and system capacity increase only, but also includes service quality and system reliability enhancement.

Outage is the most serious challenge that might affect the reliability of the distribution system, especially in the congested areas like New York City, where the outage is a threat for continuity of service for a large number of customers or for the important world institutions there. Outage incident in distribution networks normally leads to onerous financial losses as customer reimbursements and faulty equipment fixing or replacement.

Accumulation of unrepaired secondary open main incidents causes a network deficiency especially in high load season due to the limited available paths to deliver customers loads. Most of times, such situations overload some network equipment that put the correspondent protection devices in action and eventually cause outage incident. Consolidated Edison Company of New York maintains a reliable distribution system in one of the biggest cities, the occurrence of limited

outage incidents during the last years makes it essential requirement to implement an automatic open main detection mechanism as possible causer for some incidents to protect the system reliability from same events in the future.

This novel study presents an effective detection system for open main and transformer outage incidents using statistical approaches. Based on periodic network transformers loads readings provided by Remote Monitoring System (RMS), any transformer load change exceeds the normal load change boundary will be listed as suspect event to be analyzed. Sensitivity analysis is implemented in this study based on the actual real time transformer load changes and pre-calculated values for transformer load changes for each expected incident in the network. The calculated values can be obtained using power flow program (Poly Voltage Load Flow PVL).

Transformer outage sensitivity analysis is implemented on the suspect event taking into consideration the load response at most nearby transformers. According to this part results, open main incident sensitivity may be launched to confirm or banish the open main incident depending on the response of near by transformers. Those transformers can be determined as the most affected nearby transformers according to pre-calculated values for each possible open main location.

Eventually, detailed report supported by chart plots is issued to identify the nature of the incident (is it transformer outage or open main incident), to indicate the transformer or the main at which it took place and to list the real time load changes for all the network transformers included in the sensitivity analysis. All of that to facilitate an immediate repair of the faulty part and to easily investigate the incident root causes to be avoided later and eventually improve the distribution system reliability.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Background

Since system reliability is the principal criterion affecting the consumer's satisfaction on the supplied electric service performance, it becomes one of the greatest concerns of the power suppliers to continuously maintain uninterrupted service with high quality standards. IEEE dictionary defines the system reliability as: " the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure". That raises the importance of identifying all possible failures causes in addition to the necessity of real time performance monitoring and early detection for equipment failure, where failed equipment needs to be replaced or maintained quickly to avoid wide area outage due to failures accumulation over extended period of time.

Some failures that affect the reliability of distribution system happen more often in most of systems due to the similarity in the installed equipment (overhead or underground networks). Singularity of some networks due to the system design, load demand intensity, equipment aging, area weather or repeated upgrading and extensions not only brings up some types of faults more often than they should, thereby affecting the reliability of the system, but also makes it difficult to locate or diagnose the problem due to the difficulty in figuring out the present system configuration. In such cases, increased hours are needed to restore the system, a matter that deeply affects the reliability according to the common consideration used to evaluate the network reliability.

The accumulation of undetected open circuit in secondary mains is one of the most challenging fault incidents in distribution systems, especially without implementation of suitable monitoring mechanism introduces early indications about such incidents occurrence. Such implementation facilitates the mission of the maintenance team to locate and replace the faulty

parts and, therefore, protect the network from possible incoming service interruption or decrease the interruption duration, the thing which worthily improves the system reliability.

### 1.2 Secondary Distribution Network Challenges

Some times and especially in high load seasons, the operation of secondary distribution network encountered by internal or external events that affect the whole distribution system reliability and performance, below some of them are explicated.

#### *1.2.1 Network outage*

Outage is a network harmful event that affects the reliability of the distribution system. It normally takes place as a response for certain operation abnormality in one or more of network equipment or as a result of external factors. Some of the most common outage causes include:

- Dig-in cable area.
- Flood.
- Power shortage.
- Power equipment failure.
- Human control and operation mistakes.
- Protection system action.

#### *1.2.2 Effects of Open Main / Blown Limiter incident*

If the open main incidents are not detected one by one, long term secondary distribution network performance will be affected due to the appearance of the following serious challenges:

- Load increased at some transformers around the incident location to high level that exceeds transformer KVA rating, especially during peak load time that may lead to put the transformer protection in operation.

$$\sum_{\substack{n \neq T.out \\ n=1}}^N (\Delta S_{T.n})(P.F_{T.n}) = (S_{T.out})(P.F_{T.out}) + \Delta P_{losses} \quad (1.1)$$

$$[S_{T.n} + \Delta S_{T.n}] \geq S_{T.n.Rated} \Rightarrow \text{Over heat / Protection device operation} \quad (1.2)$$

$\Delta S_{T.n}$  : Transformer (n) total power (KVA) change due to transformer ( $T.out$ ) outage.

$P.F_{T.n}$  : Power factor for transformer number (n).

$S_{T.out}$  : Total power (KVA) for the disconnected transformer by blown limiter ( $T.out$ )

$\Delta P_{losses}$  : Network power losses change due to transformer ( $T.out$ ) outage.

$S_{T.n.Rated}$  : Rated KVA of transformer  $T.n$ .

- If one transformer or more becomes out of service for any reason, the load flow through secondary mains will be redistributed in a different way than that the network is initially designed to. That leads to more losses in the secondary network as it explicated in section 1.2.5
- Open Main incidents in heavy load conditions lead to overloading the network equipment like underground cables and transformers, which may last for long period and may eventually cause manhole fire.

### 1.2.3 Manhole Fires

Manhole fires are a serious challenge to distribution companies which implement an underground network system. Due to manhole fires, risky work conditions might harm the utility crew or nearby pedestrians. In addition, manhole fires pose possible power service interruption for the nearby customers.

Some causes for such incidents can be referred to experiencing over limit operation in one or more of the network components laid inside, overload in underground cable leads to increased temperature around the cable, especially in heavy load periods. The arc fault is one of the most frequent incidents in winter due to the infiltration of the snow solvent inside the manhole and finally reaching cable junctions. Furthermore, network transformer cooling oil temperature increase to a high enough level to produce explosive and inflammatory reaction is the most flame producing incident, this typically happens as a response to over loading the transformer for long time during high temperature season. The accumulation of undetected and repaired network open mains increases the chance of a manhole fire.



### 1.2.4 Utility Financial Losses as Customers Reimbursements

Utility is responsible for providing uninterrupted and high quality service for its customers all the time regardless of the season or how high the demand is. Therefore, the utility may have to reimburse the customers for their losses as a result of the service interruption or irregularity referred to control malfunction, equipment failure or employees negligence. As an example, according to regulations and rules for Consolidated Edison Company of New York; the company will compensate each residential customer for his/her losses due to lack of refrigeration up to maximum of \$350 and up to maximum of \$7000 for each commercial customer for any one incident, limited to \$10,000,000 per incident as company's total liability.

### 1.2.5 Open Main Effect on Secondary Distribution Network Losses

The underground secondary network in heavily crowded areas is normally designed to supply each load by several points therefore increasing the system reliability incase of main disconnection or blown fuse at one side.

Because the losses are proportional to the square value of load current, the losses in the multi fed points secondary main are less than those for the main supplied from one side due to undetected open main incident at the other side. To illustrate that, Figure 1.1 shows a sample case for secondary main that is feeding (n) equal customer loads.

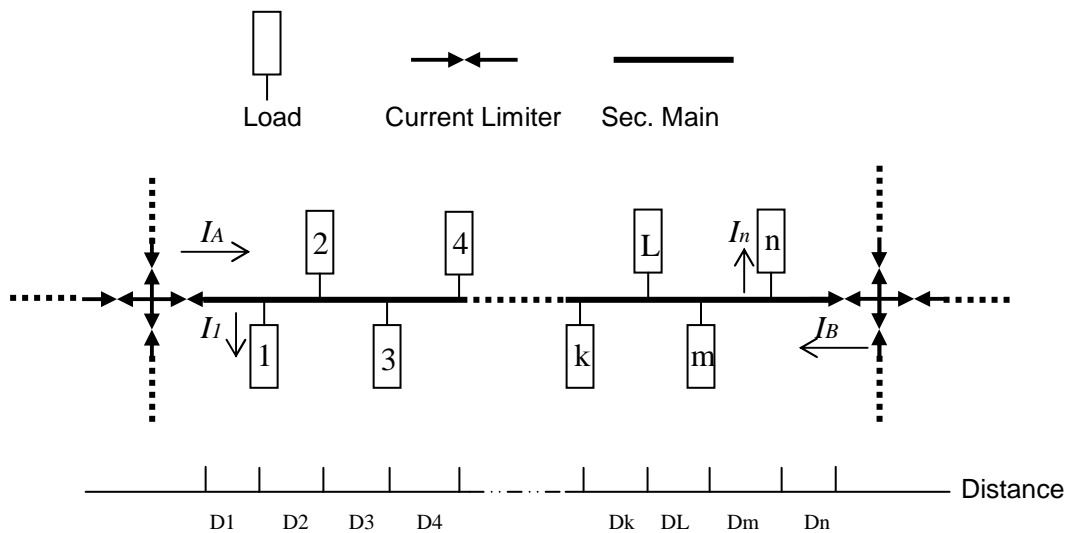


Figure 1.1 Secondary main with equal value and space connected loads

Assume that those loads are equally distributed along the length of the main. The drop ratio in the secondary main losses between the healthy operation case (two side-fed main) and one side fed main for different number of (n) can be concluded from Figure 1.2.

$$D_1 = D_2 = D_n \quad (1.3)$$

$$Z_{load1} = Z_{load2} = \dots = Z_{load.n} \quad (1.4)$$

$$Z_{D1} = Z_{D2} = \dots = Z_{Dn} \quad (\text{Secondary main section impedance between m and n}). \quad (1.5)$$

$$P_{losses} (2.side) = \sum_{i=1}^{\frac{n}{2}} I_{DA,i}^2 \times R_{Di} + \sum_{f=\frac{n}{2}+1}^n I_{DB,f}^2 \times R_{Df} \quad (1.6)$$

$$P_{losses} (1.side) = 2 \times \sum_{i=1}^{\frac{n}{2}} I_{Di}^2 \times R_{Di} \quad (1.7)$$

$$I_{A.Di} = I_A - \sum_{j=1}^i I_j, \text{ IA value while passing Di main section.} \quad (1.8)$$

$$I_{B.Df} = I_B - \sum_{h=n}^f I_h, \text{ IB value while passing Df main section.} \quad (1.9)$$

$R_{Di}$  : Section (Di) resistance.

$P_{losses}$  : Total power losses in the main.

One-side fed secondary main operation may last long if no automatic mechanism to detect the open main incident and no load outage is reported while the other side is still connected, which is a risky situation from reliability point of view and a considerable cause for additional secondary network losses.

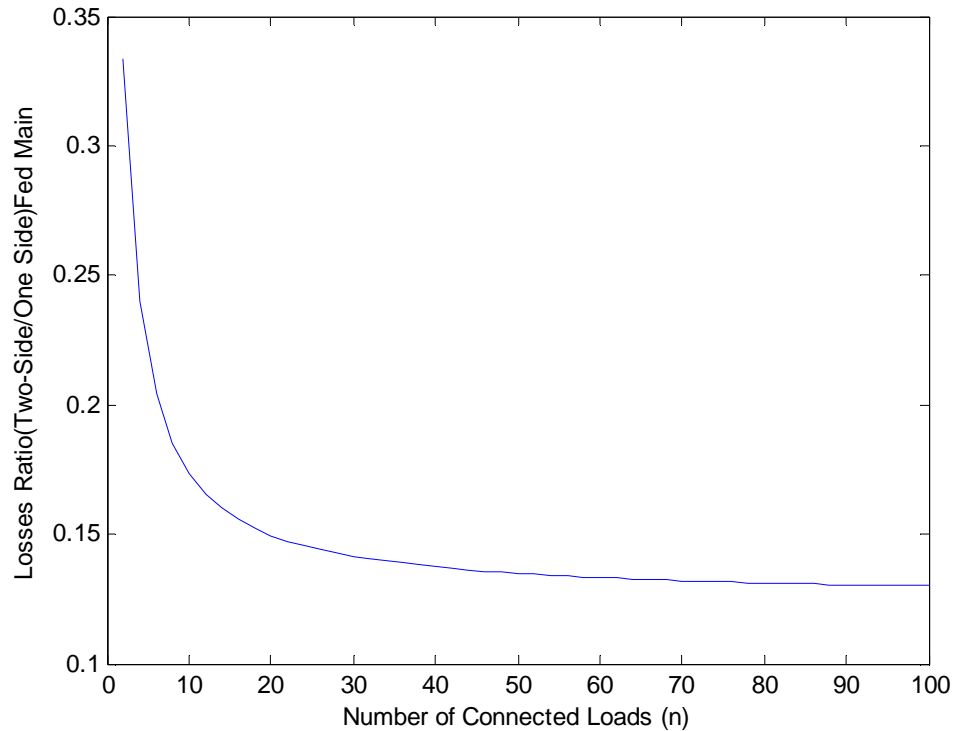


Figure 1.2 Losses Drop Ratio Comparison for Two and One-Side Fed secondary Main

### 1.2.6 Blackout in Distribution System

Blackout incidents are rare, but the huge effects that they usually leave in the economic, security and psychical life of the individuals, plants, companies and utility itself make it essential to investigate any possible causes for such events, in addition to particularize many researches to enhance the operational environment, equipment specifications, protection schemes and faulty parts early detection monitoring. These requirements aim to minimize the future possibility for same incidents repetition and eventually to improve the service quality currently supplied.

Consolidated Edison Company of New York supplies one of the most important and highly loaded areas in the world that explicates Con Edison's concern to maintain a high reliability system. The system experienced small number of blackout incidents in the past. In

July 6th, 1999 Con Edison's Washington Heights Network power outage took place during high heat and humidity wave where approximately 170,000 customers experienced service outage for different periods of time that reached to 19 hours in some areas.

According to a report from the Office of the Attorney General to the people of the state of New York on March 9, 2000:

- They concluded that the cause of this outage mainly was due to the increase in system demand during that hot weather days while the distribution system suffering from inadequate or defective components.
- Also the report mentioned to the long period of time taken to restore the failed parts and cables in the outage area.

This report shows the need for a detection mechanism which is capable of detecting and locating the incoming failure or open in the secondary mains as very important parts in the distribution system. The repeated undetected open main incidents might lead to load redistribution in the mains and network transformers in a way completely different from that the network was designed to operate with. This may lead to overload some network components at high load situation; this overload normally involves the network transformers outages that could possibly cause transformer cascade outages or an increase in the load at some feeders and a decrease at others.

During the last years, Con Edison invested billions of dollars to upgrade, reinforce the distribution system and to improve system reliability. Just 2008 alone, Con Edison has invested \$1.7 billions in order to:

- Install 1700 new transformers
- Create two new substations.
- Install 989 miles of secondary cables, in addition to install and replace 900 miles of primary cable.
- Install 51 new feeders in addition to reinforcing other exist 246 feeders.

Moreover, it is expected to invest 5.2 billion dollars for the next three years, which reflects the observance of Con Edison to improve the system reliability and performance.

Open main detection approach implemented in this dissertation goes through Con Edison secondary distribution system components as one of the most complicated distribution structure, to figure out an effective real time monitoring and early detection mechanism for such incidents that mitigates the undesired consequences and makes the restoration process faster and easier.

### 1.3 Study Objectives

The network of Con Edison, (the company supplies New York City), has experienced power outage due to open main incidents. As a continuation for Con Edison's efforts to keep their reliable system supplying the current high quality service, such open main incidents are considered as a serious threat for the system reliability.

According to Con Edison present system operations, actual network configuration and the available data sources, this novel study aims to develop a transformer outage and an open main incidents detection algorithm. Con Edison distribution system includes many large networks that make the installation of new sensors or other detection equipment a non applicative choice, high-priced and time consuming approach.

Taking all of these challenges into consideration, study objectives can be summarized by:

- Present a novel mechanism using three statistical approaches (Transformer Load Change Rate, Unbalance Change Rate, and Estimated Value) to identify the abnormal behavior in the incoming readings for any network transformer. The readings are received periodically by Remote Monitoring System (RMS). Previous normal day load change for each transformer is prepared to form boundary for the normal load change,

- If any real time load change exceeds the normal load boundary, this event declared as initial suspect event.
- Refine the suspect event according to the load responses in the nearby transformers to confirm this event as suspect incident or banish the occurrence of transformer outage or open main incident.
- Calculated load changes for all network transformers in case of every possible open main or transformer outage to identify the most affected ones and list them in specific matrices.
- Implement sensitivity analysis according to real time load changes obtained by RMS to determine the most possible location for the open main incident if it actually took place or transformer name at which the outage occurred.
- This study deals with the data of each phase separately (phase by phase process), to consider the differences between the phases loads of the same transformer. This criterion is essential, especially if the incident took place in one or two phases.

Using LABIEW, the RMS readings are processed as soon as they are delivered to the Windows environment from the UNIX unit at Con Edison data network. Logical conditions and comparisons needed to figure out transformer outage or open main incidents are precisely constructed to reach to the most possible incident location and to exclude those that do not satisfy the conditions. That facilitates and fastens the maintenance crew mission especially in outage periods.

To make it easier for the user to follow every detected incident, a detailed report supported by figures for every incident to show the load at all transformers involved in this detection process before and after the change.

#### 1.4 Study Motivation

Open main incident is one of the most serious incidents that harms the reliability of the systems implementing the underground network design. The shortage in a detection mechanism able to detect and locate the open incidents leads to accumulation of open mains in many networks that weaken the system and makes it more subject to local outage incidents or complete network blackout. Also this shortage is responsible for the difficult and time consuming repairing process in the absence of any monitoring tools that indicate the occurrence and incident location.

Without costly and time consuming installation for new equipment, this study introduces a novel mechanism based on statistical approaches to detect the incoming open main incident. This helps identify the faulty mains one by one as soon as a fault takes place.

Locating and repairing of open main incidents positively influence the reliability of the distribution system and help the network to avoid the risky consequences may appear due to the accumulation of unrepaired open mains. Detecting and locating open mains also protects the distribution companies from the burden of customer reimbursements and losing revenue that might reach millions of dollars for one incident.

Moreover, early open main detection contributes to keeping the system safe from possible outage incidents, these incidents, most of the time; leave considerable psychological, security and economical side effects on the inhabitants.

For all of that, this study is particularized to present a detection system serves to provide an early detection and locating for the open main incidents may take place at Con Edison system. The study will go through Con Edison system first, then proposed approaches and analysis process will be presented.

Chapter two describes some of Con Edison System components, introduce a description for the challenge of the open main incidents on the system, and reviews two previous related works.

While chapter three presents three statistical approaches developed by this study to detect the abnormal change in the transformer load supported by the actual data examples. Transformer outage and open main sensitivity analysis process are also explained in details.

Chapter four is particularized to study implementation and test part, describes the use of MATLAB as test tools, test input data and output report. Chapter five shows some results for actual open main and transformer outage incidents that are automatically detected, in addition to output detailed reports for incident circumstances. Also double check information is included to test the results creditability.

Chapter six indicates study contribution, future work to be accomplished and concluding remarks.



## CHAPTER 2

### OPEN MAIN INCIDENTS

Open circuit in one of the underground cables forming the low voltage grid is possible to happen any time as long as the causes for network equipment overloading are foreseen. The repair process of open main in any network is a matter of three issues:

- Incident detection capability.
- Ability of open main incident locating.
- Nature of the open circuit: is it due to blown current limiter, melted cable section or cable cut caused by external digging?

It is not only required to have an effective system to detect the open main incident, but it is also necessary to locate the most possible open main locations for this event. Incident locating reduces the time needed for faulty equipment replacement and indicates the trouble areas in the network. That effectively benefits the operators in their diagnostic and remedial analysis for incident root causes.

#### 2.1 Consolidated Edison Company of New York, Inc.

Consolidated Edison Company of New York, Inc. (Con Edison) is a regulated utility provider for the services of steam, gas, and electricity with \$12 billion annual revenues and \$28 billions assets. It serves nearly nine million people spreading through 660 square miles of high density load areas reaching 2100MW per square mile in some networks. It supplies 13 GW of total networks electric peak load that covers the electrical energy demand for very important area. Con Edison distribution system includes 60 underground networks at (Manhattan, Brooklyn, Queens, Bronx, and others), the network is fed by number of primary feeders (from 8

to 28) at voltage level of 4kV,13kV, 27kV or 33kV with approximate total primary feeder cables length 17,000 miles.

### 2.2 Con Edison Secondary Network Components

Secondary Network is the electric grid connected to the network transformers secondary sides (low voltage), where 80% of the customer load is supplied by underground mesh-type network. The underground network serves to avoid overhead conductors congestion and to obtain better service reliability and higher quality service. Currently, Con Edison has 60 underground networks to server its loads. Each secondary network different voltage levels (208/120V, 240/120V and 460/265V) are supplied by 250-750 network transformers. Which all fed from one area substation through 12-24 primary feeders which usually serve 7,500 to 75,000 customers.

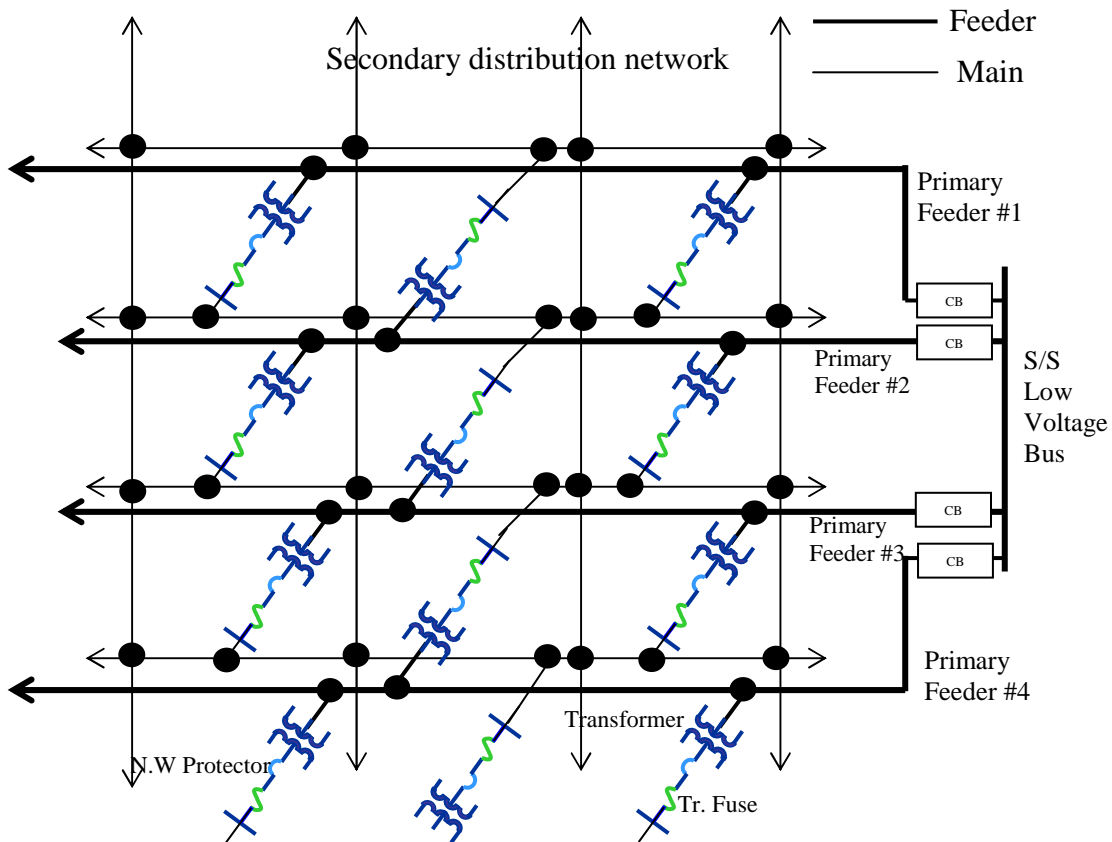


Figure 2.1 Small Section for a Typical Underground Secondary Network

Secondary distribution networks installed in Con Edison system are both overhead and underground systems, Figure 2.1 shows a simplified small section of the underground network design.

Underground network design is implemented in most of Con Edison secondary networks for the following reasons:

- The congested area makes it difficult to install overhead network equipment.
- These networks serve high density commercial and residential areas which require better reliability services and well regulated voltage at the customer side.
- To obtain high reliability electric service in any weather and environmental situations.

The network transformers are located in a manner that shows equal load distribution and minimum voltage drop. To ensure better reliability, each transformer should be connected to primary feeder different from that the adjacent transformer is connected to.

Each network is supplied by only one substation to avoid differences in substations voltages which normally lead to extra VAR flow in network components, that might be overloaded in case of high load season, and also to avoid network protector operation that could be caused by reverse power flow in light load case as a response to differences in substations voltage angles.

### *2.2.1 Secondary Mains*

Most of Con Edison secondary mains are 3 phase - 4 wire underground cables (4\*500 MCM copper, 600V rubber/neoprene insulated). The cables are installed in duct lines under street and manholes with enough space to include the cable connections and limiters; the neutral wire used in secondary networks is "full size" bare neutral cable.

Selection of the secondary main cable cross section area should take into consideration the maximum load it may carry to maintain good voltage regulation at any load level. The voltage drop under normal load cases must be less than 3% along the secondary mains.

Current limiters are installed in Con Edison secondary networks at the junction of the secondary mains to limit the damage that may be resulted from faults or over loaded equipment.

#### *2.2.2 Current Limiters / Fuses*

Melting links provide protection action once the passing current exceeds the rating value based on time-current characteristic. For many years, the protection of the secondary mains in case of cable failure was based on self-clearing as long as the fault current still exists, sometimes it does not work, and the fault would not burn clear which may lead to serious cable damage, manhole fires, and service interruption. In 1936 Con Edison started installing current limiters (high capacity fuses) at both secondary main sides and junctions to isolate the faulty or overloaded sections, therefore achieving fast clearing before network transformer failure.

#### *2.2.3 Network Transformers*

The majority of Con Edison network transformers are having one of the following ratios: (13kV, 27kV, 33kV or 4kV) /208V with standard sizes of 500, 1000, 2000 or 2500 KVA. 4% is the percent impedance for all of the above transformers, except 3.5% for those with (4kV/216V) ratio and 500kVA size. The typical cooling method for the Con Edison network transformers is Self Cooled-Oil Filled.

#### *2.2.4 Distribution Substations*

The distribution substations are the power source for distribution network primary feeder as shown in figure 2.1. The input for most of these substations is 138kV transmission lines, while the output is (4, 13, 27 or 33) kV primary feeders. Substation should be as close to the load centers as possible. The location of the substations depends on environmental, economical and future load growth considerations.

### *2.2.5 Network Protector*

The network protector is a metal case that includes air circuit breaker mechanism governed by phasing and network master relays, with back up fuse for primary and secondary faults if network protector breaker operation fails. Network protector as protection equipment serves to:

- Isolate the network transformer automatically from faulted primary feeder while the substation-feeder circuit breaker is open, to prevent the reverse power flow from the secondary to primary side.
- Provide automatic closure whenever the actual network transformer voltage magnitude equals or slightly exceeds network voltage with (2V) in phase or slightly lead phase.

The operation of the relay inside the network protector is governed by one of the following modes:

- Sensitive Mode: where network protector relay trips instantaneously once the reverse power flows.
- Intensive Mode: the tripping takes place only if the reverse current is equal to or greater than the transformer full load current.
- Delayed Sensitive Mode: operation in this mode depends on reverse current value:
  - If the reverse current is less than the half of transformer full load current, relay operation will be delayed.
  - If the reverse current is equal to or greater than the half of transformer full load current, the relay will trip instantaneously.

### *2.2.6 Vaults and Manholes*

Vaults and Manholes are usually used in high load density areas, where overhead equipment installation is inefficient for environmental reasons, construction constraints, maintenance difficulties and additional economical considerations that challenge the implementation and operation of such design. The cables placed in ducts connect the

transformers and other equipment inside manholes and vaults with each others to deliver the power to service boxes nearby the customers.

### 2.3 Statement of Problem in Con Edison System

On 1936, Con Edison installed current limiters (fuses) in the underground networks at the junctions of two or more secondary mains to limit the damage that may be produced by faults or overloaded equipment. The secondary network is designed to supply each customer load by secondary main fed by multi current paths to ensure better reliability in case of blown limiter incident at one main. Such incidents that normally blow the current limiter at one side of the main. This open will not be sensed by the customer if the other side is still connected to the grid. Since such incidents are also not detectable by distribution protection or monitoring equipment, accumulation of open secondary mains might lead to redistribute the load flow in undesired manner that overloads some network equipment, interrupts the service for certain number of customers or causes local area outage which all affect the reliability of the distribution system.

Developing an effective open main detection system is essential for all distribution systems installing the underground networks for following reasons:

- The previous outage incidents took place in some networks and caused by open main incidents.
- The high reimbursement value paid to the customers in case of outage incident.
- The long period needed to repair the affected equipment and to restore the system with out this mechanism.
- Psychological, convenience and security side effects may impact the inhabitants during the period of possible outage especially if it involves early night hours.

Currently, the detection of some of these incidents is fortuity matter that shows up in case of service interruption for the customer fed by that main, which explicates the need for a

specific study about the open main challenge in this system takes into consideration the singularity of actual system configuration.

For all of that, this dissertation was particularized to develop a mechanism contribute to protect the distribution system of such big city from possible troublous incidents that may affect the most important and high crowded areas in the world.

#### 2.4 Literature Review

Open main or open conductor event is very common incident that frequently takes place in the secondary distribution systems. Most of the time, it leaves behind unreliable operation for the surrounding subsystem that might extend to involve all around areas leading to partial or complete black out if such incidents are not detected and maintained one by one.

A lot of researches have focused on improving the reliability of the system by concentrating on the other distribution system parts. A few have focused their research on open main incident detection as early as possible to reduce the impact of the above mentioned side effects.

The complexity of actual configuration of Con Edison underground distribution system makes it difficult to implement any research that addresses challenges if it is not particularized for Con Edison circumstances. Below is a review for previous related researches.

##### *2.4.1 Arcing Fault Detection and Location in Secondary Distribution networks by On-Line RMS Processing.*

This study was prepared for Con Edison 1998, by Energy Systems Research Center / University of Texas at Arlington. Based on network transformer readings that show large enough current change in case of fault, a method was developed by this study for online arcing fault incident detection in the secondary distribution network. That can be analyzed according to the transformer at which the change takes place to confirm the arcing fault occurrence and to give approximate location for the fault by including the nearby transformers responses into consideration. This study was prepared to the same distribution system but it deals with a different operation challenge.

### 2.4.2 Open Conductor System

A.C.Westrom, A.P.Sakis, G.J.Cokkinides, A.H.Ayoub, "Open Conductor detector System," *IEEE Transactions on Power delivery*, Vol. 7, No. 3, July 1992.

On Georgia Power Company Distribution System, prototype of open conductor detector system was constructed and tested, based on this paper, the authors proposed an open phase conductor detection system that consists of two main parts; transmitter and receiver. The open conductor incident can be detected according to the monitored voltage, through the neutral conductor and by transmitter and receiver communication channel. A coded signal indicates an open conductor incident, the signal can be transmitted and received and decoded at the other neutral conductor end by the receiver. This signal is initiated once the line voltage decreases below threshold value and coded at a different specific frequency from that of other transmitters, which is decoded and received by the receiver at the other end where the relay is located to isolate that line or to close the ground switch to blow the fuse.

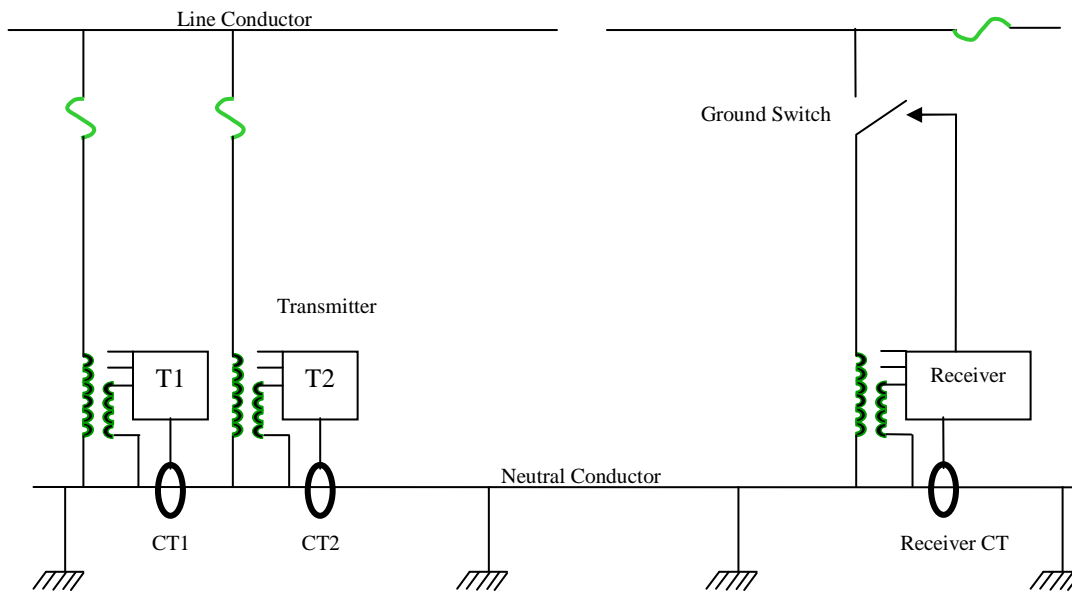


Figure 2.2 Open Conductor Detector Systems

An open main incident is an underground secondary distribution challenge, while an open conductor system is a protection mechanism for the overhead distribution system.



Moreover, the concept of installing new sensing and communication equipment is hard to implement in such big system like Con Edison system due to the high cost and the long installation time.

Therefore, this Dissertation is particularized to develop a new algorithm to detect open main events to cover the shortage in proper monitoring system for the secondary underground network.

#### *2.4.3 Design and Implement of Distribution Transformer Outage Detection System*

Hau-Ren Lu and Leether Yao, "Design and Implement of Distribution Transformer Outage Detection System," *Industrial Informatics*, 2007 5<sup>th</sup> IEEE International Conference, Volume1, 23-27, June 2007.

This study was prepared for Taiwan Power Company (TPS) to be compliant with currently installed operation Management System (OMS) to precisely locate the outage area to guide the maintenance team. Outage Detector System is installed at the secondary side of the distribution transformer to detect the voltage there, once the outage takes place, a signal will be sent to Outage Information Processing System (OIPS) by short message service SMS, where the signal is received at the by GSM modem system, also TOD returns a restore signal if the transformer is restored again.

This approach concerns on transformer outage incident, where the challenge of Con Edison underground distribution network requires a mechanism to detect also the open main incidents in the system. Implementing the communication method proposed by this paper is very costly and need for long time to install the correspondent equipment for huge number of Con Edison secondary mains and network transformers,

## CHAPTER 3

### OPEN MAIN DETECTION APPROACHES

The research implements three statistical approaches to detect any abnormal or unexpected change in the transformer load according to previous transformer load profile.

Abnormal event is recorded as tentative suspect event to be refined through a logical analysis process. The analysis takes into consideration the load change responses at the nearby transformers.

Any of the following approaches deals with each phase input data of any transformer separately, to achieve more precision in sensing the abnormal transformer load change that may appear in one phase or two phases only.

#### 3.1 Change Rate Approach

As listed in Table 3.1, for each phase in every network transformer, the difference between the just received load value reading from RMS and the previous one is calculated, to be compared with typical change for normal day load.

$$\Delta I_n = I_n - I_{n-1} \quad (3.1)$$

This comparison is implemented between two values:

- The value of real time load change.
- The prerecorded normal day load change value.

Table 3.1 Real Time Network Transformer Load Change Calculation

Reading (n)	Time/Date	Transformer Load			Change Rate		
		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	T1/D1	I <sub>A1</sub>	I <sub>B1</sub>	I <sub>C1</sub>	-	-	-
2	T2/D1	I <sub>A2</sub>	I <sub>B2</sub>	I <sub>C2</sub>	I <sub>A2</sub> - I <sub>A1</sub>	I <sub>B2</sub> - I <sub>B1</sub>	I <sub>C2</sub> - I <sub>C1</sub>
3	T3/D1	I <sub>A3</sub>	I <sub>B3</sub>	I <sub>C3</sub>	I <sub>A3</sub> - I <sub>A2</sub>	I <sub>B3</sub> - I <sub>B2</sub>	I <sub>C3</sub> - I <sub>C2</sub>

The predetermined values for transformer normal load change can be presented by two boundary curves (positive and negative) indicates the moving standard deviation for this load; where the real time transformer load change values are in-between.

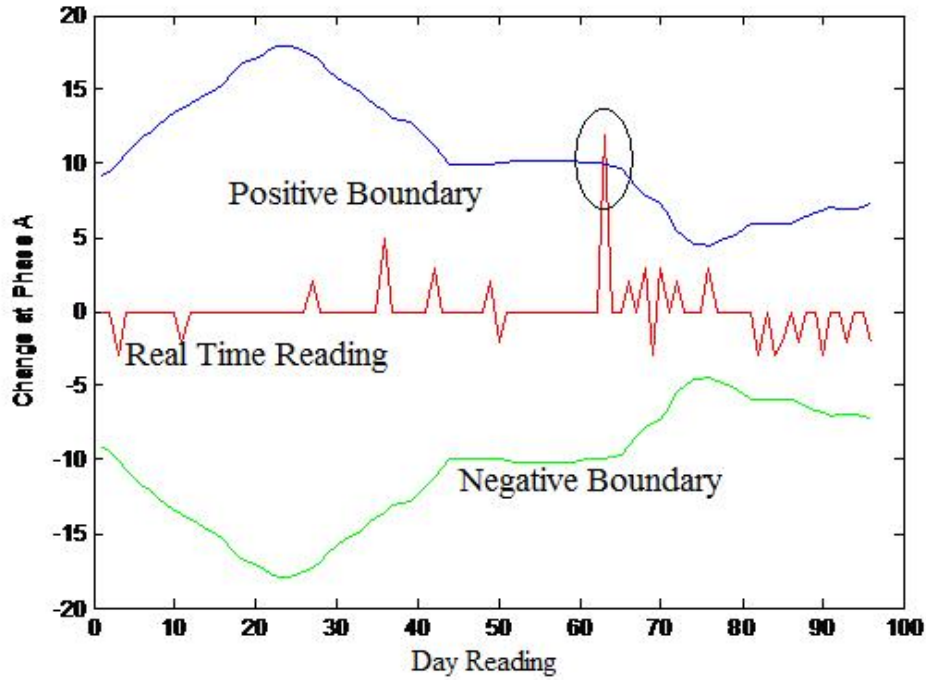


Figure 3.1 Real time load change and boundary curves for one day

Once the change in real time reading value exceeds the boundary, the event will be listed in the suspect list to be refined latter.

Each value in the boundary curve can be calculated using moving standard deviation for specific number of normal day samples ( $N_s=50$ ), which includes the event time normal reading plus ( $N_s-1$ ) readings before.

$$Q_n = \sqrt{\frac{1}{N_s} \sum_{i=b}^n (L_i - \bar{L})^2} \tag{3.2}$$

Where:

$Q_n$ : Standard Deviation for  $N_s$  normal day readings started by reading #  $b$  and terminated by  $n$ .

$N_s$ : Number of samples included by standard deviation calculation.

$L_i$ : Normal load reading #  $n$  in sequence.

$$\bar{L}: \text{Arithmetic mean of } N_s \text{ readings of transformer normal day load} = \frac{1}{N_s} \sum_{i=b}^n L_n$$

The number of normal-day load readings ( $N_s$ ) included every time in the standard deviation calculation is chosen to be 50 readings. This number is an intermediate value; not a small one that shows fast change in the standard deviation values and eventually many curvatures along the boundary curve, also (50) is not a big readings number that eliminates the special characteristic for each transformer normal load change curve.

Detection sensitivity can be adjusted to discover lower or upper change level for transformer load by multiplying the standard deviation boundary curve by proper curve level factor ( $K$ ) to expand or shrink the area enclosed between the positive and negative curves. Therefore the detection process will be more sensitive when ( $k$ ) factor value goes down.

For positive curve:  $Qc_{at.point.n} = k \times STD_n$  (3.3)

For negative curve:  $Qc_{at.point.n} = -k \times STD_n$  (3.4)

$Qc_n$ : Normal load curve value at day reading  $n$ .

$k$ : Boundary curve level factor.

$STD_n$ : Standard deviation for  $N_s$  normal load readings ended by reading  $n$ .

To be used in Standard Deviation Matrix (SDM) calculations, the selection of normal load readings among the previous recorded data for each transformer should satisfy the following requirements:

- The data should not contain any reading with zero value that assuredly indicates transformer outage and not a normal load variation.
- The readings should not have same value, or have one repeated value for a long period during the day. The values have to reflect the daily load profile for this transformer

which is clarified by the values of the moving standard deviation along this period of time.

- Any reading shows a sudden increase or decrease in value is not allowed to be included as a part of these calculations. This sudden change in value does not represent the actual load profile for any transformer. Most of the time such readings can be identified by the increase or decrease in the load value that reaches two or three times the transformer load rating.

The Boundary curve values are calculated for each phase from the correspondent transformer normal load change values. A similarity in the shape of the boundary curves for different phases may be noticed, which refers to the similarity of the transformer normal load of the different phases at that period. This is a considered criterion used while selecting a normal load change period for STD calculation, unless the nature of the connected loads always show different values for the different transformer phases.

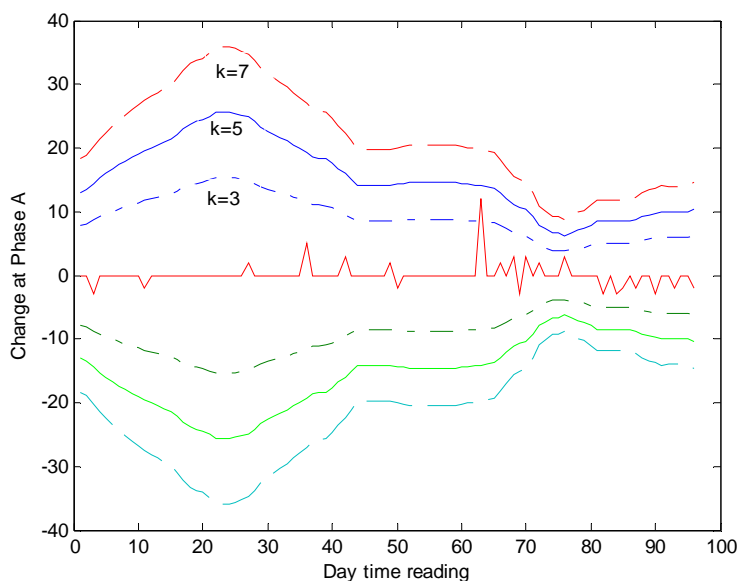


Figure 3.2 Effect of curve factor k on detection sensitivity

### 3.1.1 Change Rate Detection for Three Load Change

As examples to network transformer load change in the three phases at the same time, and in one phase only, the following two subsections explicate the figures for two actual cases obtained from RMS data that show the performance of this approach in detection of such type of changes.

Figure 3.3 shows the simultaneous increase in the three phase real time load of this transformer.

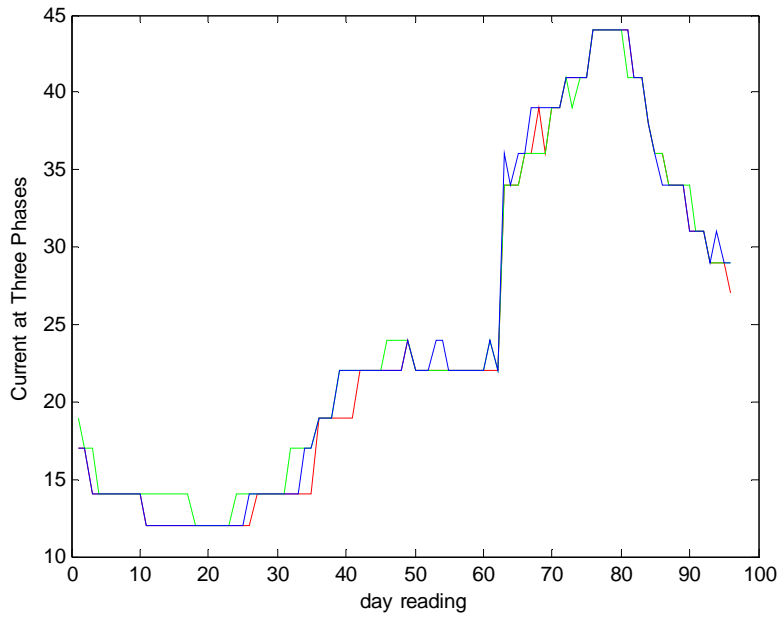


Figure 3.3 Time-Current Curves for Limited Three Phase Load Change

Figure 3.4 shows the detection of abnormal load change at phase A, that exceeds the normal day load change boundary for the same transformer and phase.

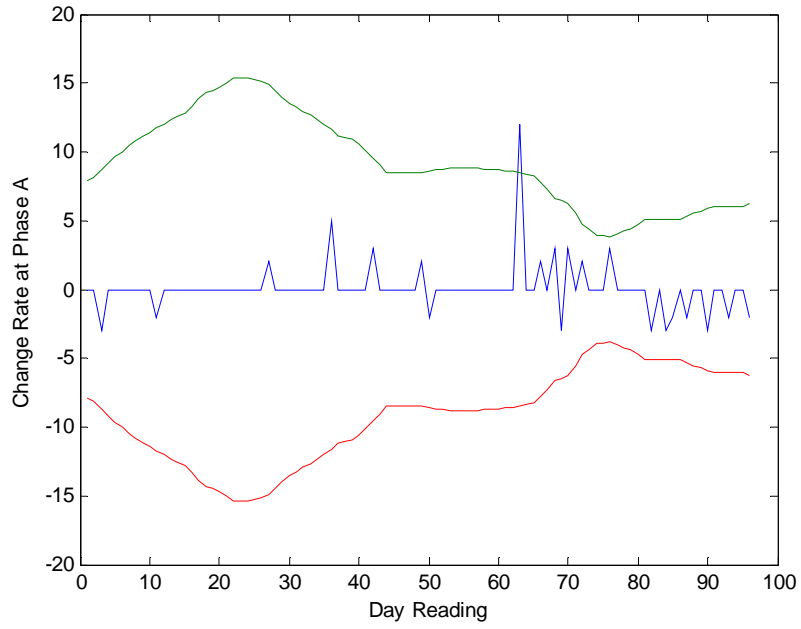


Figure 3.4 Change Rate for Phase A

Figure 3.5 and 3.6 show that real time load changes at phases B and C are also over the limit according to change rate detection approach.

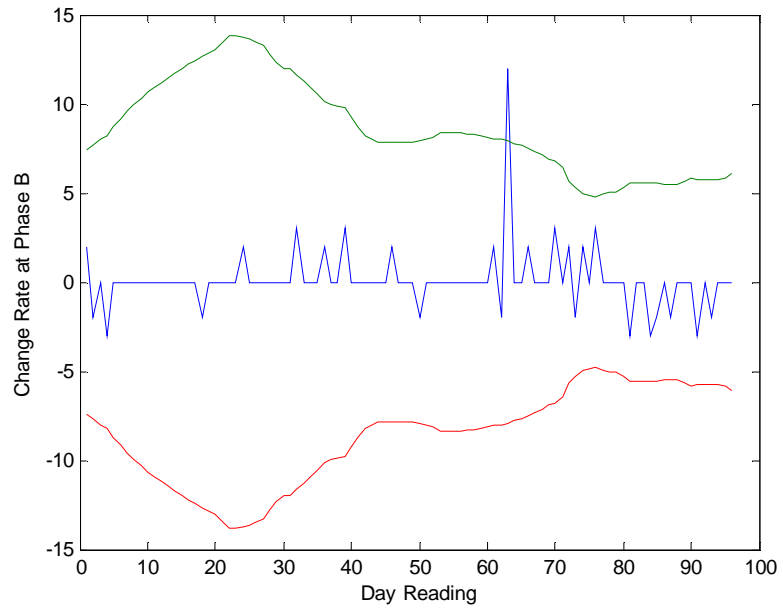


Figure 3.5 Change Rate for Phase B

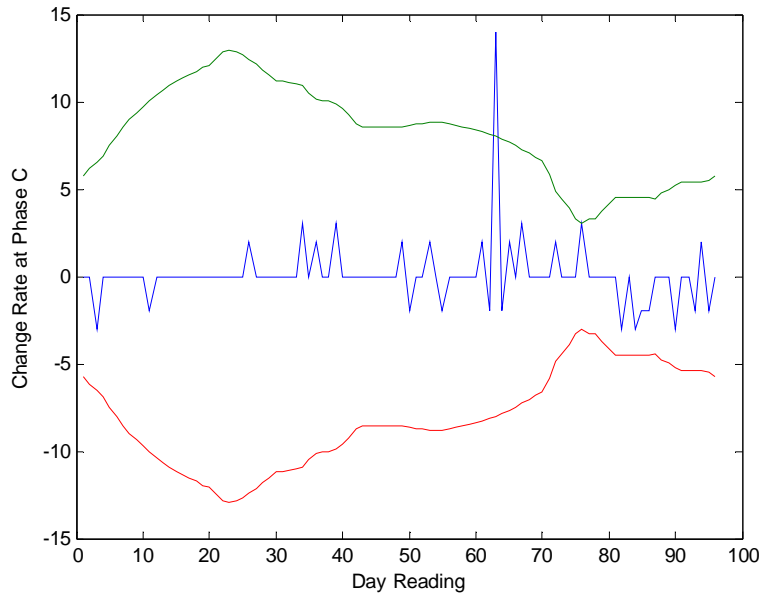


Figure 3.6 Change Rate for Phase C

### 3.1.2 Change Rate Detection for Transformer Outage in One Phase

Figure 3.7 is a plot of three phase real time load for a transformer that experienced outage in one phase(C), while the other two phases are still energized.

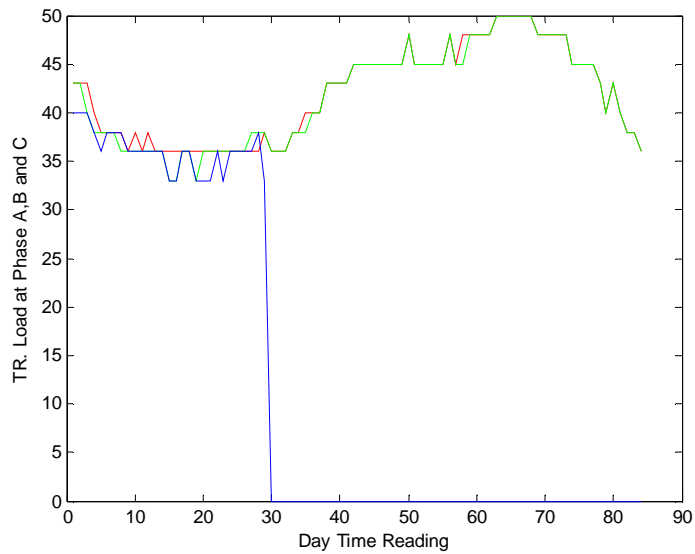


Figure 3.7 Time-Current Curves with Zero Load at Phase C



By implementing this event data in change rate approach, no over boundary load change is experienced in phase A as shown in Figure 3.8, the same is observed for phase B as explicated in Figure 3.9.

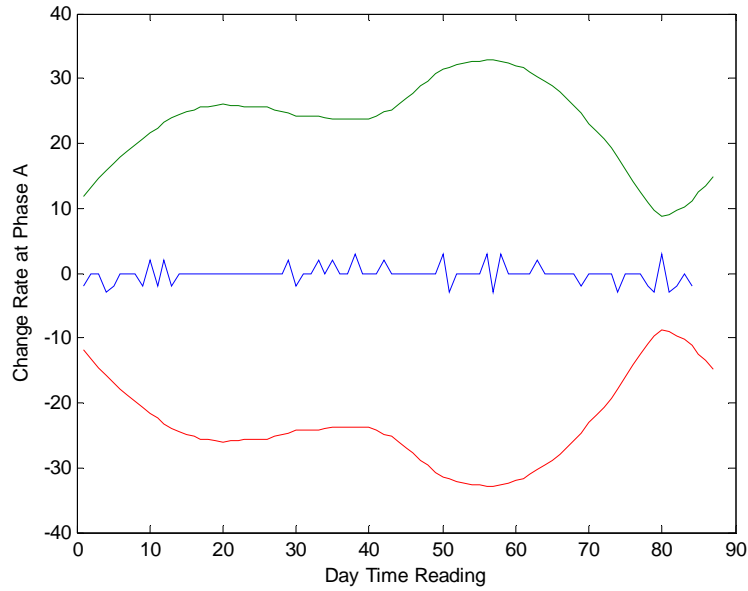


Figure 3.8 Change Rate for Phase A

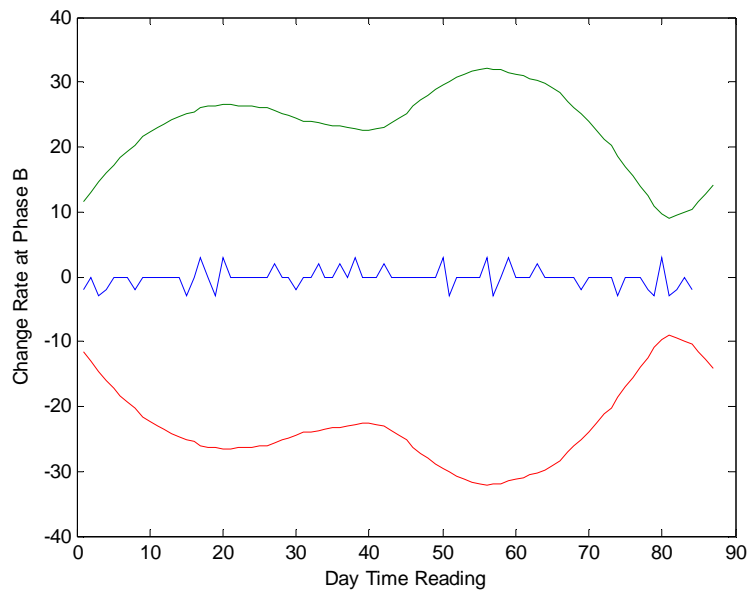


Figure 3.9 Change Rate for Phase B

Transformer outage at phase C is successfully captured by the change rate approach as illustrated in Figure 3.10 where the load change exceeds the negative boundary. This declares that a decrease in the transformer load magnitude is the source of this event.

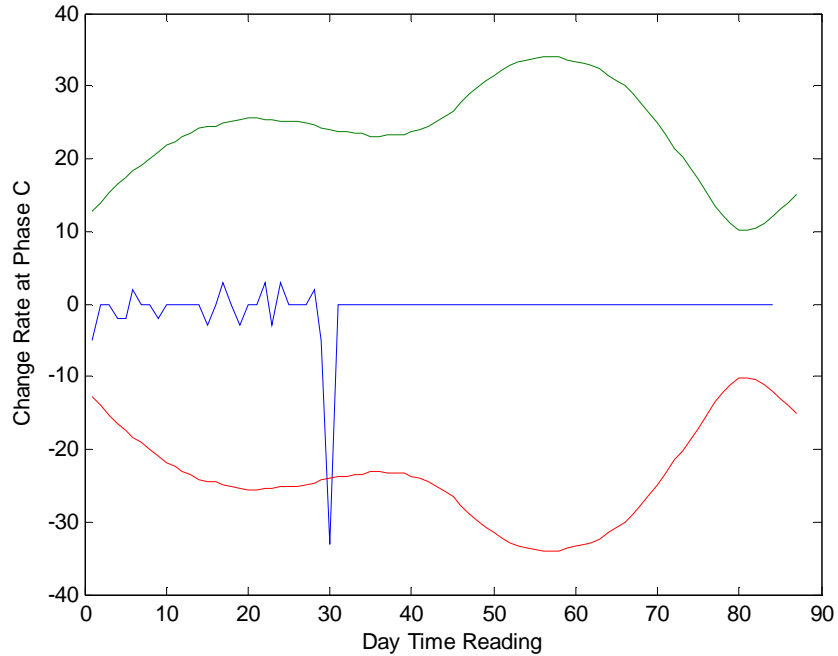


Figure 3.10 Change Rate for Phase C

### 3.1.3 Change Rate Approach Detection Challenges

In certain incidents, transformer load change is not large enough to exceed the normal load change boundary so that it can be detected. Such as the case of transformer outage incident during light load period or some open main incidents where the transformer load change may not be detectable. Therefore, it is necessary to develop another approach to increase the chance to detect such special events. Between different phases loads, unbalance may be created by a one phase or a two phase transformer load change, based on this, unbalance change rate approach is developed by this study.

### 3.2 Unbalance Change Rate Approach

Based on the unbalance among three phase loads due to one or two phase load change, some abnormal behavior in the network transformer load can be detected. Since most of the distribution network faults and blown fuses events take place in one phase. This produces large enough unbalance in transformer load. This approach will be an effective tool for single and two phase incidents. Nevertheless the three phase incidents show balanced transformer load before and after the event occurrence, so no change can be discovered by using this approach.

Followings are the procedure steps for the approach:

- The average of the three real time loads of transformer phases is calculated.

$$I_{ave.n} = \frac{I_{A.n} + I_{B.n} + I_{C.n}}{3}, \text{ the average value for reading of the day no. (n)} \quad (3.5)$$

- For each phase, the deviation of this transformer phase real time load from the average is calculated as unbalance percentage.

$$I_{ave\%.n} = \frac{I_{An} - I_{ave.n}}{I_{ave.n}} \times 100\%, \text{ unbalance percent for reading of day no (n)} \quad (3.6)$$

- The change in the value between every two successive unbalance rate valued is calculated to produce the unbalance change rate (UCR).

$$UCR_n = \Delta I_{ave\%.n} = I_{ave\%.n} - I_{ave\%.n-1} \quad (3.7)$$

Table 3.2 Unbalance Change Rate Calculations for Real Time Transformer Load

(n)	I <sub>ave.</sub>	Unbalance Percent (I <sub>ave</sub> %)			UCR (Δ I <sub>ave</sub> %)		
		A	B	C	A	B	C
1	$\frac{I_{A1} + I_{B1} + I_{C1}}{3}$	$\frac{I_{A1} - I_{ave.1}}{I_{ave.1}} \times 100\%$			-		
2	$\frac{I_{A2} + I_{B2} + I_{C2}}{3}$	$\frac{I_{A2} - I_{ave.2}}{I_{ave.2}} \times 100\%$			$I_{ave\% A2} - I_{ave\% A1}$		

Table 3.2-Continued

3	$\frac{I_{A3} + I_{B3} + I_{C3}}{3}$	$\frac{I_{A3} - I_{ave.3}}{I_{ave.3}} \times 100\%$			$I_{ave\% A3} - I_{ave\% A2}$		
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$$I_{ave\%.A.n} = \frac{I_{A.n} - I_{ave.n}}{I_{ave.n}} \times 100\% \quad (3.8)$$

$$I_{ave\%.B.n} = \frac{I_{B.n} - I_{ave.n}}{I_{ave.n}} \times 100\% \quad (3.9)$$

$$I_{ave\%.C.n} = \frac{I_{C.n} - I_{ave.n}}{I_{ave.n}} \times 100\% \quad (3.10)$$

Unbalance Change Rate (UCR) =  $\Delta I_{ave\%}$

$$UCR_{A.n} = I_{ave\% A.n} - I_{ave\% A.n-1} \quad (3.11)$$

$$UCR_{B.n} = I_{ave\% B.n} - I_{ave\% B.n-1} \quad (3.12)$$

$$UCR_{C.n} = I_{ave\% C.n} - I_{ave\% C.n-1} \quad (3.13)$$

- Special case should be considered while applying this approach; if the average is equal to zero, then the unbalance percent will be set to zero.

$$if : I_{ave.n} = \frac{I_{A.n} + I_{B.n} + I_{C.n}}{3} = 0 \Rightarrow I_{ave\%.n} = 0.0 \quad (3.14)$$

This assumption is to avoid dividing the deviation of a phase load from the average value ( $I_{A.n} - I_{ave.n}$ ) by zero while calculating unbalance percent.

- The boundary curve for each phase in this approach is the moving standard deviation for  $N_s$  unbalance percent consecutive values for that phase calculated from transformer normal readings.

$$Q_n = \sqrt{\frac{1}{Ns} \sum_{i=b}^n (I_{ave \% .i} - \bar{I}_{ave \% .})^2} \quad (3.15)$$

$Q_n$ : Standard Deviation for  $Ns$  normal day unbalance percent values, started by reading #  $b$  and terminated by  $n$ .

$Ns$ : Number of samples included by standard deviation calculation.

$I_{ave \% .i}$ : Unbalance percent values for Normal load reading #  $i$  in sequence.

$\bar{I}_{ave \% .}$ : Arithmetic mean of  $Ns$  readings of unbalance percents values at normal day load

$$= \frac{1}{Ns} \sum_{i=b}^n L_n$$

The positive and negative normal load boundary curves can be calculated by:

$$Q_n = \sqrt{\frac{1}{Ns} \sum_{i=b}^n (U_i - \bar{U})^2} \quad (3.16)$$

$Q_n$ : Standard Deviation for  $Ns$  normal day unbalance change rate values terminated by  $n$ .

$Ns$ : Number of samples included by standard deviation.

$U_i$ : Normal unbalance change rate at reading #  $i$  in sequence.

$\bar{U}$ : Arithmetic mean of  $Ns$  values for transformer normal day unbalance change rate

$$= \frac{1}{Ns} \sum_{i=b}^n U_i$$

For positive curve:  $Q_{c_{at.point.n}} = k \times USTD_n$

For negative curve:  $Q_{c_{at.point.n}} = -k \times USTD_n$

$Q_{c_n}$ : Value of normal load unbalance change rate curve at day reading  $n$ .

$k$ : Normal load curve factor.

$USTD_n$  : Standard deviation for Ns values for normal load unbalance change rate ended by reading n.

### 3.2.1 UCR Approach Detection for different transformer load changes scenarios.

Followings in Table 3.3 are all the possible scenarios for the three phases load changes, which may take place in one, two or three phases at the same time.

Table 3.3 Unbalance Change Rate cases

#	Incident Cases / Phase Load	Average Response $\frac{I_{A.n} + I_{B.n} + I_{C.n}}{3}$	Unbalance Change Rate (UCR) $UCR_n = \Delta I_{ave\%.n} = I_{ave\%.n} - I_{ave\%n-1}$		
			Phase A	Phase B	Phase C
1	A increases	increases	increases	decreases	decreases
2	B increases	increases	decreases	increases	decreases
3	C increases	increases	decreases	decreases	increases
4	A decreases	decreases	decreases	increases	increases
5	B decreases	decreases	increases	decreases	increases
6	C decreases	decreases	increases	increases	decreases
7	A & B increase	increases	increases	increases	decreases
8	B & C increase	increases	decreases	increases	increases
9	C & A increase	increases	increases	decreases	increases
10	A & B decrease	decreases	decreases	decreases	increases
11	B & C decrease	decreases	increases	decreases	decreases
12	C & A decrease	decreases	decreases	increases	decreases
13	A, B & C increase *	increases	No change	No change	No change
14	A, B & C decrease *	decreases	No change	No change	No change

\*: Equal value change at the three phases.

As concluded from Table 3.3, for each transformer load change, there is a certain response (increase or decrease) in the values of unbalanced change rate for the three phases. Every two scenarios have a similar response at the three phases, that means that for any response detected by this approach, this response can be referred to for two possible load change scenarios as listed in Table 3.4

Table 3.4 Possible Events Based on UCR Response

#	Unbalance C.R Response Phases A, B & C	Transformer Load Change causing this Response	
		Possible Scenario	Possible Scenario
		# 1	# 2
1	Increases, increases & increases	impossible	impossible
2	Increases, increases & decreases	C decreases	A & B increase
3	Increases, decreases & decreases	A increases	B & C Decrease
4	Increases, decreases & increases	B decreases	C & A increase
5	decreases, decreases & decreases	impossible	impossible
6	decreases, decreases & increases	C increases	A & B decrease
7	decreases, increases & increases	A decreases	B & C increase
8	decreases, increases & decreases	B increases	A & C decrease

To identify which of the two possible scenarios actually took place, the change in the average value should be considered (increases or decreases), to confirm one scenario and exclude the other one that discords the average change direction as listed in Table 3.5.

$$\Delta I_{ave,n} = I_{ave,n} - I_{ave,n-1} \quad (3.17)$$

Table 3.5 Using Average Change to figure out TR. Load Change Scenario

#	Phases A, B & C UCR Responses	$\Delta I_{ave \cdot n} = I_{ave.n} - I_{ave.n-1}$	Approved Event
1.	Increases, increases & decreases	Positive	A & B increase
2.		Negative	C decreases
3.	Increases, decreases & decreases	Positive	A increases
4.		Negative	B & C Decrease
5.	Increases, decreases & increases	Positive	C & A increase
6.		Negative	B decreases
7.	decreases, decreases & increases	Positive	C increases
8.		Negative	A & B decrease
9.	decreases, increases & increases	Positive	B & C increase
10.		Negative	A decreases
11.	decreases, increases & decreases	Positive	B increases
12.		Negative	A & C decrease

### 3.2.2 UCR Approach Detection for Zero Current Reading at One Phase Only

The data in table 3.6 are real readings from Con Edison network transformer that experienced zero load value at phase C.

Table 3.6 Time-Current Readings for Event of Zero Value at One Phase

Time/ Date	Transformer Load			Average	Average %			UCR		
	A	B	C		A	B	C	A	B	C
2/3/2008 7:52	36	38	38	37.33	-3.56	1.8	1.8	-	-	-
2/3/2008 8:09	38	38	33	36.33	4.5	4.5	-9.17	8.06	2.7	-10.9



Table 3.6 Continued

2/3/2008	36	36	0	24	50	50	-100	45.5	45.5	-90.8
8:26										

Figure 3.11 shows the incident time-current curve illustrating the outage at phase C while the other two phases load still have nonzero values.

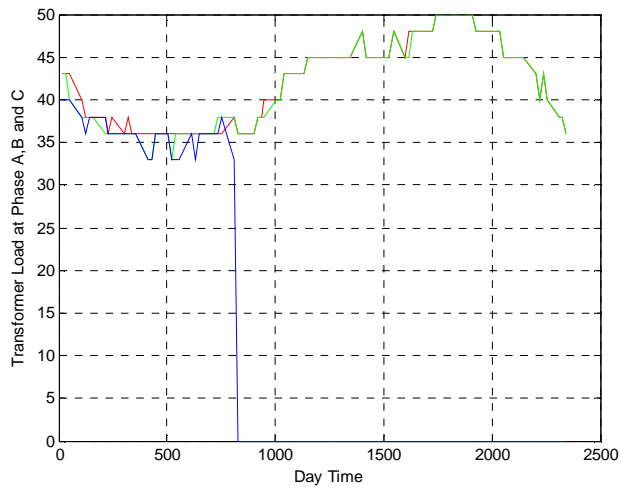


Figure 3.11 Time-Current Curve for Event of Zero Value at One Phase

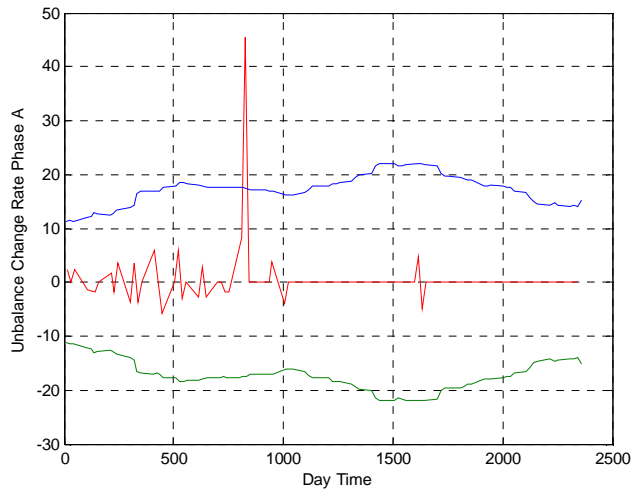


Figure 3.12 Unbalance Change Rate for Phase A

According to the values in Table 3.6, the unbalance change rate for phase A is a positive value and has an over boundary limit even if there is no outage or considerable change in this phase. The same situation is illustrated in Figure 3.13 for phase B, the unbalance change rate shows over boundary change for normal load phase.

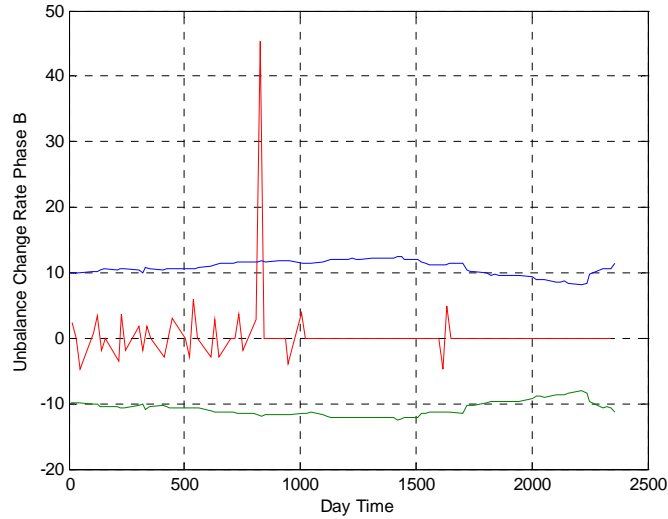


Figure 3.13 Unbalance Change Rate for Phase B

Also based on the values that appear in Table 3.6 for phase C, and as illustrated in Figure 3.14, the unbalance change rate shows negative and over the boundary change.

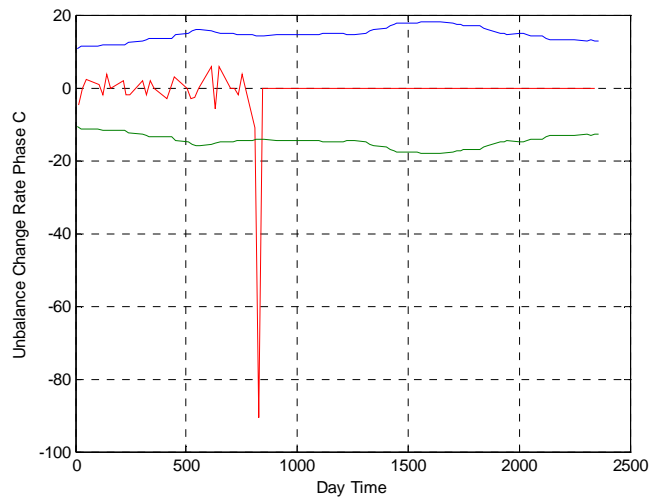


Figure 3.14 Unbalance Change Rate for Phase C

The change directions in UCR for the three phases in this case are (increase, increase & decrease), according to table 3.4, the possible two events that show this response are (Phase C Load decrease or Phase A&B loads increase), Table 3.5 indicates that a drop in phase C load took place due to the decrease in the average value in this case.

### 3.2.3 UCR Approach Response for Zero current Readings at Three Phases

Table 3.7 includes the data for real transformer readings that experienced zero load values at A, B and C phases, In addition to the calculation for each time average, unbalance percent and unbalance change rate.

Table 3.7 Time-Current Data for Three Phase Zero Load Incident

Time/ Date	Transformer Load			Average	Average %			UCR		
	A	B	C		A	B	C	A	B	C
1/11/2008 14:41	43	48	48	46.33	-7.2	3.6	3.6	-	-	-
1/11/2008 14:58	45	52	52	49.66	-9.39	4.6	4.6	-2.19	1.09	1.09
1/11/2008 15:15	0	0	0	0 *	0 *	0 *	0 *	9.39	-4.6	-4.6

\*: if the average = 0, consider the average % as zero also.

Figure 3.15 shows the incident time-current curve where the transformer three phases loads falls to zero.

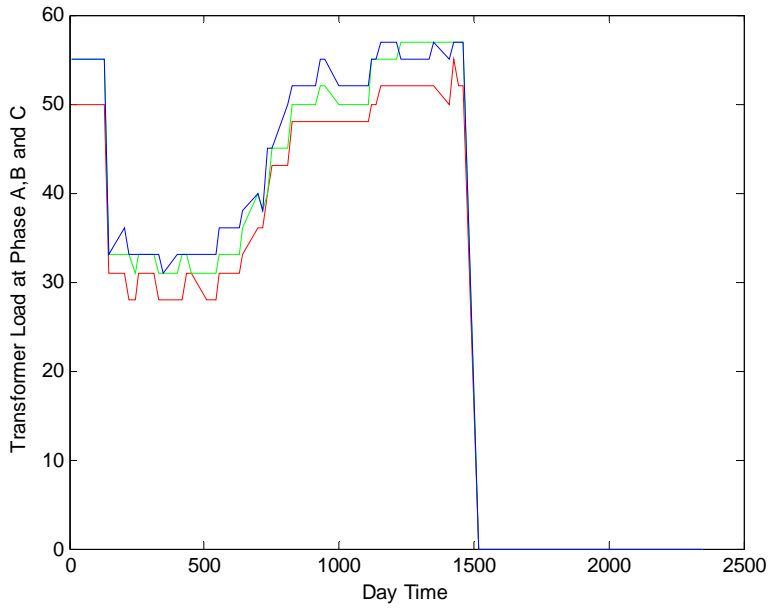


Figure 3.15 Time-Current Curves for Three-Phase Zero Load Incident

Figures 3.16, 3.17 and 3.18 clarify unbalance change rate for phase A, B and C respectively. In spite of the considerable change in transformer load at phase A, no change is experienced in the unbalance change rate as shown in Figure 3.16.

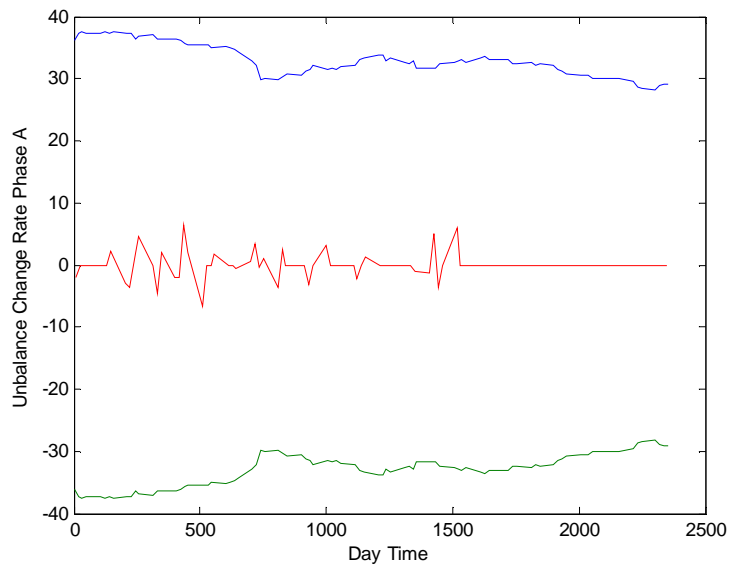


Figure 3.16 Unbalance Change Rate for Phase A

According to the concept of UCR proposed by this approach, any almost equal load change at the three phases at the same time will show very small unbalance change rate value that can not be detected as long as it does not exceed the boundary.

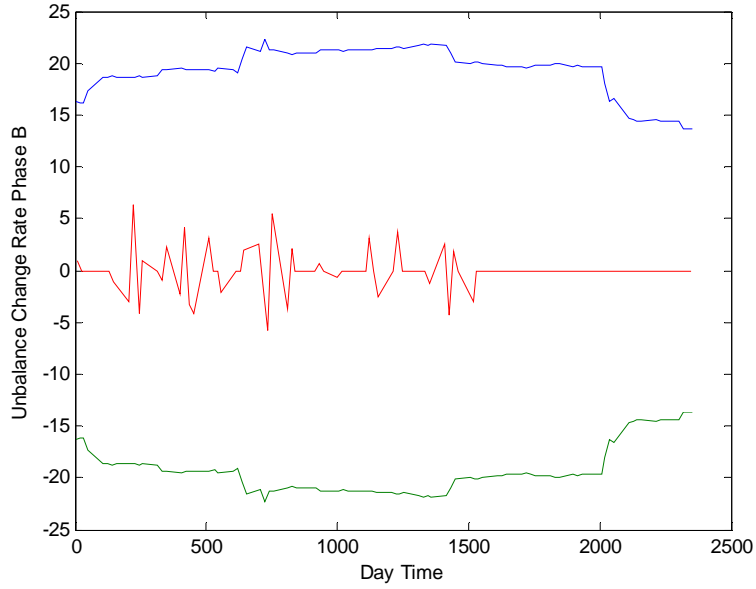


Figure 3.17 Unbalance Change Rate for Phase B

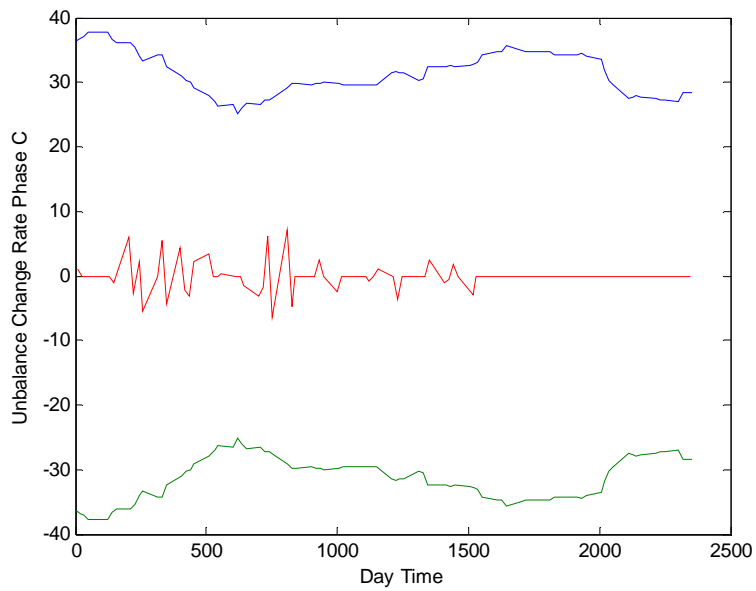


Figure 3.18 Unbalance Change Rate for Phase C

Similar response in phases B and C as that in phase A is shown in Figure 3.17 and 3.18. So unbalance change rate approach is suitable for transformer load change that may take place at one or two phases only.

#### 3.2.4 UCR Approach Detection for Small Change in One Phase

Table 3.8 includes the data and UCR approach calculation for an event shows small change in one phase only (C). The change in this transformer Load is a response for the outage in the transformer shown Figure 3.11 to pick up part of load was supplied by phase C at that transformer.

Table 3.8 Time-Current Data for Limited Load Change in Phase C

Time/ Date	Transformer Load			Average	Average %			UCR		
	A	B	C		A	B	C	A	B	C
2/3/2008 7:52	38	38	40	38.66	-1.73	-1.73	3.46	-	-	-
2/3/2008 8:09	38	38	40	38.66	-1.73	-1.73	3.46	0	0	0
2/3/2008 8:26	45	45	60	50	-10	-10	20	-8.2	-8.2	16.5

As illustrated in Figure 3.19, the increase in this transformer load at phase C took place in the same time of that outage for transformer in figure 3.11.

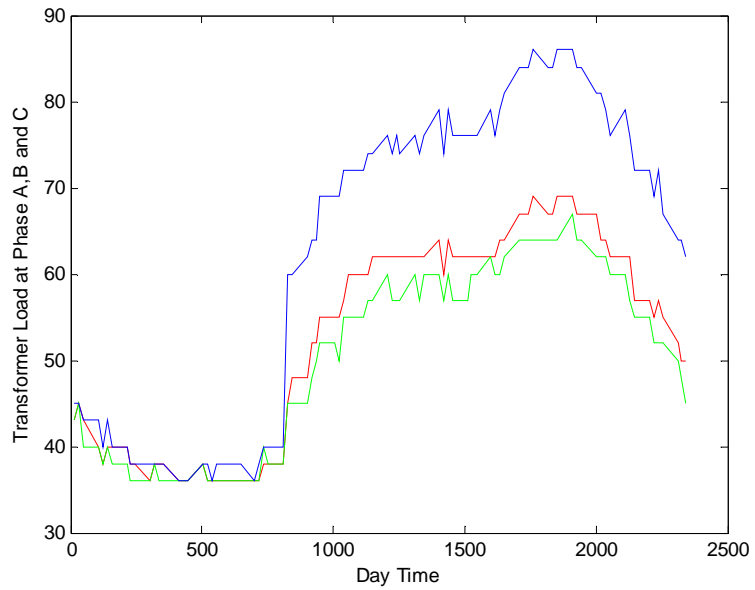


Figure 3.19 Time-Current Curves for Small Load Change at Phase C

Figures 3.20 and 3.21 shows the UCR in transformer load at phases A, B. Since the change in phase C was relatively small, no over boundary UCR detected at the other phases.

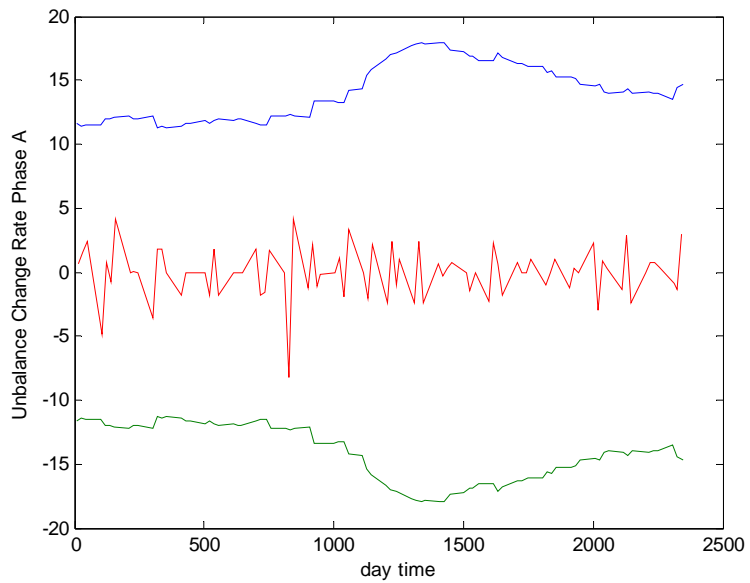


Figure 3.20 Unbalance Change Rate for Phase A

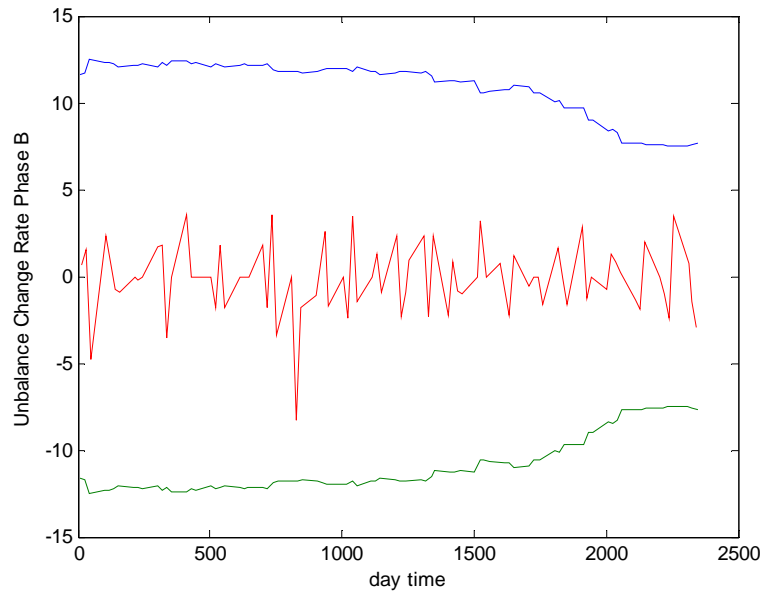


Figure 3.21 Unbalance Change Rate for Phase B

The UCR in phase C exceeds the boundary as illustrated in Figure 3.22. It is the only phase at which the event detected, the direction UCR changes at the other phases will taken into consideration to determine the actual load change scenario from those listed in Table 3.3

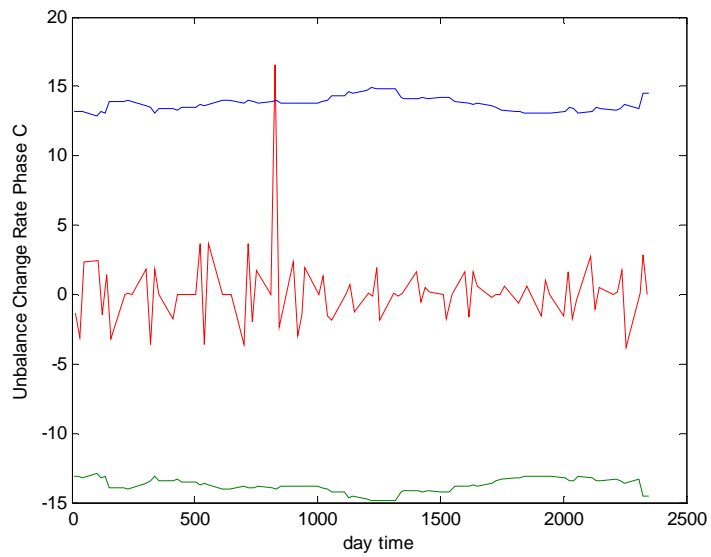


Figure 3.22 Unbalance Change Rate for Phase C



### 3.2.5 Unbalance Change Rate Approach Detection Challenges

For transformer load change takes place at the three phases at the same time with approximate equal change value, this approach is unable to detect such situation event. Since equal change shows up in the three phases, the unbalance percent will be close for all phases, and the same thing will happen for the unbalance change rate if the previous reading value is the almost equal for all phases. The next approach of this dissertation is able to cover the detection shortage in unbalance change rate approach and also to deal with some type of fluctuating readings.

### 3.3 Estimated Value Approach

Based on this approach, the incoming real time reading for network transformer load will be estimated using the Least Square Parabola method for curve fitting. This approach is implemented on the last received three real time load readings and the same time three normal day load readings in addition to that one at the same time of incoming reading. The formula for the next incoming reading value is:

$$y = ax^2 + bx + c, \text{ where}$$

y: Estimated incoming value.

x: Recorded normal day reading at the same time of y.

a, b and c: Square equation parameters to be found by parabola curve fitting.

The best fitting curve to find a, b and c should have Least Square Error

$$\Pi = \sum_{i=1}^n [y_i - f(x)]^2 = \sum_{i=1}^n [y_i - (ax_i^2 + bx_i + c)]^2 = \min \quad (3.18)$$

$$\frac{\partial \Pi}{\partial a} = 2 \sum_{i=1}^n x_i^2 [y_i - (ax_i^2 + bx_i + c)] = 0 \quad (3.19)$$

$$\frac{\partial \Pi}{\partial b} = 2 \sum_{i=1}^n x_i [y_i - (ax_i^2 + bx_i + c)] = 0 \quad (3.20)$$

$$\frac{\partial \Pi}{\partial c} = 2 \sum_{i=1}^n [y_i - (ax_i^2 + bx_i + c)] = 0 \quad (3.21)$$

By expanding these equations:

$$\sum_{i=1}^n y_i = a \sum_{i=1}^n x_i^2 + b \sum_{i=1}^n x_i + c \sum_{i=1}^n 1 \quad (3.22)$$

$$\sum_{i=1}^n x_i y_i = a \sum_{i=1}^n x_i^3 + b \sum_{i=1}^n x_i^2 + c \sum_{i=1}^n x_i \quad (3.23)$$

$$\sum_{i=1}^n x_i^2 y_i = a \sum_{i=1}^n x_i^4 + b \sum_{i=1}^n x_i^3 + c \sum_{i=1}^n x_i^2 \quad (3.24)$$

$a$ ,  $b$  and  $c$  can be found by solving the above three equations for every new RMS reading, Estimated  $y = ax^2 + bx + c$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (3.25)$$

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{bmatrix}^{-1} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} \quad (3.26)$$

$$\Delta_{estimated} = y_{real.time.value} - y_{estimated.value} \quad (3.27)$$

$y$ : Estimated load value for present time.

$y_1, y_2$  and  $y_3$ : Three last received real time load readings.

$x, x_1, x_2$  and  $x_3$ : Normal day load readings at the same time of the day, for  $y, y_1, y_2$  and  $y_3$ .

The positive and negative normal load boundary curves for change rate approach are used also for this approach.

The virtues of this approach over the other two approaches are summarized by:

- Compared to change rate approach: some of transformers loads show frequent fluctuating values due to the connected load nature or an erroneous delivered readings as listed in Table 3.9. The change rate detection depends on taking the difference between the two successive readings, which means repeated listed event for unreal incident.

In case of estimated value approach, the estimated value reflects this fluctuation that recently happened, because it is calculated based on the last three values that most of the time includes this fluctuation. So the value of  $\Delta_{estimated}$  will be less than that calculated in the change rate approach  $\Delta I_n = I_n - I_{n-1}$  for the same present real time value.

Table 3.9 Real Time Data for Fluctuating Transformer Load

Time	Transformer load at phases A, B and C		
01:48:05	20	20	23
02:02:57	34	34	31
02:18:00	20	20	20
02:33:16	23	20	20
02:48:39	31	31	28
03:03:44	20	20	20
03:18:59	34	28	31

- Compared to unbalance change rate approach: estimated value approach is able to detect the simultaneous three phase load changes in addition to the other kinds of transformer load changes,

### 3.3.1 Estimated Value Approach Detection for Small Changes in transformer Load

Figure 3.23 shows the current-day reading curve for simultaneous changes in transformer loads at the three phases. Where Figure 3.24, 3.25 and 3.26 illustrate the performance of estimated value approach in detecting this type of transformer load changes.

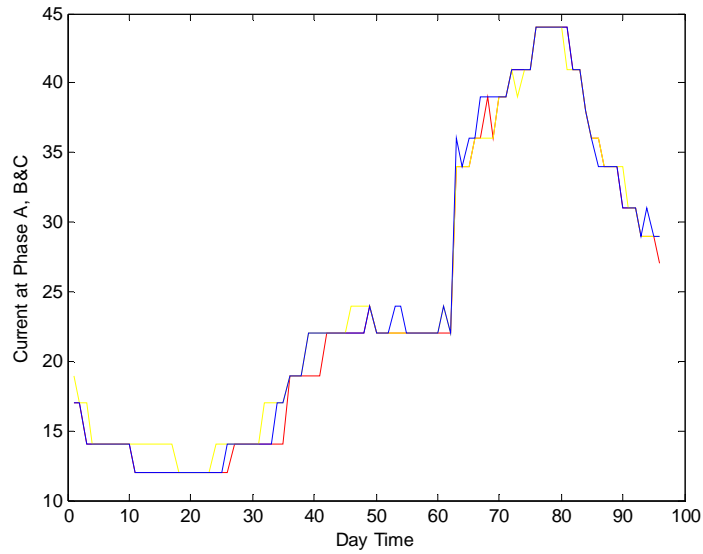


Figure 3.23 Time-Current Curves for Limited Load Change at three phases

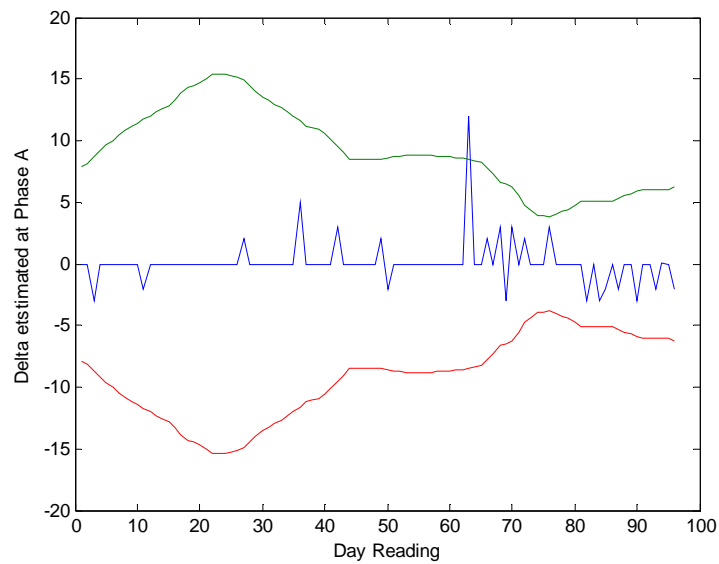


Figure 3.24 Deviancies of Real Time Readings from Estimated Values at Phase A

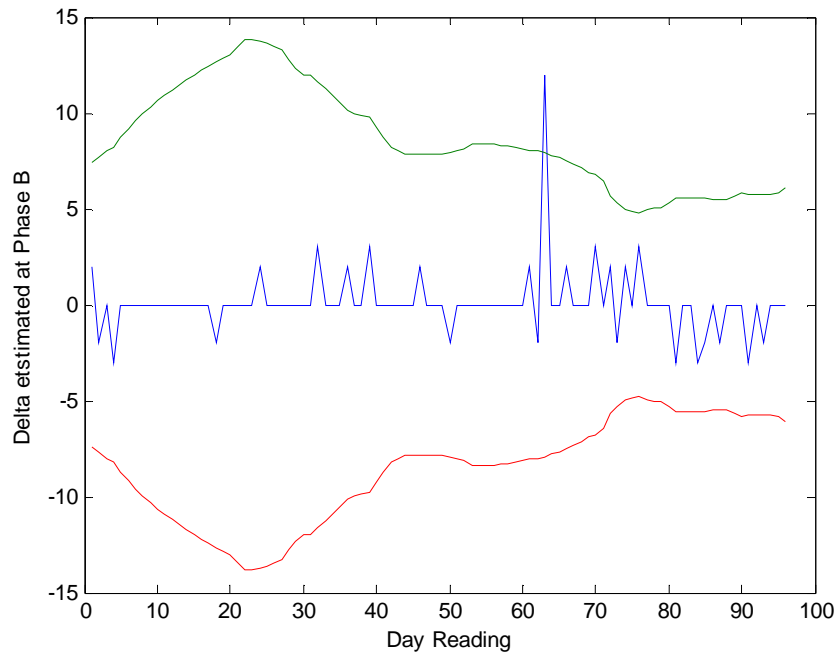


Figure 3.25 Deviancies of Real Time Readings from Estimated Values at Phase B

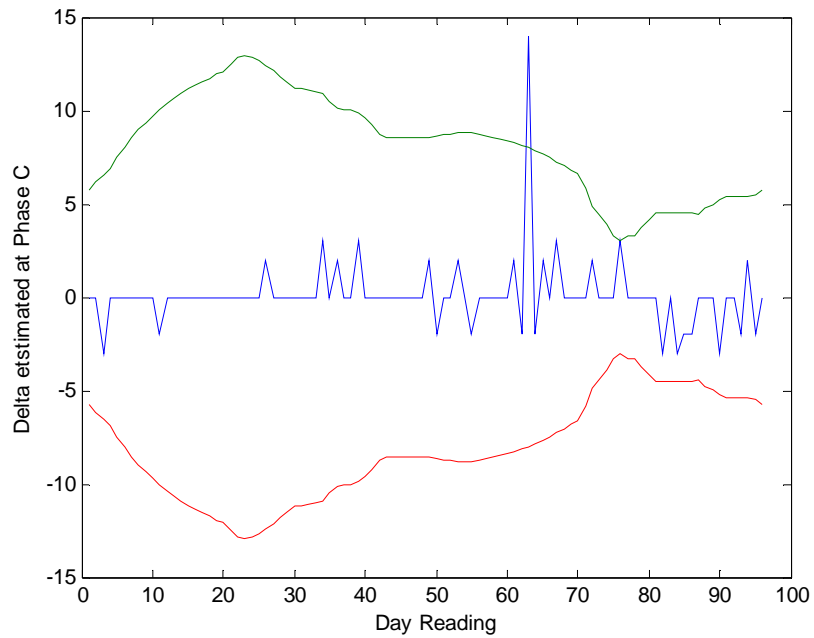


Figure 3.26 Deviancies of Real Time Readings from Estimated Values at Phase C

### 3.3.2 Estimated Value Approach Detection for Three phase Zero Readings

For a transformer three phase load change (to zero), the following figures illustrate the ability of this approach to detect such type of changes that occur at the three phases at the same time to cover the previous approach deficiency in this particular case.

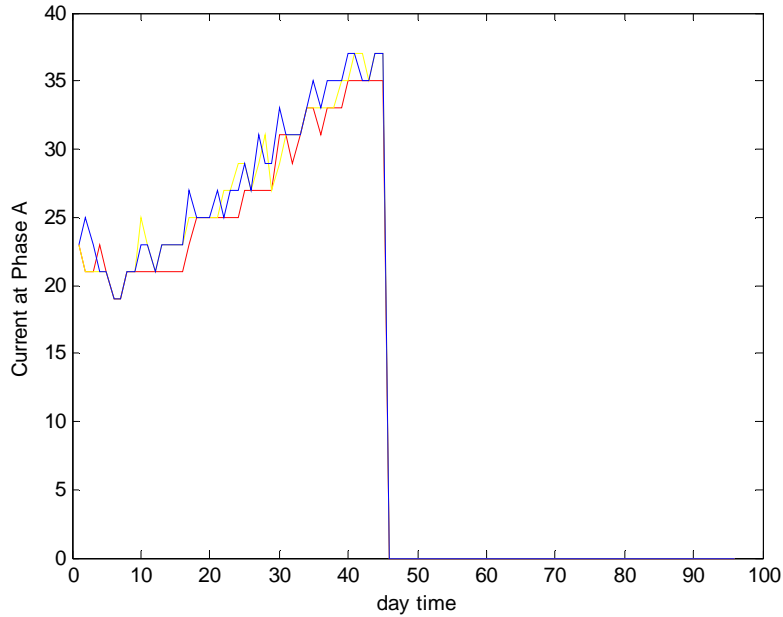


Figure 3.27 Time-Current Curves for three- phase zero Load incident

Figure 3.28 shows the estimated value approach detection for the load change at phase B. As illustrated from the figure, the starting point of reading for the curve inside the boundary is reading of the day no. 4, because all the readings we are using are for the same day, so we need the first three readings to estimate the fourth one and compare it with the same day time real time reading.

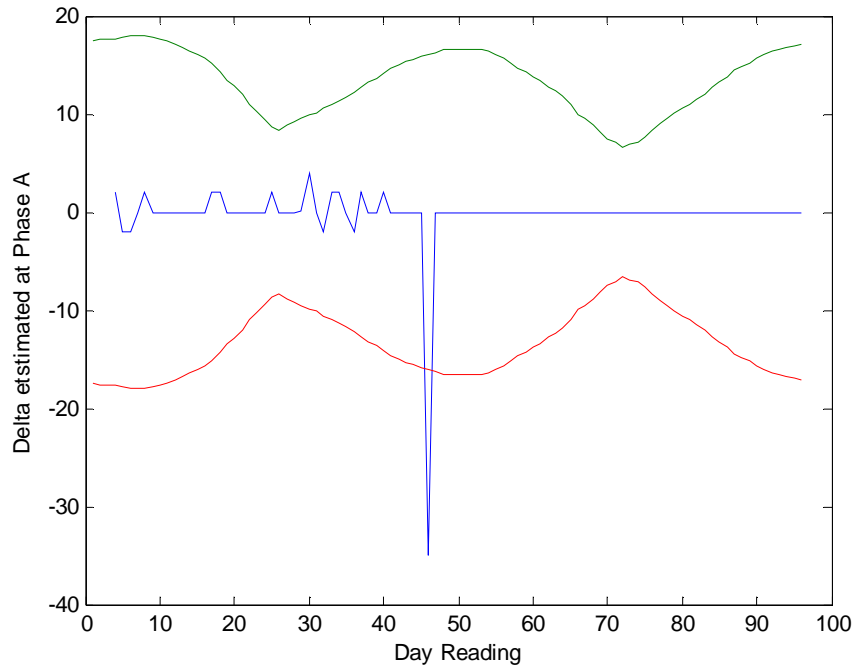


Figure 3.28 Deviancies of Real Time Readings from Estimated Values at Phase A

To start the internal curve that shows the deviancies between real time reading and the estimated one from reading no.(1), we should include three previous day readings among the data of the day we are viewing.

The next two figures show the deviancy of the real time load from the estimated one, which show a big value at the time of the transformer outage, because the estimated value for that reading according to the three previous ones is so far from the real one (zero). This deviancy from the expected value is big enough to exceed the boundary as an indication for the success of this approach to detect the simultaneous changes in the three phases.

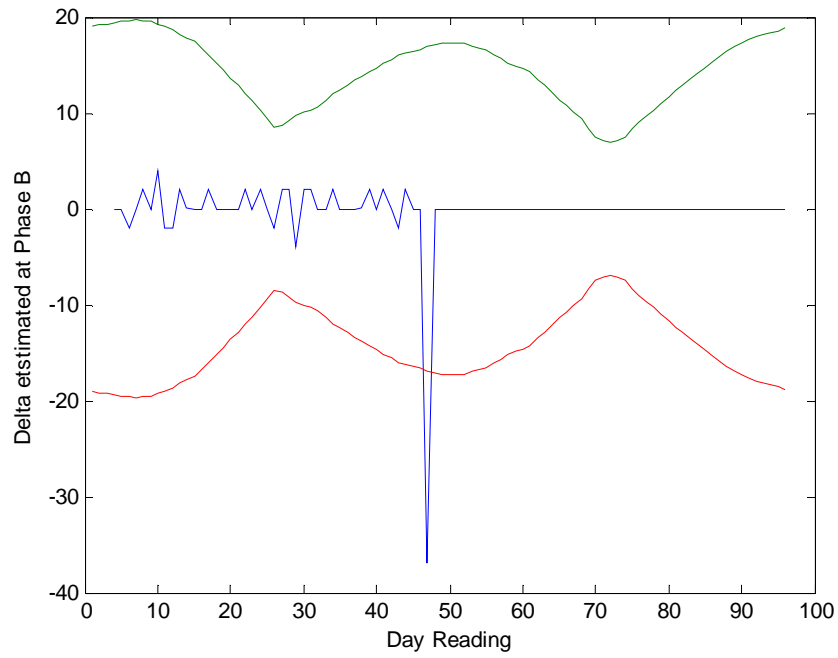


Figure 3.29 Deviancies of Real Time Readings from Estimated Values at Phase B

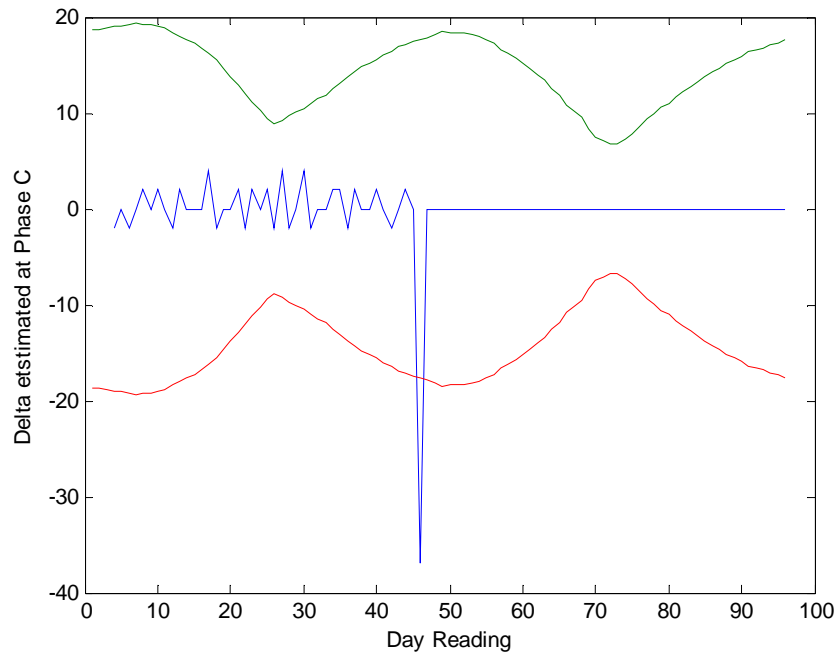


Figure 3.30 Deviancies of Real Time Readings from Estimated Values at Ph. C



### 3.3.3 Estimated Value Approach Detection for One Phase Zero Reading

It is the a frequent type of faults in the distribution networks, this single phase outage case is included here to show the ability of the estimated value approach to detect the load change results from this type of events.

As shown in Figure 3.31, the current in phase B falls to zero while other two phases are still loaded.

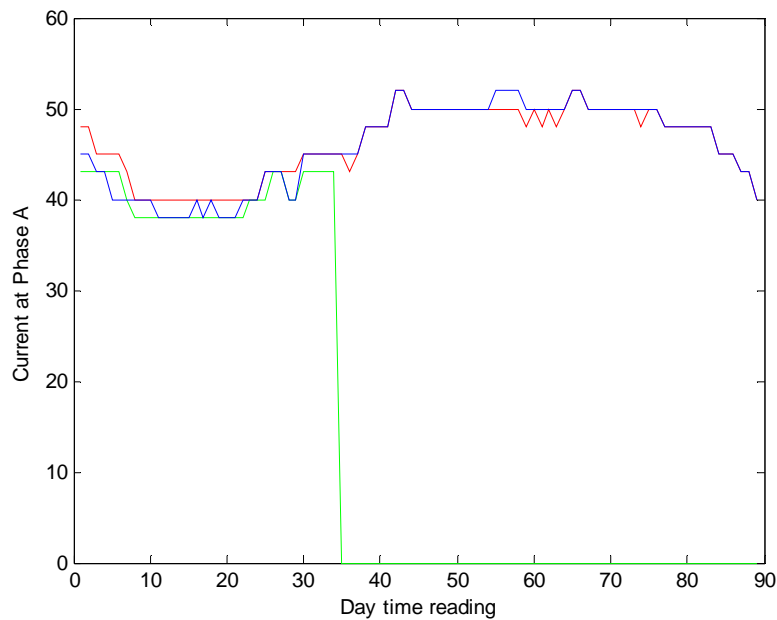


Figure 3.31 Time-Current Curves for one- phase zero Load Incident

No detected over boundary deviancy for the real time load from the estimated values in phases A and C, because the estimated values approximately match the real time ones as long as no abnormal event like outage took place.

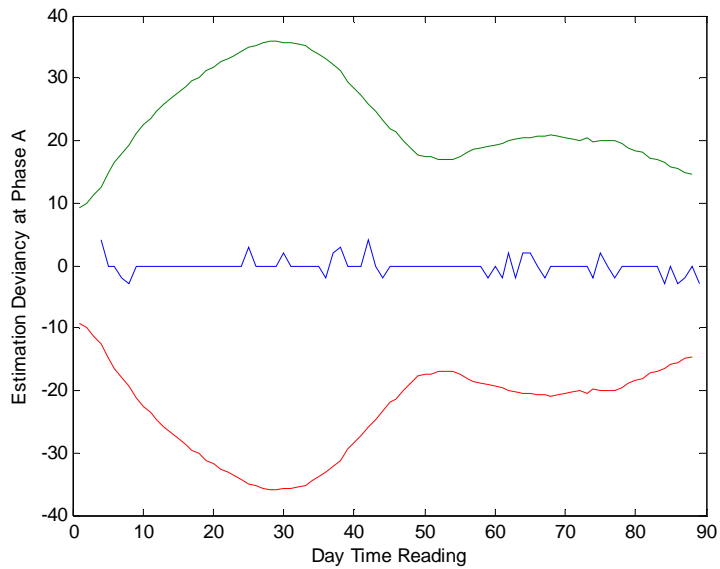


Figure 3.32 Deviancies of Real Time Readings from Estimated Values at Phase A

The Case is completely different at phase B, where the occurrence of the outage makes the deviancy of the real time load value from the estimated one is big enough to exceed the boundary limit therefore declaring this as an abnormal event.

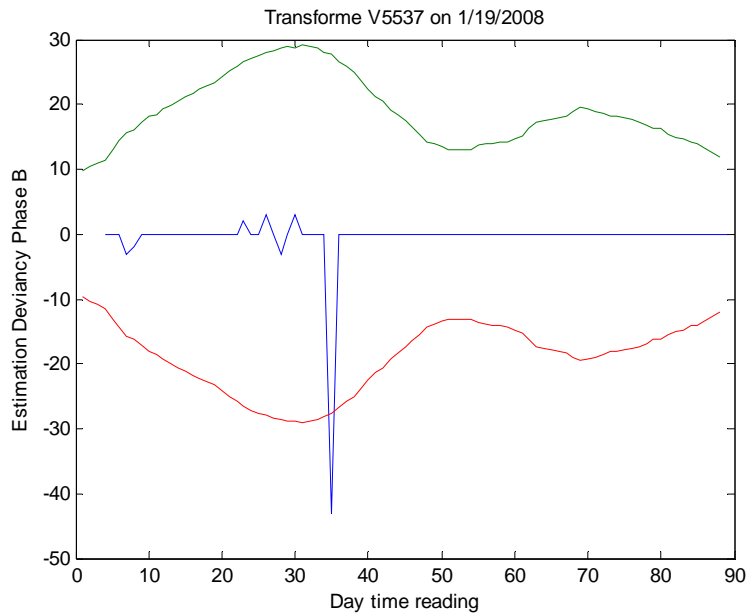


Figure 3.33 Deviancies of Real Time Readings from Estimated Values at Phase B

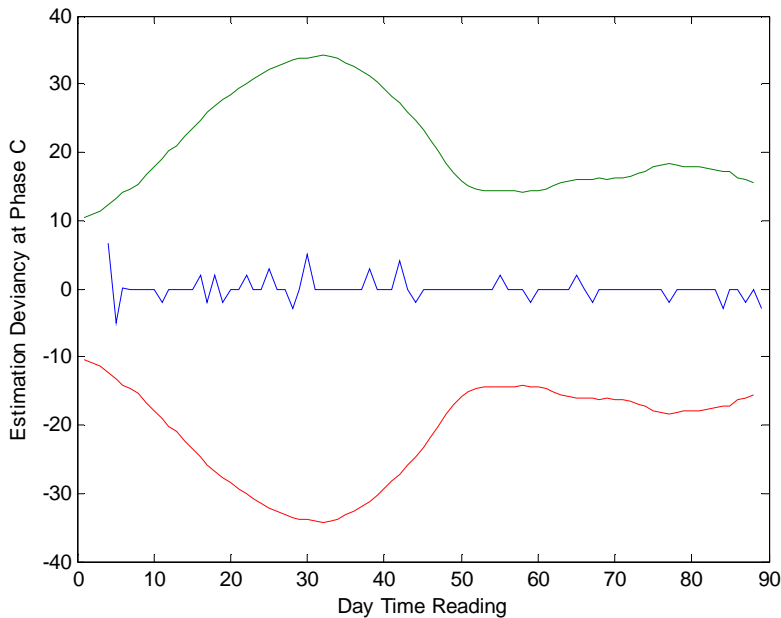


Figure 3.34 Deviancies of Real Time Readings from Estimated Values at Phase C

Including the effect of the erroneous reading (if it is delivered by RMS) in the next three estimated reading calculations is the main challenge of this approach.

The detection of abnormal change in any phase by any of the previous mentioned three statistical approaches will be enough to move to the next step of event investigation. It helps in knowing more about the suspect event circumstances and to determine the type, whether it is a transformer outage, an open main or none of them.

### 3.4 Suspect Incident Refinement Process

Any over boundary network transformer load change detected by any of the statistical approaches should comply with a set of logical statements in order to confirm the occurrence of a transformer outage or an open main incident. The response of most nearby transformers to such detected load change will be carefully examined using a sensitivity analysis process. Accordingly, this detected load change may be neglected or a report indicates incident type and location may be issued.

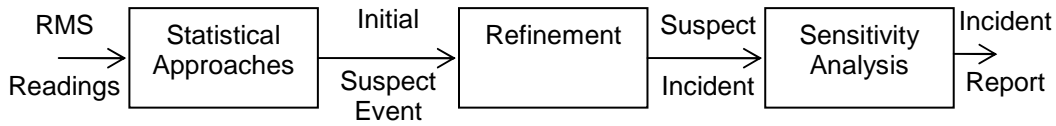


Figure 3.35 Incident Reporting Procedure

### 3.4.1 Transformer Load Change Features

Load change in one or more network transformers can be caused by one of the following incidents:

- Actual change in customer connected loads around those transformers.
- Network Transformer Outage that is caused by a network protector tripping or a transformer blown fuse.
- Small Change (increase or decrease) in the network transformer load. This can be a response to other transformer outage or open main incident in a nearby part of grid.
- Electric fault at one of the network equipment that lasts for a period of time. This time depends on the fault type and the implemented protection isolation mechanism.

Network real power load consumed by the customers at constant voltage and certain power factor can be expressed in terms of each transformer out put current and network load:

$$I_L = I_{xfr.1} + I_{xfr.2} + \dots + I_{xfr.nw} \quad (3.28)$$

$I_L$ : Network Total Load.

$I_{xfr.n}$ : Network transformer n output current.

Transformer output change will be replaced immediately by equal value and opposite current change at other network transformers if this change is caused by open main in secondary grid, or completely interruption in transformer output due to blown fuse.

$$\frac{dI_L}{dI_{xfr.event}} = zero \quad , \text{ assumed that network total load is constant before and after the incident.}$$

$$dI_L = dI_{xfr.1} + dI_{xfr.2} + \dots + dI_{xfr.nw} = zero \quad (3.29)$$

For the transformer at which abnormal load change is detected ( $dI_{xfr.event}$ ), its current change equals in magnitude to the sum of all changes in the other transformers:

$$-dI_{(xfr.event)} = dI_{xfr.1} + dI_{xfr.2} + \dots + dI_{xfr.event-1} + dI_{xfr.event+1} + dI_{xfr.nw} \quad (3.30)$$

$xfr.event$ : The transformer at which the out put change took place.

$Xfr.n$ : Network transformer  $n$ .

$L$ : Network total load at change event time.

$n_w$ : Number of network transformers.

$\frac{dI_{xfr.n}}{dI_{xfr.event}}$  is a function of underground grid electric distance between transformers ( $xfr_n$ ) and

( $xfr.event$ ), so the closest transformers to transformer ( $xfr.event$ ) show more output power changes than those for the others.

$\frac{dI_{xfr.n}}{dI_{xfr.event}}$  for those far enough from ( $xfr.event$ ) equals zero or very small value.

### 3.4.2 Initial Suspect Event Refinement

The event listed in the initial suspect list by one or more detection approaches is not necessarily a real incident that requires maintenance or replacement action, such fallacious event may referred to one of the followings reasons:

- Prescheduled transformer switching (in/out) operation.
- Erroneous current readings.
- Urgent change in transformer load that does not coincide with the normal day load profile.

Any suspect event in the list assuredly caused by one of the previous mentioned causations should be excluded according to specific refinement procedure to avoid the mistake of mobilizing the maintenance team to take care of such an ostensive incident.

#### 3.4.2.1 Erroneous transformer load reading

Sometimes, the incoming real time RMS reading for network transformer load is erroneous value that does not reflect the actual values supplied by this transformer. Accidentally zero load value may appear in transformer load registers, while the power is still supplied in normal rates, the detection approaches tentatively lists the event as suspected incident. This unreal incident can be excluded from the suspect list during the refinery step by checking the response of nearby network transformer load. If no change is experienced to compensate the expected lost load supplied by this transformer, the received reading is erroneous value and there is no real incident, Thereby no equipment repair or replacement are required.

#### 3.4.2.2 Scheduled Transformer (In/ Out) Switching

For maintenance, replacement, repair, or construction activities, network transformers occasionally are subjected to be isolated from the network according to the work team schedule and approved work permit. Once the transformer is taken offline or online, a change in the transformer load will be discerned by detection approaches and this event will be included in initial suspect event list. Elimination of such incident from the list will be based on the transformer incoming data that should indicate this prescheduled switching.

### 3. 5 Sensitivity Analysis

In order to investigate the type of the incident that might cause the detection of an abnormal load change event by one of the statistical approaches; a refinement process for this event will be implemented. Refinement process depends on the sensitivity analysis for the load change at the transformer at which the change detected, in addition to the response of the load at nearby transformers.

Nearby transformers ( $xfr_{NB,n}$ ) are the transformers that show the most changes due to the load change in event transformer at which the event is detected. Nearby transformers can be determined for every single network transformer by using power flow program to calculate the load change in all of network transformers in case an outage is experienced in the event transformer. This study considers ten most affected transformers. But in some cases the whole number of the nearby transformers show response for this outage is limited to less than ten transformers.

In the open main incident, and for each incident scenario, most affected transformers ( $xfr_{OMNB,m}$ ) can be determined by using power flow program to simulate an open incident in certain main, while the response in all network transformers is observed to identify the most affected transformers.

Sensitivity analysis is implemented first for transformer outage detection purposes. If the suspect event is not transformer outage incident according to this sensitivity results; open main sensitivity analysis should be launched.

Once the transformer incident is confirmed, if we have considerable mismatch between real time responses of the nearby transformers that are obtained from Poly Voltage Load flow (PVL) program for “perfect” network to check possible pre-exist open main situations.

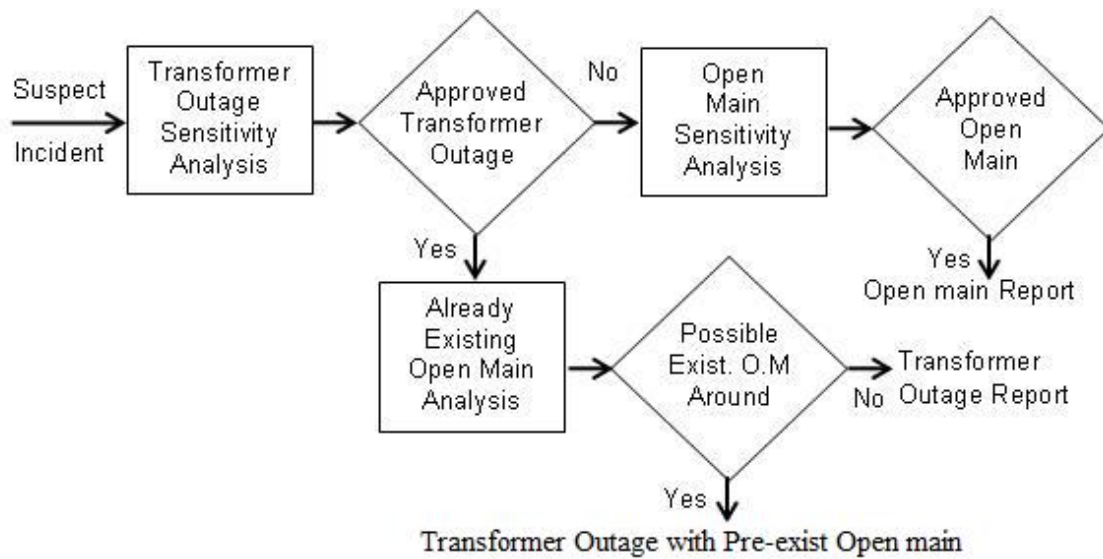


Figure 3.36 Sensitivity Analysis Procedure

### 3.5.1 Transformer Outage Sensitivity Analysis

Once the initial suspect event is refined and approved as suspect incident, transformer outage analysis will be started. Two main purposes for implementation of transformer outage detection analysis in this study:

- To recognize the real outage incident that leads to transformer power flow interruption from other misleading information apparently indicating outage but actually is not.
- In order to utilize the outage decision in open main incident analysis. The open main detection process requires that no outage incident is approved in one of the nearby transformers involved in this process.

For suspect events detected by the mentioned statistical approaches and confirmed as real events through the primary refinement of the event, the presence of zero-load value reading is an indication for highly suspected transformer outage incident due to possible protection device operation or due to feeder outage.

To declare this suspect incident as confirmed outage incident, nearby transformers load change sensitivity analysis should be implemented. To formalize transformer outage sensitivity



matrix, power flow program (PVL) is implemented to calculate the nearby transformers load changes for every case of a transformer outage incident. The network transformers show most load change will be the listed as nearby transformers.

### 3.5.1.1 Nearby Transformer List for Transformer Outage Incident (TONTL)

Beside each network transformer at which the outage is possible, other nearby transformers are listed to show where most load changes will be experienced as a result of that individual outage incident. The list can be obtained by the power flow program used by Con Edison; Poly Voltage Load flow (PVL). Here, transformers are taken out once at a time while the load response at the other transformers is being observed and compared with the actual values in base case (perfect network).

The network transformers show most load change will be the listed as nearby transformers.

$$\Delta I_{R.xfr.NBn} = I_{R.xfr.NBn} - I_{R.xfr.NBn-} \quad (3.31)$$

$$\Delta I_{R.xfr.event} = I_{R.xfr.event} - I_{R.xfr.event-} \quad (3.32)$$

Because the number of considered nearby transformers is not the total number of the network transformers, the expected lost load by one transformer outage will be greater than the changes in the ten nearby transformers in the most of cases.

$$\left| \Delta I_{R.xfr.event} \right| > \left| \sum_{n=1} \Delta I_{R.xfr.NBn} \right|, \text{ where} \quad (3.33)$$

$\Delta I_{R.xfr.NBn}$  : Load change for nearby transformer  $n$ .

$I_{R.xfr.NBn}$  : Load of nearby transformer  $n$  at the event time.

$I_{R.xfr.NBn-}$  : Load of near by transformer  $n$  at previous reading.

$\Delta I_{R.xfr.event}$  : Load Change for the transformer at which over boundary change detected.

The list indicates the top ten most affected transformers that show the highest load changes due to outage at one transformer. The size of each transformer should be taken into consideration if transformer rating load ratio is used as load unit instead of current value in Amperes. Another pattern of the list is prepared to show the value of load change in transformer load to be used later in investigating an already existing open main in the transformer outage area.

Table 3.10 TONTL Pattern for Transformer Names

Transformer Outage at	Names of Nearby Transformers				
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	.....	10 <sup>th</sup>
xfr <sub>1</sub>	xfr NB.A	xfr NB.B	xfr NB.C		xfr NB.J
....	...	...	...	...	...
xfr <sub>nw</sub>	xfr NB.I	xfr NB.II	xfr NB.III		xfr NB.X

Table 3.11 TONTL Pattern for Transformer Load Change Values

Transformer Outage at	Top Ten Transformer Load Changes Values				
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	.....	10 <sup>th</sup>
xfr <sub>1</sub>	ΔIc.A	ΔIc.B	ΔIc.c	...	ΔIc.J
....	...	...	...	...	...
xfr <sub>nw</sub>	ΔIc.I	ΔIc.II	ΔIc.III	...	ΔIc.X

ΔIc.A : Calculated load change for transformer (A)

Since the regular real time reading received by the RMS system is a percentage of the transformer full load, transformer Size Factor (K<sub>s</sub>) has to be used to rectify the actual load change contribution ratio for different size nearby transformers with respect to the one at which the abnormal load change is detected (event).

$$K_s = \frac{\text{Nearby.Transformer.size(KVA)}}{\text{Event.Transformer.Size(KVA)}} \quad (3.34)$$

$$P_{xfr.NBn}(\text{unified}) = P_{xfr.NBn}(\text{load.percent}) \times K_s \quad (3.35)$$

### 3.5.1.2 Transformer Outage Analysis and Logical Sequence

In order to determine if the suspect incident actually is a transformer outage or an open main incident, transformer outage sensitivity analysis will be implemented first on the suspect incidents. If it is confirmed as an outage incident, the possibility of pre-exist open main around

could be dropped or embraced according to how close the real time nearby transformers load changes ( $\Delta I_{R.n}$ ) are from the calculated values ( $\Delta I_{C.n}$ ).

The incoming RMS readings for all of network transformers are continuously processed by the three statistical approaches to detect any abnormal load change, which can be nominated as a suspect event if the load change at a specific transformer exceeds the boundary of the normal day load change, this event is identified by:

- The name of transformer at which the maximum abnormal change is detected.
- The time at which the reading shows up according to RMS system.

Using Open Main Detection System (OMDS), the following logical statements are programmed. Suitable logical tools are used to refine the initial suspect list of events to confirm or banish final transformer outage incident decision. Any detection for unusual transformer load change should be refined by going through the following steps that includes the primary refinement:

- Does the present real time reading ( $I_{R.event}$ ) show zero value in any of the three phases? If it does not, this event will be refined through open main incident process.
- Is there a scheduled maintenance operation for this transformer at this time? which is enough reason to exclude this event from the suspect list ( $S_m$ ):(1:No maintenance, 0:maintenance)
- Does the load change at this transformer ( $\Delta I_{R.event}$ ) happen together with other changes ( $\Delta I_{R.n}$ ) at certain transformers listed in Nearby Transformers List for Transformer Outage (TONTL)? if it does not, so this load change does not reflect a real transformer outage and mostly is an erroneous reading.

### 3.5.1.3 Transformer Outage sensitivity analysis

Once abnormal change in one of the network transformers ( $\Delta I_{R.event}$ ) is detected and primarily refined, transformer outage sensitivity analysis will be initiated, if the present load shows zero value. Outage analysis depends on how close the summation of real time changes in nearby transformers loads ( $\sum \Delta I_{R.NBn}$ ) are from the load change at the event transformer ( $\Delta I_{R.event}$ ). From the Nearby Transformer List for Transformer Outage (TONTL), we can know the nearby transformers to compare the sum of their real time load changes ( $\sum \Delta I_{R.NBn}$ ) to that of event transformer  $\Delta I_{R.event}$ , taking into consideration:

- Transformer size ratio,  $K_s = \frac{Nearby.Transformer.size(KVA)}{Event.Transformer.Size(KVA)}$ . This serves to adjust the effect of different network transformers sizes on the sensitivity calculations. For every nearby transformer involved in the sensitivity calculation process, correspondent transformer size factor  $K_s$  will be used.

Sometimes, the distribution system parameters implemented in the power flow calculation do not exactly conform to those actually installed in the system due to continuous grid extensions that have not been updated to power flow program yet or due to undetected faulty equipment, which usually redistribute the load at the nearby transformers in a way different from that calculated by PVL. For this reason, the number of nearby transformers to be analyzed in the sensitivity process is chosen to be most ten affected nearby transformers in TONTL to include such possible redistribution case, where the summation of real time load change for these transformers should be close to the load change at that transformer shows zero load value. Most of the time, the sum is not close to this value for the previous mentioned causes, therefore mismatch tolerant value ( $MIS_{tol}$ ) is used in this study. Cases with mismatch values summing less than  $MIS_{tol}$  will approved as transformer outage incident.

$$\left| \frac{\Delta I_{R.event} - \sum_{i=1}^{10} \Delta I_{R.NBi}}{\Delta I_{R.event}} \right| \leq MIS_{tol} \Rightarrow Trans.Outage \quad (3.36)$$

$MIS_{tol}$ : The maximum tolerant mismatch absolute value between  $\Delta I_{R.event}$  and  $\sum_{i=1}^{10} \Delta I_{R.NBi}$  as ratio of  $\Delta I_{R.event}$ .

The selected value for  $MIS_{tol}$  mainly depends on how different the actual network configuration is from that used in power flow program (PVL) by which the ten nearby transformers selected. Tentative value for  $MIS_{tol}$  was chosen as 0.6.

### 3.5.2 Transformer Outage with Pre-exist Open Main

Once a transformer outage decision is confirmed, another sensitivity analysis will be implemented in this study to determine if this transformer is close to a pre-exist open main or not. This brief decision implies the implementation of another sensitivity analysis process that compares the RMS real time load change ( $\Delta I_{R.n}$ ) for the most affected five nearby transformer in TONTL to the calculated change values ( $\Delta I_{C.n}$ ). To confirm that this transformer outage took place around an already existing open main, two conditions should be satisfied:

1. The maximum mismatch value between real time and calculated load change that shows up in one of the five nearby transformers must exceed a predetermined value ( $MIS_{EXISTING}$ ), taking into consideration:

- Interrupted load ratio (between the interrupted transformer load in power flow program case and that actually interrupted in real time case.

$$K_i = \frac{I_{C.event (from.power.flow.calculation)}}{I_{R.event (from.real.time.values)}}, \text{ So, for specific event sensitivity calculation, we}$$

have one interrupted load ratio factor ( $K_i$ ).

For any abnormal load change event taking place at network transformer ( $xfr_{event}$ ), transformer real time interrupted load ( $\Delta I_{R.event}$ ) and the same load calculated in power flow program ( $\Delta I_{C.event}$ ) should be considered in addition to the changes for the most affected five nearby transformers ( $xfr_{NB1}, xfr_{NB2}, \dots, xfr_{NB5}$ ),

Table 3.12 Real Time and Calculated Nearby Transformers Load Changes

Outage at TR. ( $xfr.event$ ), Load change ( $\Delta I_{R.event}$ )			
Nearby TR.	Real Time TR. Load Change( $\Delta I_R$ )	Calculated TR. Load Change ( $\Delta I_C$ )	Mismatch $\Delta I_R - \Delta I_C$
Xfr.NB1	$\Delta I_{R.NB1} \times K_{S1} \times K_i$	$\Delta I_{C.NB1} \times K_{S1}$	$\Delta 1$
Xfr.NB2	$\Delta I_{R.NB2} \times K_{S2} \times K_i$	$\Delta I_{C.NB2} \times K_{S2}$	$\Delta 2$
....	...	...	...
Xfr.NB5	$\Delta I_{R.NB5} \times K_{S5} \times K_i$	$\Delta I_{C.NB5} \times K_{S5}$	$\Delta 5$

2. None of the present loads ( $I_{R.NBn}$ ) at the five nearby transformers should be zero.

$$\Delta_n = |\Delta I_{R.n} - \Delta I_{C.n}| \quad (3.37)$$

$$\text{If: } ((\Delta_{mx} = |\Delta I_{R.mx} - \Delta I_{C.mx}| \geq MIS_{existing}).AND.(I_{R.NBn} \neq zero)) \quad (3.38)$$

⇒ Possible Already Existing Open Main.

$xfr_{NB.mx}$ : The nearby transformer at which ( $\Delta n$ ) is the max.

$MIS_{EXISTING}$ ; is chosen to be 15 as tentative value.

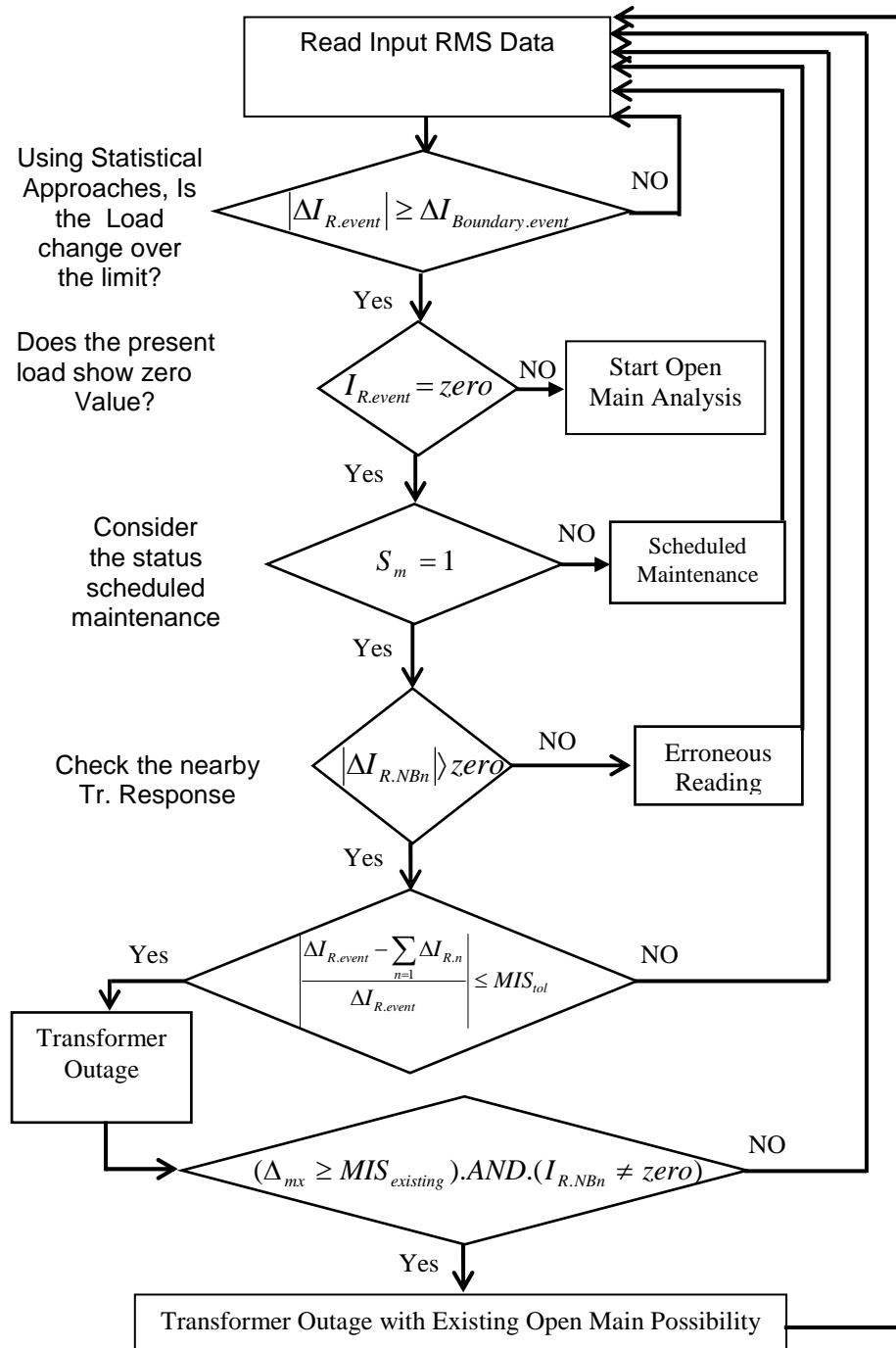


Figure 3.37 Transformer Outage Incident Analysis Sequence

### 3.5.3 Open Main Detection Analysis

A secondary distribution network consists of huge number of secondary mains connected in a way that assures the continuity of the service for all customers by different current paths. These mains are protected via current limiters that serve to protect the cables and other network equipment from faulty parts and overload situation that may occur.

Having blown current limiter does not mean that nearby customers will be disconnected from the service, as long as the current supplied to customers has other tracks to follow through. In the short run, no indication for blown current limiter incident may be sensed, but for long term performance, the repetition of such incident leads to weak network that can possibly be unable to withstand the faulty incidents and be susceptible to local or complete blackout.

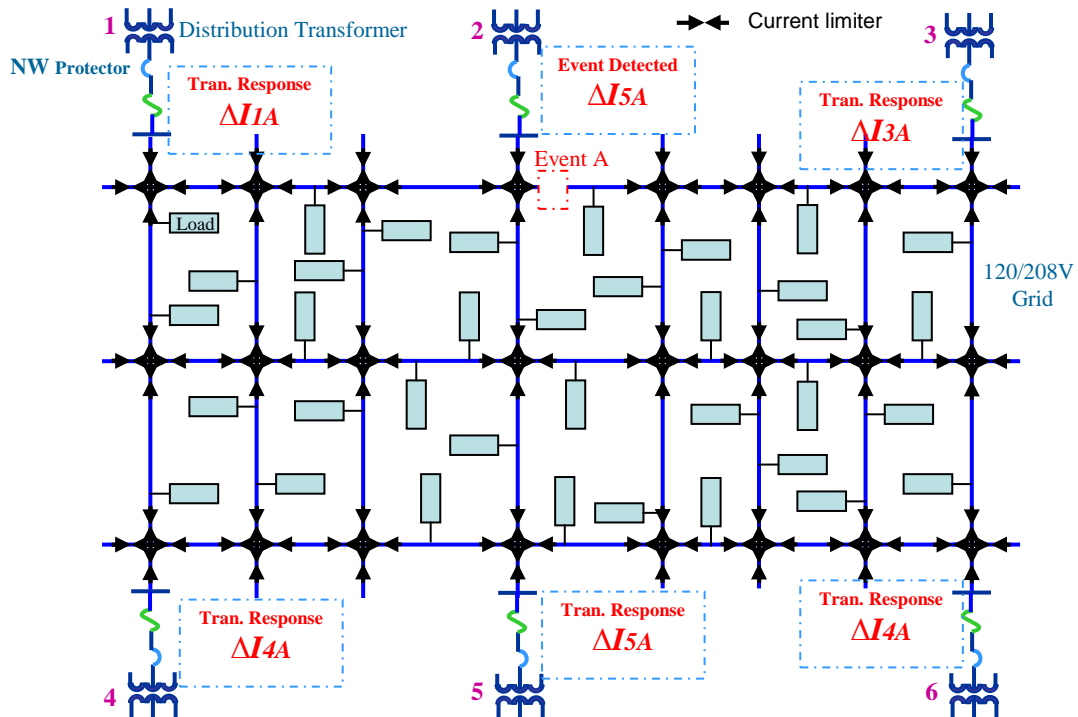


Figure 3.38 Supposed Open Main Incident (A) in Small Section of Network



In most of open main incidents, the power flow in the surrounding area redistributes showing nearby transformer loads different from those before the incident. The change at one transformer load can be an increase or a decrease based on the open main incident location among the most affected transformers.

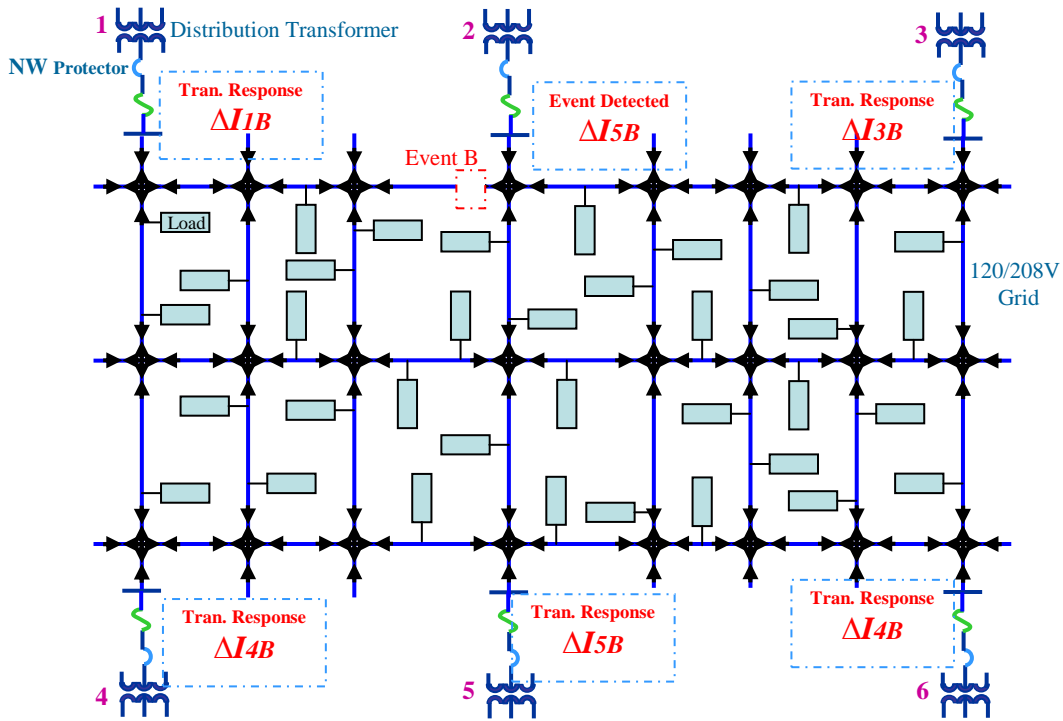


Figure 3.39 Supposed Open Main Incident (B) in Small Section of Network

For the proposed open main incident locations (A) shown in Figure 3.38 and location (B) shown in Figure 3.39, each location may show different load changes at the nearby transformers especially those close to the incident.

Figure 3.40 shows different expected locations for blown limiter. For each location, different nearby transformer responses can be calculated using PVL software. These calculations formalize an Open Main Nearby Transformer List (OMNTL) indicating the most affected nearby transformers by each open main incident to be used later in open main incident analysis to confirm or negate the incident occurrence.

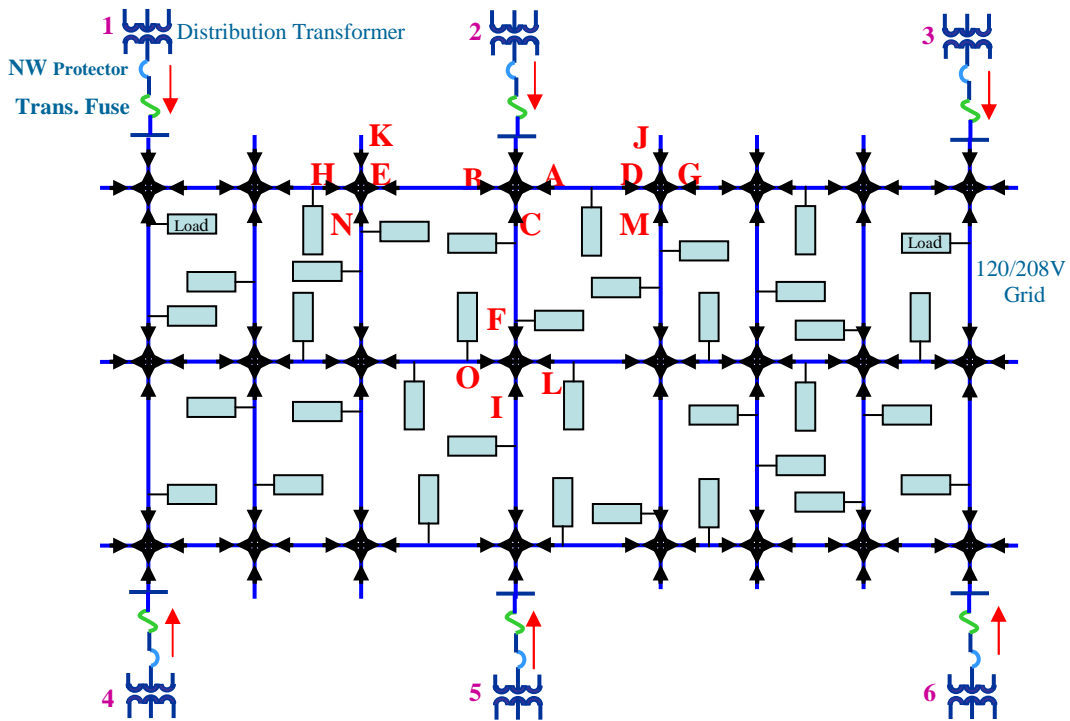


Figure 3.40 Expected Scenarios for the Open Main Incident

Table 3.13 Real Time Load Change for the Nearby Transformers

Ambiguous	Most affected Nearby Transformer Real Time Load Change					
Location	# 1	# 2	# 3	# 4	...	# 10
Incident	$\Delta I_{R1}$	$\Delta I_{R2}$	$\Delta I_{R3}$	$\Delta I_{R4}$	...	$\Delta I_{R10}$

Table 3.14 Nearby Transformers for Every Open Main Location Scenario

Expected Location scenarios	Most affected Nearby Transformers					
	Figured out by (PVL)					
A	$xfr_{A.1}$	$xfr_{A.2}$	$xfr_{A.3}$	$xfr_{A.4}$	...	$xfr_{A.10}$
B	$xfr_{B.1}$	$xfr_{B.2}$	$xfr_{B.3}$	$xfr_{B.4}$	...	$xfr_{B.10}$
C	$xfr_{C.1}$	$xfr_{C.2}$	$xfr_{C.3}$	$xfr_{C.4}$	...	$xfr_{C.10}$
D	$xfr_{D.1}$	$xfr_{D.2}$	$xfr_{D.3}$	$xfr_{D.4}$	...	$xfr_{D.10}$
...	...	...	...	...	...	...

$\Delta I_{R,n}$  : Real time load change in nearby transformer (n)

$xfr_{A.1}$  : Nearby transformer number 1 for Possible open main scenario (A).

Most of the time, the most probable location for an open-main incident is some where in between the transformer that shows the most real time load increase and the one that shows the most load decrease as a response to the incident. It may happen that more than one current limiter is installed in between these two transformers, that makes the decision depends on which proposed open main location causes the more similar transformers responses to that in the real time RMS data.

### 3.5.3.1 Open Main Nearby Transformer List (OMNTL)

For every probable open main incident, load response for all network transformers is observed using power flow program PVL. Nearby transformers that show most load changes are listed beside that main in descending order to form a complete list that has a number of rows equals to that of network secondary mains.

Table 3.15 OMNTL –Transformers List Pattern

Secondary Main	Affected Nearby Transformer				
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	.....
M1	$xfr_A$	$xfr_B$	$xfr_C$	$xfr_D$	....
...	...	...	...	...	...
Mm	$xfr_I$	$xfr_{II}$	$xfr_{III}$	$xfr_{IV}$	....

3.5.3.2 Most Sensitive Transformer List (MSTL)

According to OMNTL, almost every network transformer is listed one time or more as the most affected nearby transformer due to open main location. In MSTL, for each network transformer, all possible open mains at which this transformer shows the maximum load change are listed in one row. Therefore MSTL number of column is different from transformer row to another depending on how sensitive this transformer is to the different open main incidents.

Table 3.16 MSTL Pattern

Transformer	Secondary mains lead to max. load change at this transformer				
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	...
$xfr_1$	Main.A	Main.B	Main.c	Main.D	...
...	...	...	...	...	...
$xfr_n$	Main.I	Main.II	Main.III	Main.IV	...

3.5.3.3 Open Main Detection Analysis and Logical Sequence

As soon as an abnormal load change detected at the present RMS reading for one of the network transformers ( $\Delta I_{R.event}$ ) by any of the statistical approaches explained before, transformer outage detection system checks the response of nearby transformers to decide whether it is transformer outage or not. If it is not an outage; open main detection procedure is initiated to locate the possible open main incident. Some logical events should be confirmed to declare the incident occurrence:

- One of the network transformers should show abnormal load change ( $\Delta I_{R.event}$ ) that overmatches the normal day load change limit ( $\Delta I_{Boundary.event}$ ) for that transformer

at this time of day. 
$$\Delta I_{R.event} > \Delta I_{Boundary.event}$$

- No transformer outage decision ( $T.O$ ) should be recorded as a response for this over limit transformer load change. If so; the cause for the change is already known and no need to plunge into open main detection process.
- As one of the distinctive feature for transformer load change response in case of open main over that for transformer outage case, it is necessarily that at least another nearby transformer shows opposite load change ( increase or decrease) regardless of ratio value ( $k$ ),

$$\Delta I_{R.n} = -k(\Delta I_{R.event})$$

$$k = \frac{|\Delta I_{R.n}|}{|\Delta I_{R.event}|} \quad (3.39)$$

For transformer ( $xfr_{event}$ ) that shows maximum over limit load change ( $\Delta I_{R.event}$ ), the possible open main incidents that lead to maximum load change at this transformer ( $xfr_{event}$ ), can be found from Most Sensitive Transformer List (MSTL), where every incident ( $SM_n$ ) from these will also affect a number of nearby transformers ( $xfr_{OMNB.n}$ ) listed in OMNTL. The detection sequence goes through these possible secondary mains ( $SM_n$ ) one by one to examine the real time response for its nearby transformers ( $xfr_{OMNB.n}$ ).

Every proposed open main in OMNTL, that its nearby transformers load changes ( $\Delta I_{R.OMNBn}$ ) fulfill the three conditions mentioned above:

- $\Delta I_{R.event} > \Delta I_{Boundary.event}$
- No transformer outage decision ( $T.O$ )
- Another nearby transformer shows opposite load change.

will be a possible open main location (POM), on which a sensitivity analysis will be implemented.

### 3.5.3.4 Open Main Incident Sensitivity Analysis

Once a load change is detected at one of the network transformers ( $xfr_{event}$ ), and it is not due to transformer outage incident, a list of open main locations, by which this transformer is the most sensitive for can be obtained from MSTL. According to above mentioned three conditions, some of these open main locations might be accepted ( $POM_n$ ). Sensitivity analysis should be implemented here to exclude those main locations that do not satisfy nearby transformers load changes feature and to decide which location is more possible than the others. The following open main locations should be excluded first:

- The main location that one of the nearby transformers ( $xfr_{OMNB.n}$ ) shows zero load in the present reading (Off-switch.) or zero load in the previous reading (ON-Switch.),

$I_{R.OMNBn} = zero$ , or  $I_{R.OMNB.n-} = zero$  in the same time that:

$$\Delta I_{R.OMNBn} \geq \Delta I_{Boundary.OMNBn}$$

- The main location with nearby transformers loads changes summation greater than predetermined level value ( $LEV_{tol}$ ).

$$\left| \sum_n \Delta I_{R.OMNB.n} \right| \geq LEV_{tol} \quad (3.40)$$

The selection of ( $LEV_{tol}$ ) value depends on how sensitive we need the detection process to be, also how close network actual configuration to the ideal one used in PVL calculation to Identify the ten nearby transformers. A value of 5 is chosen as tentative tolerant value.

Sensitivity analysis on the rest possible open main locations should be implemented to determine which location is more possible than the others as shown in Table 3.17.

Table 3.17 Open Main Incident Analysis

Possible Open Main (POM <sub>j</sub> )	Open Main Nearby Transformer Load Change				Sum
	$xfr_{R.OMNB.1}$	$xfr_{R.OMNB.2}$	$xfr_{R.OMNB.3}$	$xfr_{R.OMNB...}$	
POM <sub>1</sub>	$\Delta I_{R.OMNB.a}$	$\Delta I_{R.OMNB.b}$	$\Delta I_{R.OMNB.c}$	...	$\sum_{n=a} \Delta I_{R.OMNBn}$
...	...	...	...	...	...
POM <sub>m</sub>	$\Delta I_{R.OMNB.A}$	$\Delta I_{R.OMNB.B}$	$\Delta I_{R.OMNB.C}$	...	$\sum_{n=A} \Delta I_{R.OMNBn}$

The most probable location is the main that shows least summation value for it's nearby transformers load changes.

$$\min(\sum_{n=1} \Delta I_{R.n}) \Rightarrow \text{Most Probable Open main Location.} \quad (3.41)$$

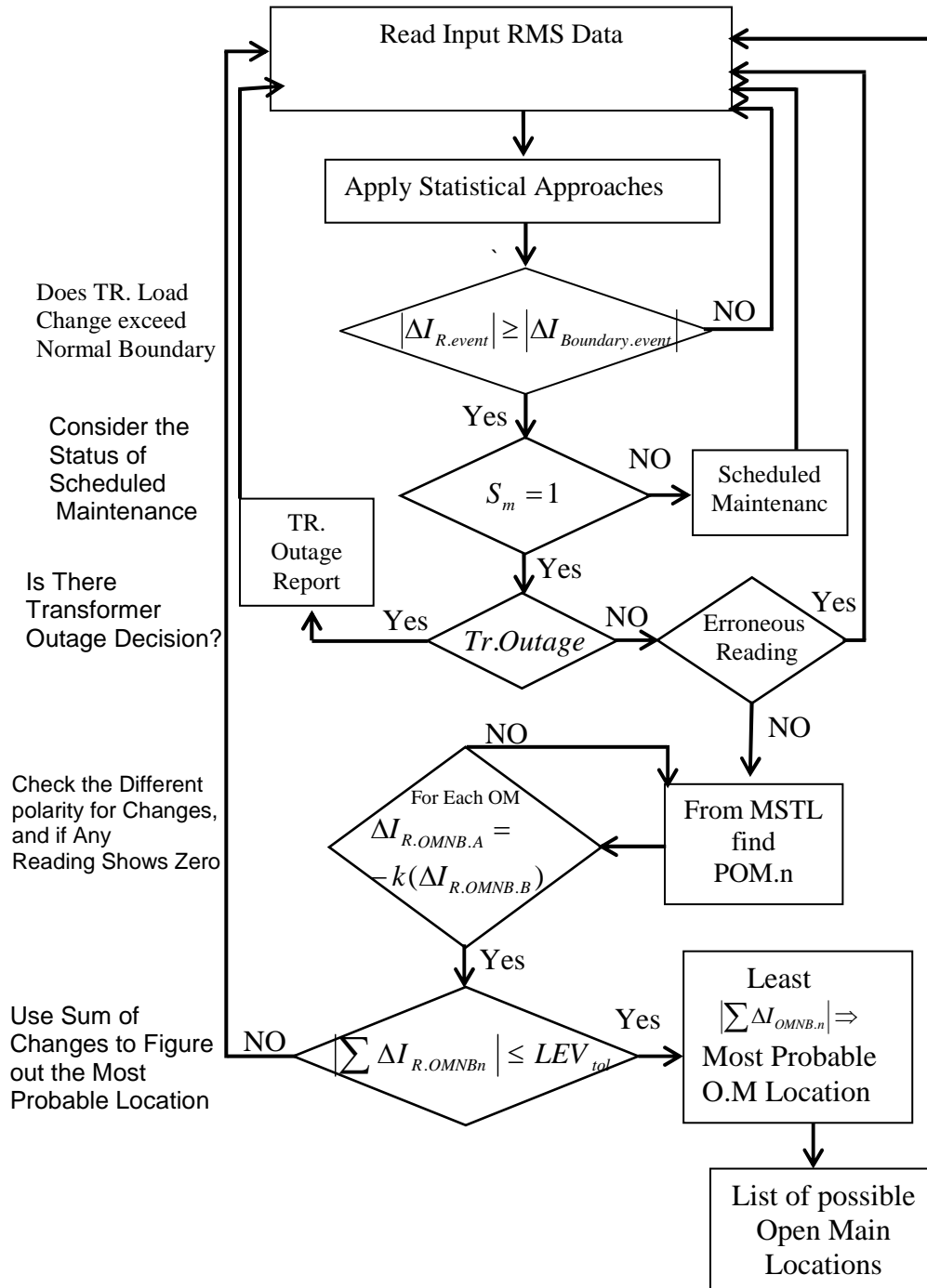


Figure 3.41 Open Main Incident Analysis Sequence



CHAPTER 4  
IMPLEMENTATION AND TEST

In order to implement the three approaches mentioned in the previous chapter, and to apply the sensitivity analysis process needed to refine the detected suspect event, it is necessary to use a computer tool like LabVIEW to develop Open Main Detection System (OMDS) to facilitate the interface process for incoming RMS data from Con Edison system. Moreover, it is required to put out the results in a way encloses the data for all nearby transformers that are part of this incident detection process. The presentation of the data facilitates the mission of incident root cause analysis later.

4.1 Input Data Preparation

The input data for the open main detection system prepared by this study are mainly the RMS readings for the network transformers loads, provided by Con Edison HP-UNIX environment. The necessary portion of RMS data required in the detection process is delivered to certain file under windows system periodically to be picked up by OMDS.

Table 4.1 Sample of RMS Data Delivered To OMDS

Time/Date	Transformer	I(A)	I(B)	I(C)	Schedule Maintenance
20070401051557	TM2872	26	24	24	0

Other input data have to be formatted as matrices; these are listed below and were explained previously in details:

- Transformer Outage for Nearby Transformer List (TONTL).
- Standard deviation matrices (SDM).

- Open Main Nearby Transformers List (OMNTL).
- Most sensitive transformer List (MSTL).
- Network transformers sizes list.

#### 4.2 LabVIEW

LabVIEW stands for Laboratory Virtual Instrumentation Engineering Workbench. It is a programming tool for testing, measurements and control applications. It is effective tools to interface the input measurement data, analyze it and share the results. The selection of it to be the programming tool in this study was for the following reasons:

- Using the front panel of OMDS, it is easier to create an interface that satisfies the application requirements for the benefit of incident detection and root causes analysis.
- Using OMDS, we can construct and customize the output data graphs and archive which benefit the open main detection analysis.

#### 4.3 Front Panel for Open Main Detection System OMDS

At the front panel of OMDS program, spaces are specified to view the most important information about the open main or transformer incident that can be easily viewed by personnel monitoring the network status.

Some of the information at the front panel relate to recent incidents. Others are general monitoring information for the network transformers. Followings are the detailed descriptions for both of them:

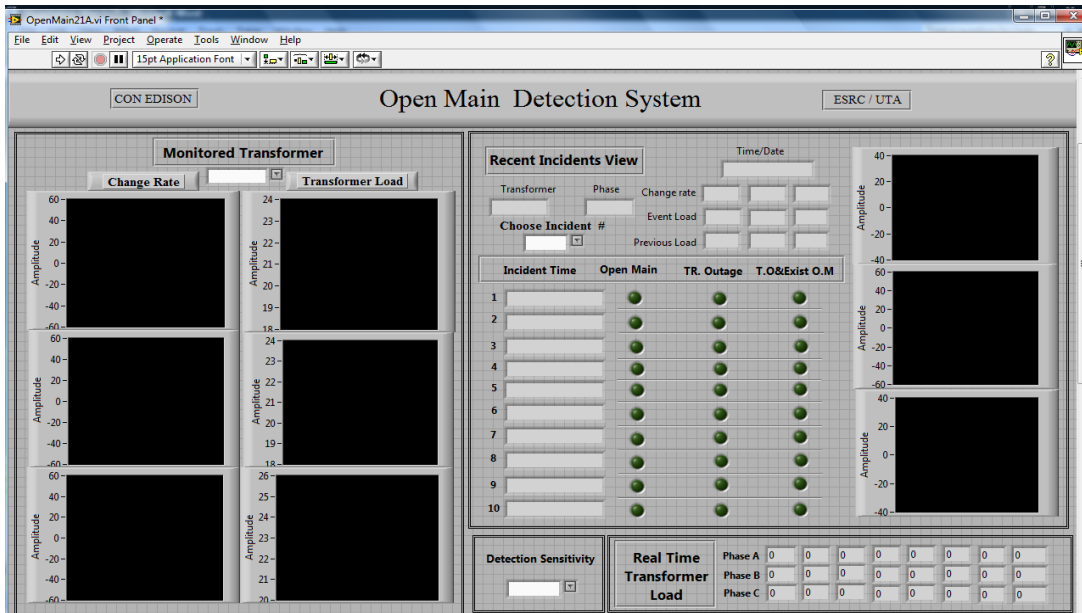


Figure 4.1 Front Panel for Open Main Detection Program

#### 4.3.1 Real Time transformer Load

At the right bottom corner of the front panel, eight indicator boxes for each transformer phase are specified to view the last two hour real time readings (8x15 minutes).



(a)



(b)

Figure 4.2 (a) Three Phase Real Time Transformer Load Readings (b) Combo box

This is a long enough period to review the historical trend of this transformer load prior to the incident time. The transformer to be viewed can be chosen from the combo box at the left upper corner.

#### 4.3.2 Transformer Change Rate Waveform Chart

For any network transformer chosen from the combo box at the left upper corner of the front panel, each phase real time load change can be monitored for the last two hours. The chart also explicates the boundary curve for the normal load as shown in the left part of Figure 4.3.



Figure 4.3 Sample of Phase A Charts for Transformer Load Change and Load Magnitude

#### 4.3.3 Transformer Load Magnitude Waveform Chart

Right side part of Figure 4.3 shows the chart specified to monitor the last two hour real time load magnitude for the selected transformer.

#### 4.3.4 Detection Sensitivity Factor

Boundary curve of the change rate approach is used in monitoring the left part of Figure 4.3, changing the boundary curve level factor ( $k$ ), will adjust the sensitivity of the program for load change detection. As  $K$  increases the expected detected events decreases as explicated in Figure 3.2. The boundary curve level factor ( $k$ ) can be adjusted by the combo box for a range value from 1 to 10 as shown in Figure 4.4.

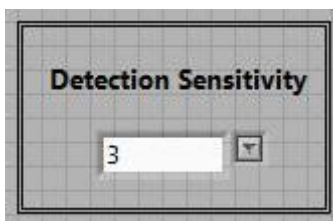


Figure 4.4 Combo box to select Detection Sensitivity

#### 4.3.5 View of Recent Incidents

On the front panel, 10 most recent incidents will be listed. Each one indicates the time of occurrence according to RMS system and the type of the incident (open main, transformer outage or transformer outage with possible pre-exist open main). The previous incidents that took place prior to incident number 10 are automatically saved in incident archive Excel files. The recent incident view includes the following information about the selected incident:

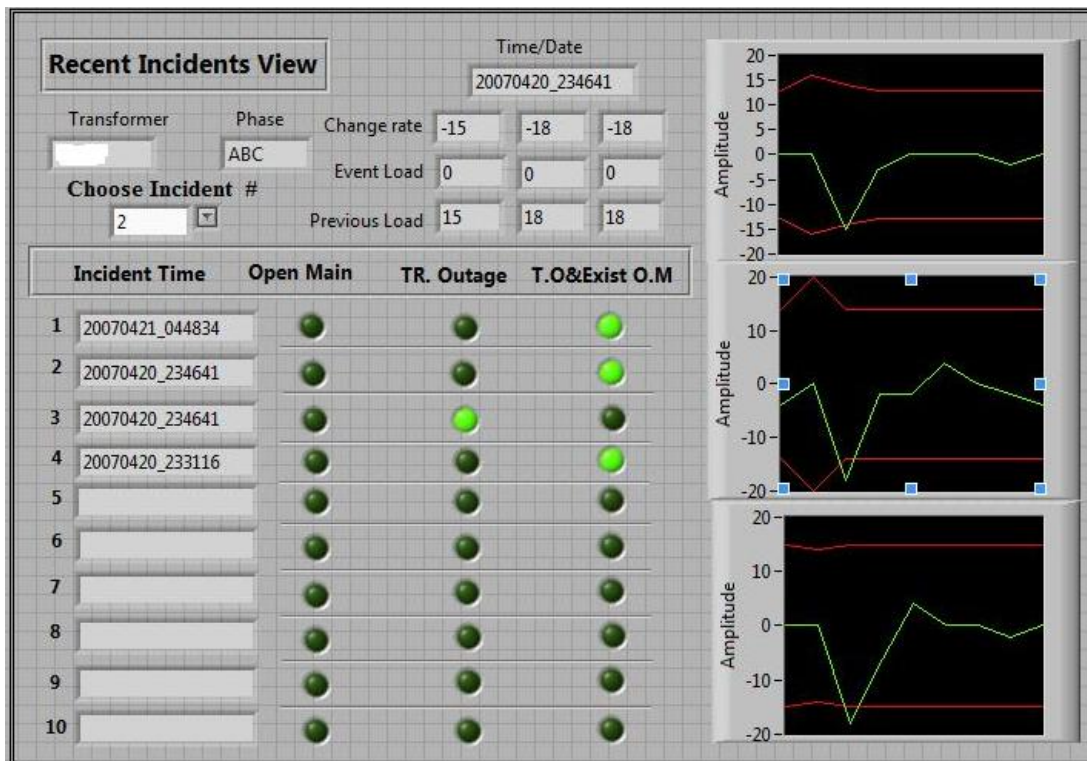


Figure 4.5 Recent Incidents View at Open Main Detection System Front Panel

1. Transformer name at which the over limit load change was detected to start the incident refinement procedure that eventually view this incident.
2. Time and date for the incoming RMS reading at which the load change detected.
3. The transformer phases at which the incident occurrence was confirmed.
4. Transformer previous and present 3-phase load magnitudes, in addition to load change rates.
5. Transformer 3 phase load change charts, including the recent two hours.

#### 4.4 Major Portions of The Implemented OMDS

Implemented open main detection approaches and logical statements were programmed using multi portions block diagram in OMDS. Each one was prepared to perform a certain function in over-limit load change detection, event refinement and incident confirmation processes. Followings are the major components of the diagram used to the result previously mentioned at the front panel and archive.

##### *4.4.1 Input Data Readers*

Open main detection system input data includes two types of matrices:

- Time dependent matrix content: like the one that includes the real time RMS readings and prescheduled maintenance warning for all network transformers for the most recent 15 minutes.
- Same matrix content any time, which includes the matrices with the calculated values using PVL, such as TONTL, OMNTL and MSTL.

The first type of matrices is read one time every 15 minutes once new readings delivery is confirmed by the following procedure:

1. OMDS periodically checks status of a flag already prepared to give an indication that new readings are received from RMS system and ready to read.
2. As soon as this new readings are delivered, flag status will be changed by RMS side from zero to one.

3. Since OMDS checks the flag status periodically, it will sense this new flag status and check the time of the new reading, if it is the expected one in the sequence (different from the previous), OMDS will start detection process and reset the flag to zero again.

The other type of matrices is read once the program starts operation for one time only.

#### *4.4.2 Over- Boundary Transformer Load Change Tester*

A certain decision about each transformer phase, whether the load change exceeds the boundary or not (initial suspect event) is taken here, according to processing the most recent read real time RMS readings for all network transformers, in addition to multiply the contents of the already read DMS matrices by  $k$  (boundary factor level).

#### *4.4.3 Initial suspect event Refiner*

This part refines the erroneous readings if the event transformer abnormal load change does not coincide with other nearby transformers changes. Also it is responsible to block the detection process if we have a prescheduled maintenance warning.

#### *4.4.4 Transformer Outage Incident Refiner*

Once the initial suspect event is confirmed, TONTL will be implemented to confirm transformer outage incident. Output decision for this stage will declare the event as transformer incident or will start the open main incident refinement process.

#### *4.4.5 Open Main Incident Refiner*

If the suspect event is confirmed not a transformer outage, open main incident refinement process will be launched using MSTL and OMNTL to confirm and locate the open main incident or to banish it.

#### *4.4.6 Output Archive writers*

Since the front panel provides summarized report for limited number of recent incidents, this study lists all the confirmed incidents that took place in an Excel file (archive.xls). Every previous incident listed in the archive is linked to a detailed Excel file report named by incident type, date/time and transformer name. For the purpose of later incident analysis, an incident

detailed report is prepared to include the same information that appears in the front panel in addition to:

- Real time load change for all nearby transformers listed in TONTL for a transformer outage incident or in OMNTL for open main incident.
- Hyperlink for three images show transformer three phase load change charts.
- 

#### 4.5 Test of Data

The system is designed to communicate Con Edison HP-UNIX system to receive real time readings for network transformers load and to immediately start processing them. For the purpose of testing previous recorded real time data for any network combined with the correspondent input matrices, OMDS presented by this study is flexible enough to run such data in relatively short time compared to that of 15 minutes/one reading for real time test.

Previous one year RMS data for a network in Con Edison distribution system was used as real time input readings for the open main incident detection system to detect the open main and transformer outage incidents during this period of time. Next chapter shows in details some results for running of the detection system.



## CHAPTER 5

### STUDY RESULTS

One Year data for a certain network in the Con Edison distribution system was tested. The approaches implemented by this study were executed in OMDS. The automatically produced incident reports by running the program:

1. Examined closely by referring to a schematic diagram for the incident location and checking the credibility of the results.
2. Double check procedure was followed for some of them to verify the consistency of different program stages.

Since the data received from RMS is the transformer load as percent of the transformer rating current, the actual magnitude of the load current depends on transformer size. The following results are for network that installing transformers with sizes of: 500, 1000, 1500, 2000 and 2500 kVA, in this chapter the values appears in excel file reports for a comparison purpose are those received by RMS multiplied by the ratio between transformer size and the smallest one size.

$$I_{comparison} = I_{RMS} \times \frac{TR.Size}{500kVA} \quad (5.1)$$

Which adjusts the differences in network transformer sizes, and shows the values at the all reports referred to the same value regardless the size of the event transformer.

Followings are three incidents reported by OMDS that implements this study approaches and logical statements.

### 5.1 Transformer Outage Reported Incident

As one of many incidents detected by running detection program, below is the detailed Excel report for one transformer (TR) outage incident in addition to load change plot for two hour period.

Phase :ABC												
Time/Date	DATE.TIME											
Transformer:	TR											
Previous Reading:	72	66	66									
Event Reading:	0	0	0									
Change Rate:	-72	-66	-66									
Nearby TRs	TNB1	TNB2	TNB3	TNB4	TNB5	TNB6	TNB7	TNB8	TNB9	TNB10		
Ph.A Change Rate	22	26	8	6	10	6	0	0	0	0		
Ph.B Change Rate	32	26	10	0	4	6	0	0	0	0		
Ph.C Change Rate	26	20	10	6	6	0	0	0	0	0		
	<a href="file:///C:/ConEdison/plot/TRA_DATE_TIME.bmp">file:///C:/ConEdison/plot/TRA_DATE_TIME.bmp</a>											
	<a href="file:///C:/ConEdison/plot/TRB_DATE_TIME.bmp">file:///C:/ConEdison/plot/TRB_DATE_TIME.bmp</a>											
	<a href="file:///C:/ConEdison/plot/TRC_DATE_TIME.bmp">file:///C:/ConEdison/plot/TRC_DATE_TIME.bmp</a>											

Figure 5.1 Excel Detailed Report about (TR) Outage Incident Circumstances

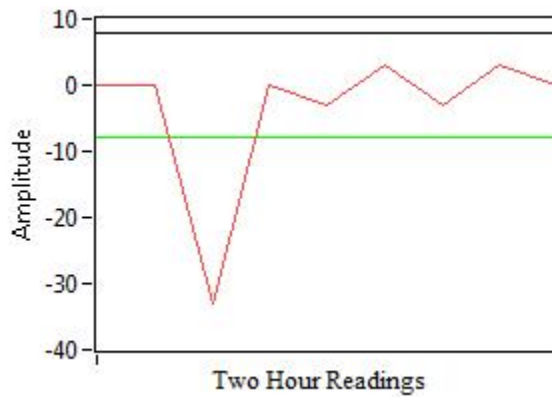


Figure 5.2 Transformer (TR) Load Change

The plot in Figure 5.2 can be viewed automatically by clicking on the hyper link below the Excel report. It shows the over boundary load change at (TR) as reported by Open Main Detection System OMDS. The plot provides the load change archive for two hour period, the name of the file showing this figure recognizes the date, time, transformer and phase at which this incident took place.

To check the creditability of such automatic delivered report as one of many similar reports delivered for one year data; double check investigation was applied referring to the real time data for each transformer included in the Excel report. This is to make sure that the detection process depends on actual true data or not. Figure 5.3 shows the plot for that day real time readings at which the incident took place.

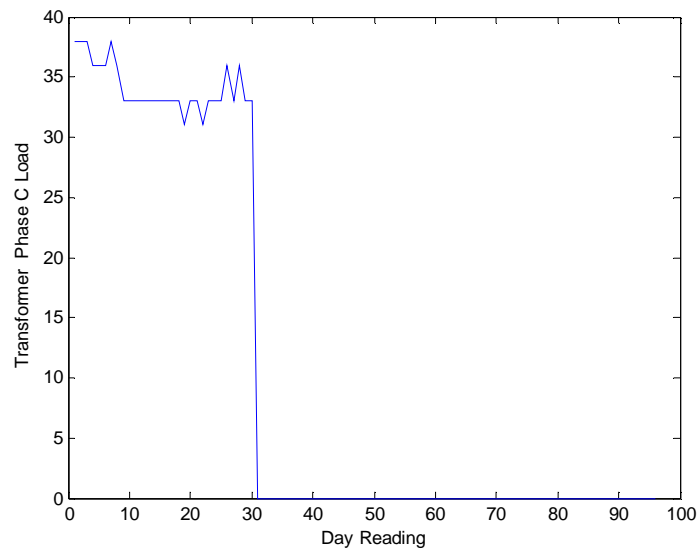


Figure 5.3 Transformer (TR) Real Time Load at phase C

The response to the outage incident can be noticed at the Time-Load plot for the most affected nearby transformer (TNB1) in Figure 5.4, It is obvious that (TNB1) load increased to carry a part of the load that was supplied by (TR) before outage.

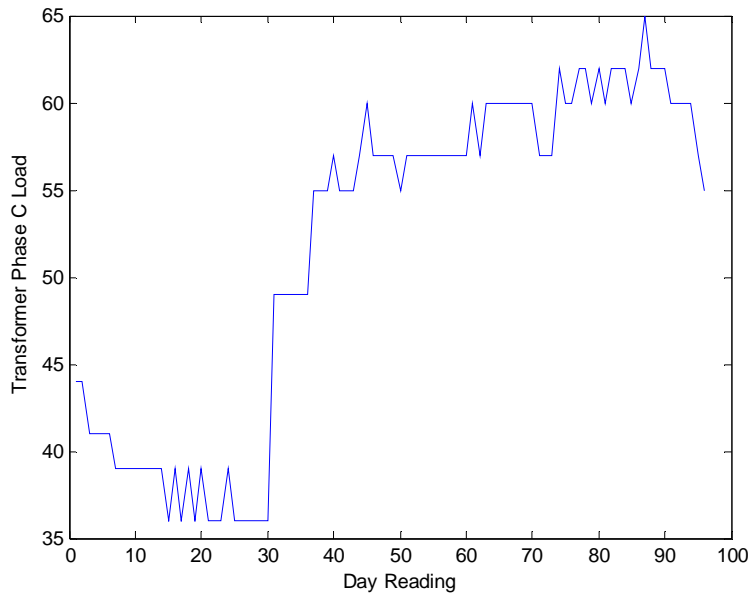


Figure 5.4 Nearby Transformer (TNB1) Real Time Load

The same thing happened in (TNB2), a considerable load change experienced as shown in Figure 5.5.

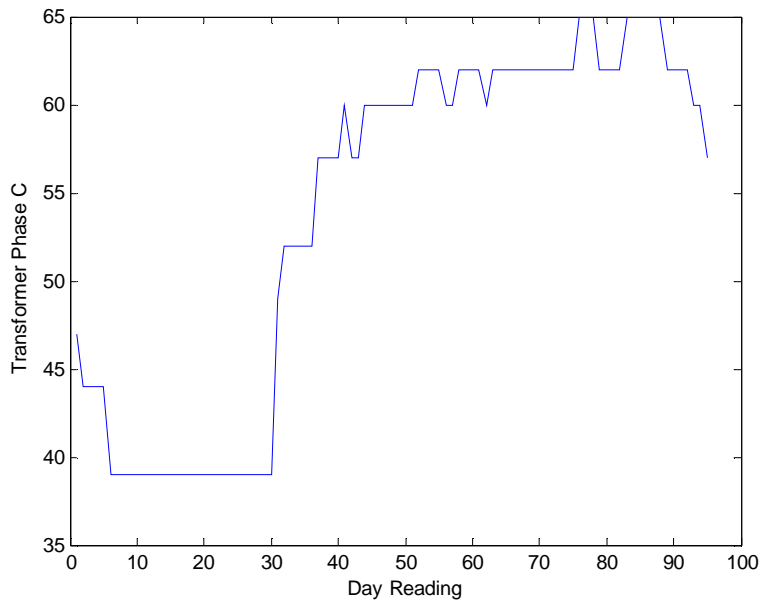


Figure 5.5 Nearby Transformer (NB2) Real Time Load



## 5.2 Transformer Outage with Pre-Exist Open Main

While OMDS was in action to detect the incident in the one year data for a network of Con Edison system, the Excel file in Figure 5.7 was reported. It indicates the occurrence of transformer outage with pre-exist open main. It includes the date\time of the incident according the data received from RMS system, in addition to the transformer name at which the abnormal load change detected to start the analysis process. The load changes at the nearby transformers are also included, hyperlinks to the three phases change plots for two hours before the incident are listed below to make it easy to access to access the information about the incident.

Phase :ABC					
Time/Date	Date..Time				
Transformer:	TR1				
Previous Reading:	264	276	264		
Event Reading:	0	0	0		
Change Rate:	-264	-276	-264		
Nearby TRs	NB1	NB2	NB3	NB4	NB5
Ph.A Change Rate	48	8	20	40	24
Ph.B Change Rate	72	28	28	48	36
Ph.C Change Rate	48	20	8	40	24
	<a href="file:///C:/ConEdison/plot/TR1A_DATE_TIME.bmp">file:///C:/ConEdison/plot/TR1A_DATE_TIME.bmp</a>				
	<a href="file:///C:/ConEdison/plot/TR1B_DATE_TIME.bmp">file:///C:/ConEdison/plot/TR1B_DATE_TIME.bmp</a>				
	<a href="file:///C:/ConEdison/plot/TR1C_DATE_TIME.bmp">file:///C:/ConEdison/plot/TR1C_DATE_TIME.bmp</a>				

Figure 5.7 Excel Detailed Report about (TR1) Outage Incident Circumstances

The report shows the name of the transformer at which the outage is detected and its load change, in addition to the time / date, nearby transformers and their correspondent load changes.

Also the plot in Figure 5.8 was reported, it shows the load change for the transformer at which the outage occurred.

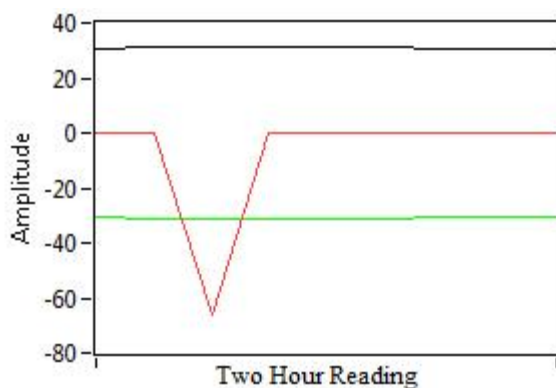


Figure 5.8 Transformer (TR1) Load Change

To investigate the creditability of reporting this incident, and to see how true the load changes for the nearby transformers in the report are, the following figures was prepared for some of them.

Figure 5.9 shows the load at phase A of transformer (TR1), where the load at this phase and the other phases falls to zero.

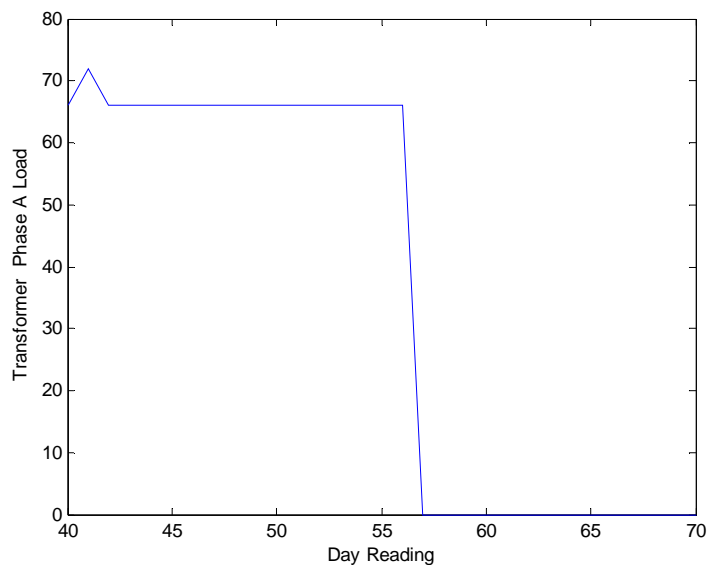


Figure 5.9 Transformer (TR1) Real Time Load at Phase A

The load change rate as reported by OMDS shows that the change in the transformer load exceeds the negative boundary as indication to the occurrence of abnormal event.

Illustrated in Figures 5.10, 5.11, 5.12, 5.13 and 5.14 is the load change at the closest transformers that shows most change value due the outage at TR1, it is obvious for this selected phase that transformer NB1 experienced the highest change value.

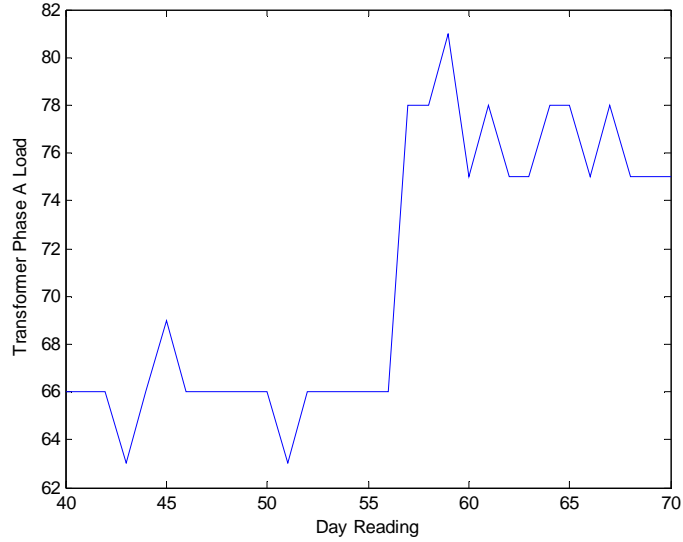


Figure 5.10 Transformer (NB1) Real Time Load

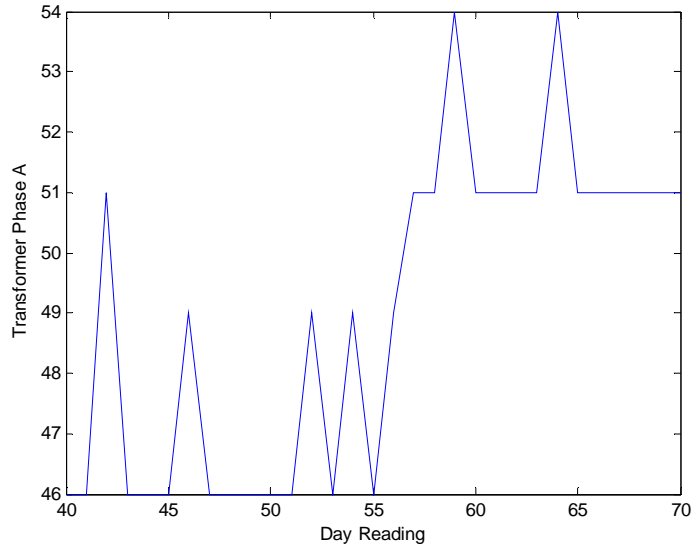


Figure 5.11 Transformer (NB2) Real Time Load



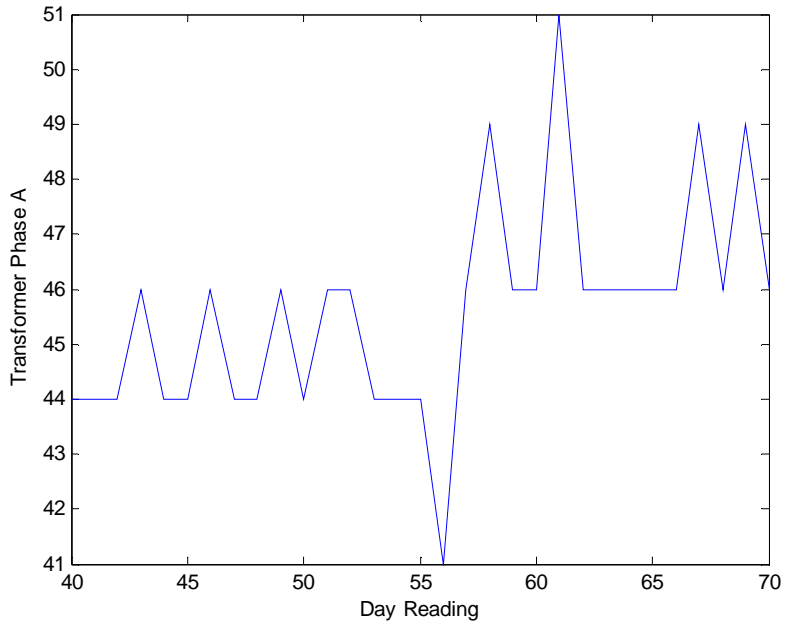


Figure 5.12 Transformer (NB3) Real Time Load

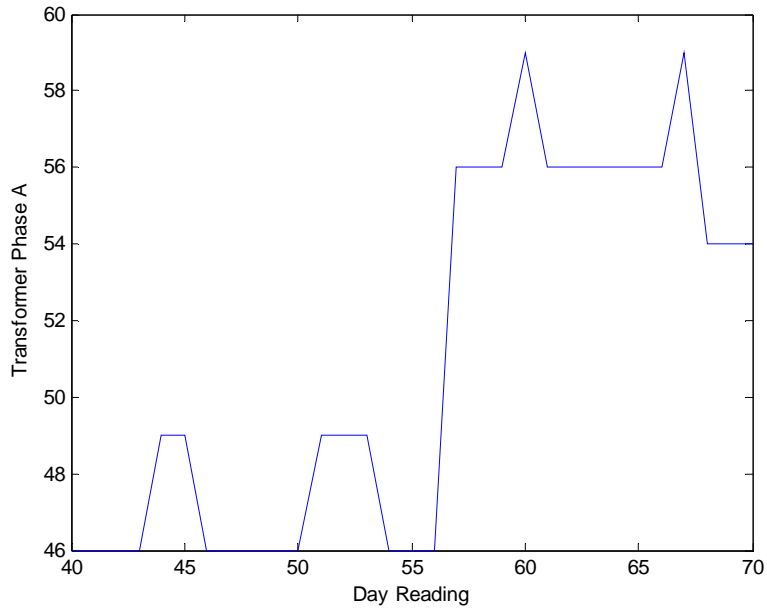


Figure 5.13 Transformer (NB4) Real Time Load

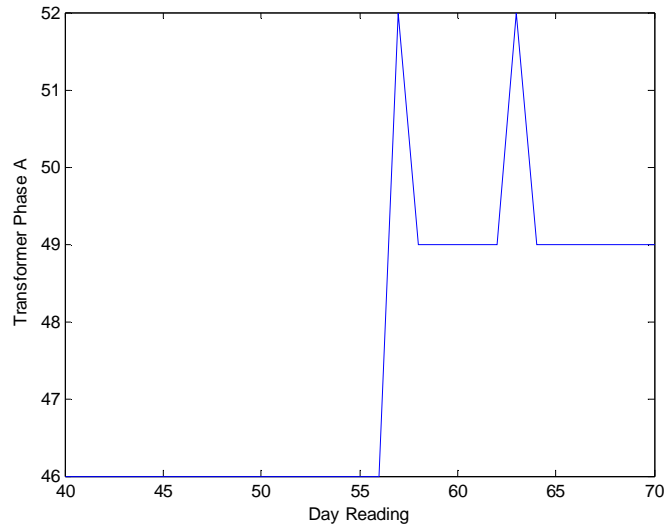


Figure 5.14 Transformer (NB5) Real Time Load

According to the values listed in Table 5.1, the mismatch between the calculated response and the real time one in this incident exceeds the predetermined mismatch tolerant value  $Mis_{existing}$ , where their load can be calculated by  $I_{comparison} = I_{RMS} \times \frac{TR.Size}{500kVA}$ . This justifies the declaration of this incident at the front panel as transformer outage with pre-exist open main.  $Mis_{existing}$  Selected here to be 16 for all network transformers to adapt the mismatch in the network configuration modeled by PVL and that actually installed in the system and not caused by open mains).

Table 5.1 Calculated and Real Time Load Changes for (TR1) Most nearby Transformers

Change at Transformers	$\Delta I_{event}$	$\Delta I_{NB1}$	$\Delta I_{NB2}$	$\Delta I_{NB3}$	$\Delta I_{NB4}$	$\Delta I_{NB5}$
	TR1	NB1	NB2	NB3	NB4	NB5
Calculated	-304	76	60	60	60	56
Real Time Change	-264	48	8	20	40	24
Mismatch( $\Delta_n$ )	-	18	44	32	12	25



O.M at Phase :A													
Transformer	TR2												
Phase	A												
NB Mains	476	477	553	554	560	561	731	743	744	1114	1115	1117	
Possible at	560	561							560				
NBTRs C.R	22	0	-4	0	-4	-6	0	4	0				
NBTRs C.R	22												
NBTRs C.R	22												
NBTRs C.R	22	0	0	-12	-4	-4	6	0	-4	-6			
NBTRs C.R	22	0	0	-12	-4	6	0	-4	-6	0			
NBTRs C.R	22												
NBTRs C.R	22	0	-4	0	0	0	0	0	-4	0			
NBTRs C.R	22	0	-4	0	0	0	0	0	-4	0			
NBTRs C.R	22	4											
NBTRs C.R	22	4											
NBTRs C.R	22	4											

Figure 5.16 Excel Detailed Report about Open Main Incident Around (TR2)

Also the plot in Figure 5.17 was reported, it shows the load change for the transformer (TR2) which shows maximum load change due to these possible locations for the open main incident. Since the size of this transformer is 1000kVA, so the change rate in figure 5.17 is equal to 11, while the change in the Excel report is always referred to the smallest network transformer (500kVA), which means multiply 11 by factor 2 to make the comparison between different size transformer easier.

Each row in the excel report starts by (NBTRs C.R) indicates one of the mains listed in the fourth row, and the real time change rate for this main nearby transformer are listed beside, those nearby transformers names for every network main are included in OMNTL

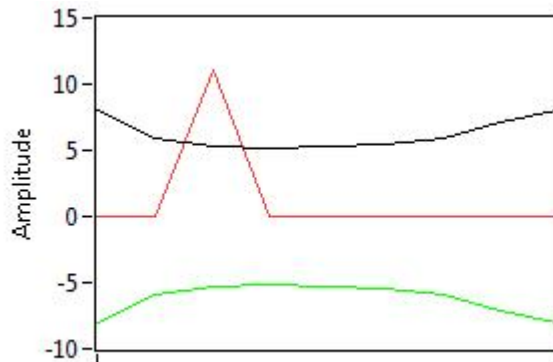


Figure 5.17 Transformer (TR2) Load Change

Double Check for the automatically reported information about this incident was accomplished to test the creditability of the reported results.

Figure 5.18 illustrate the load at transformer (TR2), where the increase in the load is obvious.

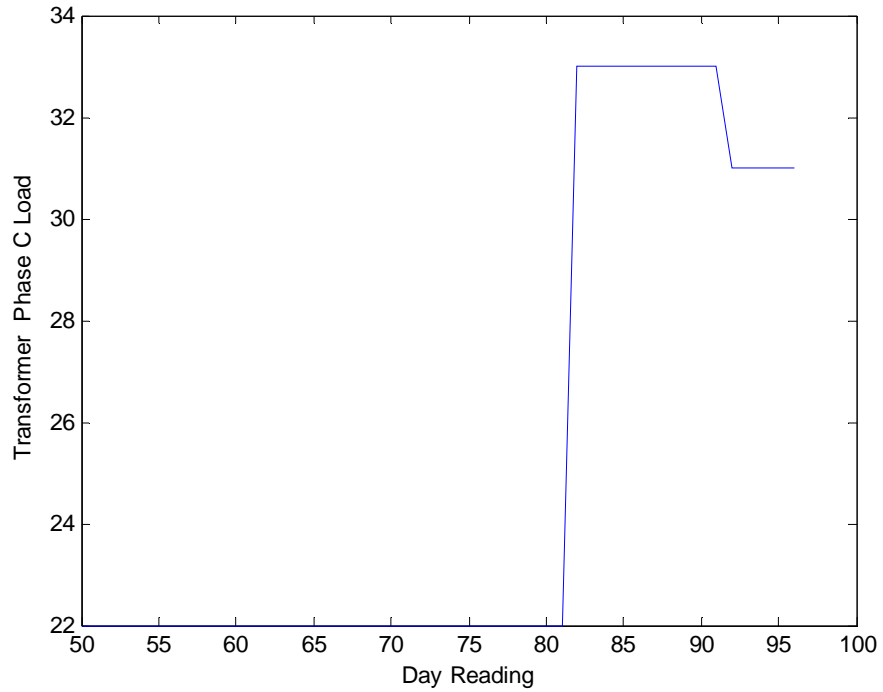


Figure 5.18 Transformer (TR2) Real Time Load at Phase A

Main and service plate for the open main area is shown Figure 5.19, the view includes some of nearby the transformers and others are far enough to be included, like (TRnb3) which locates below the mid bottom of the viewed section.



The case is different for open main location (M476); load changes for its nine nearby transformers are listed in Table 5.3.

Table 5.3 Open Main M476 Nearby Transformers Load Changes

TR2	TRnb.A	TRnb.B	TRnb.C	TRnb.D	TRnb.E	TRnb.F	TRnb.G	TRnb.H
22	0	-4	0	-4	-6	0	4	0

The sum of changes is equal to 12, which is greater than the tolerant level, for this reason it was excluded from the possible main locations list.

## CHAPTER 6

### DISCUSSION AND CONCLUSION

#### 6.1 Concluding Remarks

Investigating carefully the factual design and operation circumstances for the system encountering technical challenges is the main requirement for pursuing an efficient solution. System available data and operation parameters should be taken into consideration while going through the implemented approaches.

Due to the unavailability of an open main detection mechanism in the monitoring system, every network includes an unknown number of isolated mains. That increases the ambiguity of present configuration for the network. The study overcame this challenge by increasing the number of nearby transformers at which the load changes will be considered.

Algorithms, techniques and tools are developed in this dissertation to build on what already are subsistent in the Con Edison distribution system. To make this study more efficient, it avoids proposing installation of new equipment in such huge system, which requires more investment, labor force and time.

#### 6.2 Dissertation Contribution

This study presents a novel mechanism to be implemented in monitoring system for distribution networks utilizing the underground system. The major contributions of this work are:

- Implementation of three statistical approaches to detect the abnormal change in transformer loads.
- Implementation of a sliding standard deviation concept to determine the boundary of the normal load change that reflects each transformer load profile for one day.



- Implementation of an effective algorithm to detect the outage in any network transformers. The algorithm is able to recognize the outage event from the erroneous incoming data or from those created due to some network routine operations.
- Ability of the study to indicate the existence an open main around the transformer at which the outage is recently detected.
- Implementation of open main detection algorithm able to detect the occurrence of an open main incident and to identify the most possible incident location that facilitates the mission of repairing team.
- The study eventually improves the distribution system reliability through its contribution to early detection and locating the open main incidents. This action drops the possibility of network open mains accumulation which is a major cause for network outage incidents.
- Development of Open Main Detection System (OMDS) that implements the statistical approaches and the previously mentioned detection algorithms to introduce an effective detection, monitoring and reporting tool.

### 6.3 Future Work

In the future, some topics should be taken up to reach better over all performance for the study, one of them concern on the input data quality, another topics is about improving the boundary formation criterion for the different approaches. Also once this study is applied in the real time monitoring system, any possible feed back may rise will deserve specifying part of future work to deal with it.

#### *6.3.1 RMS Data Checking*

The readings received from RMS system supposed to reflect the actual load behavior of network transformer, not only the reading value but also the time at which this reading is registered and delivered. The possible time of registering transformer load value is not equally

spaced during the day, and the time of reading delivered from RMS to OMDS is not necessarily the exact time at which the load was registered.

Since this study algorithm mainly depends on the response of the nearby transformers for any change in the event transformer, so it is important to develop a mechanism to reduce the possibility of comparing the load of different transformers according to readings apparently have the same time, but actually some of them may not show the actual response to the event if they registered in different actual time.

### *6.3.2 Normal Load Boundary Curve Formation Criterion*

As clarified from the study algorithm, the main part in incident detection process is sensing the abnormality in the incoming RMS data, abnormality determination precession depends on the input data quality where first future work topic is particularized for, and the boundary limits that if any real time change exceeds one of them, it will be detected as initial event.

To improve the sensitivity of the statistical approaches in sensing abnormal load change of the transformer, a development for the criterion by which the boundary curve is formed can be effective work. Reconsidering the selected readings involved in boundary value calculation can be tested and the effect on the overall detection process performance will be observed.

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## BIOGRAPHICAL INFORMATION

**Abdalgany A. Athamneh** was born in 1974 in Irbid/ Jordan. He received his Bachelor degree in Electrical Power Engineering at Yarmouk University/ Jordan in June 1997, he worked as protection engineer in National Electric Power Co. /Jordan for 18 months. Then he worked as lab and tutorial instructor in Yarmouk University for four years.

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