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Contribution a l'évaluation de la fiabilité d'un réseau électrique

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ABSTRACT

Reliability evaluation of generation, transmission and distribution systems is an important requirement in overall power system planning and operation. Due to the enormity of the problem, reliability analysis is not usually conducted on a complete power system and reliability evaluations of generating facilities, transmission systems, and of distribution system segments are usually conducted independently. The reliability indices obtained for each segment are then used to make decisions. This kind of analysis generally assumes that the other parts of the system are fully reliable and capable of performing their intended functions. A more realistic procedure involves categorizing the generating, transmission and distribution zones into hierarchical levels and performing reliability analysis of these levels. This research illustrates the reliability indices which can be obtained at these hierarchical levels *(HLs)*. The analysis considers element outages in all parts of an electric power system to provide a comprehensive assessment of the overall system. The concepts involved in the reliability evaluation of a complete power network are presented using an educational test system developed at the University of Saskatchewan-Canada known as the Roy Billinton Test System *R.B.T.S*.

An electric power system is a three segments system, of generation, transmission and distribution. These segments are referred to functional zones. The functional zones can be combined to form hierarchical levels *(HL)*.

This thesis illustrates how system planers and operators can incorporate the reliability assessment in a range of power system application. All the approaches used in the research are described in details, permitting the comprehension of the techniques to assess power systems for reliability studies. The evaluation allows engineers to take judgments for different system configuration and at the end decide on the optimal system for a fine operation.

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I would like to express my sincere thanks and gratitude to my supervisor ***DR. ABOUBOU ABDENACER*** for his guidance, support and encouragement during the research through its different stages. I am indebted to him for his help, suggestions and valuable comments and hope he will still help me in any of my further researches.

THIS WORK IS DEVOTED TO:

MY DEAREST GREAT FATHER:

ROUINA MOHAMED GHANTER.

*May **ALLAH** The Most Gracious Accept Him.*

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LIST OF ABBREVIATIONS

HLI=	Hierarchical level one
HLII=	Hierarchical level two
HLIII=	Hierarchical level three
LOLE=	Loss of load expectation
LOEE=	loss of energy expectation
RBTS=	Roy Billinton Test System
A=	Availability
U=	Unavailability
ELC=	Expected load curtailment
EENS=	Expected energy not supplied
EDLC=	Expected duration of load curtailment
OOP=	Object-oriented programming
OOA=	Object Oriented Analysis
OMT=	Object Modeling Technique
TOO=	Theory Oriented Object
DG=	Distributed Generator.
DR=	Distributed Resource.
EPS=	Electric Power System.
RA=	Reliability Analysis.
Relative_CAIDI=	Relative Customer Average Interruption Duration Index.
CEA=	Canadian Electric Association.
SAIDI=	System Average Interruption Duration Index.
CAIDI=	Customer Average Interruption Duration Index.
EPRI=	Electric Power Research Institute.
S=	Segment of interest.
L=	Set of all segments whose failure cause loss of power to S.
SSL=	Set of segments that may be isolated between S and the original source.
NSSL=	Set of segments that cannot be isolated between S and the original source.
SL=	Set of segments that can be switched away from S, and S may be fed by an alternate source.

NSL=	Set consists of the segments that cannot be switched away from S. That is the segment of interest it self.
SAF=	Set, if the failed component lies in these segments, it is possible to restore power to S by an alternate source.
NSAF=	Set, if the failed segment belongs to this set, S cannot be temporarily restored from an alternate feed.
SF=	Set of all segments that can be isolated from S and an alternative source, allowing power to be restored to S from the alternative source (without system constraint violations during the restoration).
NSF=	Set of all segments may be isolated from S and an alternative source, and it is not possible to restore power to S because of violating system constraints.
SIC=	Set of all the segments in the circuit.
SW=	Set of all the sectionalizing devices in the circuit.
AF=	Set of available alternate sources (feeds).
IS=	Set of sectionalizing devices that will isolate *S* from the original sources.
IS=	Set of sectionalizing devices that will isolate the segment of interest *S* from the original sources.
NIS=	Set of switches that do not isolate the original source from the segment of interest.
EC=	Set of ending components for the circuit.
PD=	Set of protective devices in the circuit that isolates a load point of interest from its source.
FTm=	Forward component Trace beginning with component *m*.
BTm=	Backward component trace beginning with *m*.
FPTm=	Feeder Path component Trace of the component *m*.
ECT=	Ending Component Trace.
FSTm=	Forward Segment Trace from segment *m*.
FPSTm=	Feeder Path Segment Trace for the element *m*.
AFT=	Alternative Feed Trace.
pFSeg=	Pointer to Forward Segment.
pBSeg=	Pointer to Backward Segment.

$PSeg$=	Pointer to Segment device for component.
C_{AFK}=	Minimum remaining component power capacity in the FPT_{AF} for the k^{th} alternative feed, $k=1,2,3\ldots n$.
C_{AFm}=	Represents the greatest minimum remaining capacity available among the alternative sources.
Fr_j=	The failure rate for component j.
FR_i=	Failure rate for segment i.
Rep_j=	Average repair time for component j.
REP_i=	Average repair time for segment i.
DT_i=	Down time for segment i.
SOT_i=	Switch operation time to re-supply segment S due to the failure of segment i
DTC=	Total customer down time.
RT_s=	Average restoration time for segment S.
Seg_LP_FR=	Segment load point failure rate.
Seg_LP_REP=	Segment load point repair time.

INTRODUCTION

1. Background

The basic function of an electric power system is to meet customer electricity requirements, with adequate quality and reliability, and in an economical manner. Electric utilities have for the most part, attained this objective. This has been accomplished by employing reliability criteria in generating, transmission, and distribution planning based on the application of probabilistic techniques and rules-of-thumb that have evolved over many years of operating experience. There is, however, an emerging recognition in the industry that the traditional practice of providing all users with a uniform and a very high level of service reliability merits a re-examination. There is a growing feeling that investments related to the provision of electric service reliability should be more explicitly evaluated as to their cost benefit implications. Such an overall power system reliability evaluation answering the fundamental reliability question in power system planning: How much reliability is adequate. Specifically, utilities are recognizing the need for information on customer interruption and costs. This activity is often referred to as a value of service reliability assessment. [*1*]

A wide range of probabilistic techniques have been developed in this field [*2-7*]. The basic trust is the recognition of the stochastic behavior of power systems and that all input and output event parameters are probabilistic variables. These techniques attempt to recognize the severity of an outage event, its impact on system behavior and operation, together with the likelihood (probability) of its occurrence. While estimates of unreliability can be derived, such as expected un-served energy due to supply short falls, there is a strong requirement for developing techniques which put also these estimates in economic terms.

2. Power System Reliability

The basic aim of every electric power utility is to meet its energy and load demand requirement at the lowest possible cost to the customers while maintaining acceptable levels of quality and continuity of supply. The ability of an electric power network to provide an adequate supply of electrical energy is usually designated by the term of *(power system reliability)* [2, 8-10,12]. The generic term ‘reliability’, however, has a very wide range of meaning and cannot be associated with a single specific definition. Reliability, in general terms, can be defined as the probability of a device performing its intended function adequately over the period of time intended under the operating conditions encountered [1]. It is therefore necessary to recognize the extreme generality of this term and to use it to indicate in a general rather than a specific sense the overall ability of a system to perform its intended function. The concept of power-system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. Power system reliability assessment, both deterministic and probabilistic, can be divided into the two basic aspects of system adequacy and system security [1,], which is shown in Figure *1*.

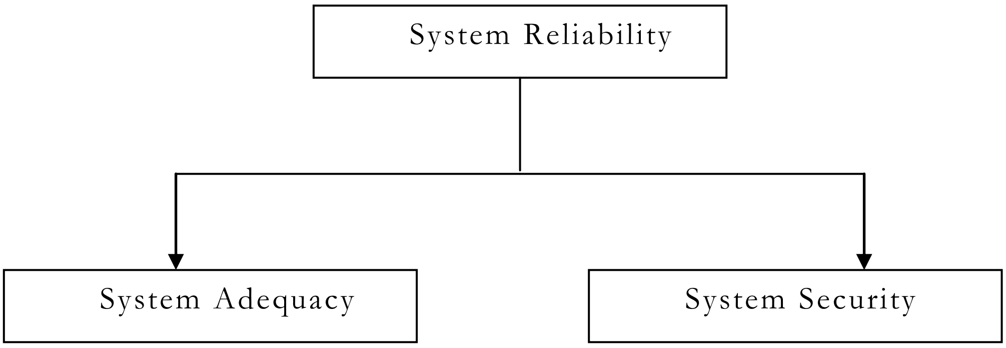

Figure 1 Sub-division of System Reliability

System adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. The system adequacy includes the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Adequacy therefore relates to static system conditions. System security, on the other hand, is associated with the ability of the system to respond to disturbances arising within that system and therefore linked with system dynamics [12,*18*]. Most of the indices used at the present time are adequacy indices and not overall reliability indices. Most of the probabilistic techniques presently available for power-system reliability evaluation are in the domain of adequacy assessment. The techniques presented in this work deals strictly with adequacy assessment of electric power systems.

3. Functional zones and hierarchical levels

An electric power system can be broadly divided into the three segments of generation, transmission and distribution. These segments are commonly referred to as functional zones [9]. While this division of the power system may seem somewhat simplistic, it is very appropriate as most electric power utilities are either divided into such zones for the purposes of organization, planning and/or analysis or are solely responsible for one of these functions. Adequacy studies can be, and frequently are, conducted individually in each of these three zones [3]. The functional zones of an electric power system can be combined to form hierarchical levels. This categorization is depicted in figure *2.* Adequacy assessment techniques can also be grouped under these hierarchical levels (*HL*). Adequacy evaluation at *HLI* is concerned with only the adequacy of the generation to meet the system load requirement and this area of activity is usually termed as generating capacity reliability evaluation. Both generation and the associated transmission facilities are considered at *HLII* adequacy assessment and are sometimes referred to as composite system or bulk system adequacy evaluation. *HLIII* adequacy assessment involves the consideration of all the three functional zones in an attempt to evaluate customer load point adequacies.

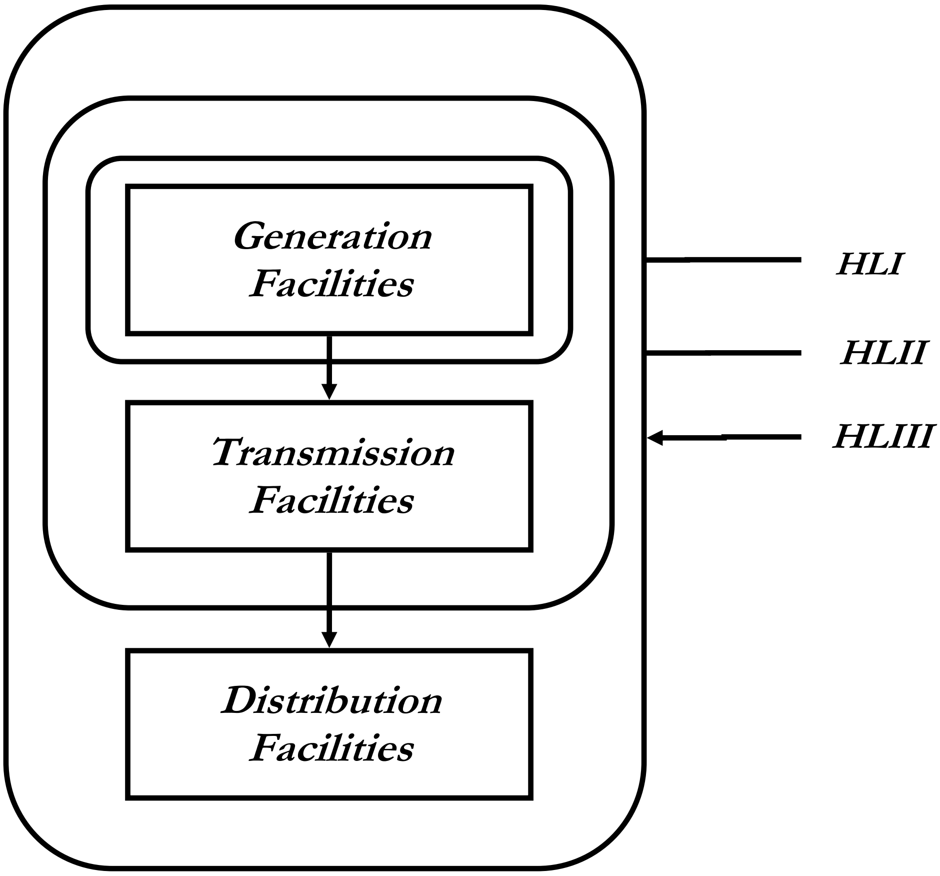

Figure 2 Hierarchical Levels in Electric Power systems

Evaluation at *HLIII* is therefore termed as overall power system adequacy assessment. *HLI* indices are utilized by most utilities. The most popular technique used in *HLI* assessment is the loss of load expectation approach (*LOLE*) [*2,40*]. Some utilities utilize normalized values of loss of energy expectation (*LOEE*) as their *HLI* adequacy criteria. At the *HLII* level, various predictive and performance indices have been recommended and are utilized. Small utilities also produce an annual summary of utility service continuity performance at *HLIII*.

4. Objectives of the research

Reliability evaluation of a complete electric power system including generation, transmission and distribution facilities is an important requirement in overall power system planning and operation. Due to the enormity of the problem, reliability analysis is not usually conducted on a complete power system and reliability evaluations of generating facilities, transmission systems, and of distribution system segments are usually conducted independently. The reliability indices obtained for each segment are then used to make decisions. This kind of analysis generally assumes that the other parts of the system fully reliable and capable of performing their intended functions. This form of analysis may therefore provide a highly optimistic appraisal of the system behavior. *HLIII* evaluation, which includes random failures in all the functional zones is quite complex in most systems as it involves starting at the generation points and terminating at the individual customer load points. The prime objective of the research on one hand is to put a foot in the world of power system reliability assessment by performing a reliability assessment at *HLIII*, i.e., to consider the independent failures in the three functional zones of generation, transmission and distribution, in order to obtain practical estimates of the reliability indices for each system customer load point. On the other hand, the objective was to build a base in the world of technical software, and specially reliability evaluation software. The effect on the customer reliability indices of some basic factors associated with each functional zone within the system was investigated. A reliability test system is used to illustrate the concepts. This is the Roy Billinton Test System (*RBTS*) [*32-34*].

5. Outline of thesis

There is an increasing interest in power system reliability evaluation for planning, design, operation and expansion. Reliability analysis is concerned with the evaluation of reliability with different system configurations/operating practices and the corresponding customers end indices. The actual or perceived customer end indices can used to determine the worth of electric service reliability. This thesis presents an approach to perform reliability analysis in an overall power system considering the influence of outages in all parts of the electric power system. Application of reliability analysis in generating, transmission and distribution planning is illustrated using a test system.

This research has been divided into four chapters. The basic concepts of reliability assessment in composite generation and transmission systems are given in chapter 1. This chapter briefly describes the frequency and duration method used to analyze the system for reliability study for the *HLII* hierarchical level, and various reliability indices utilized in composite generation and transmission systems were depicted.

The distribution system is that part of an electric system which provides a link between the bulk load centers and the actual customer locations in the system. It can be categorized into a sub transmission system and the radial or meshed distribution system. Most distribution systems operate as radial systems even if they are capable of being connected in a mesh though normally open points. In chapter 1 also *the* most common components of the approach used in d*istribution system reliability evaluation* are discussed and theories behind them are briefly introduced, such as *"performance indices, reliability analysis components, reliability analysis sets"*. Moreover this chapter shows how reconfigurations of the system and by appropriate switching operations improve the reliability of the power system.

One of the objectives of this research is to evaluate power system reliability analysis improvements with *DGs* (distributed generations) while satisfying equipment power handling constraints. In this research, a computer algorithm involving pointers and linked list [*3*] is developed to analyze the distribution power system reliability. This algorithm needs to converge rapidly as it is to be used for systems containing thousands of components. So an efficient computer software design and implementation is investigated.

Chapter 1 presents the models used in the thesis. It provides an overview of applying circuit traces in determining the reliability analysis *(RA)* sets by using pointers and linked lists. This chapter presents the computer algorithm used to develop the reliability analysis *(RA)* sets. This analysis relies on two general classes of information to estimate the distribution system reliability; component reliability parameters and system structure. After finding the reliability analysis sets for the segment of interest *S "load point of interest"*, distribution system reliability indices are found. A measure of reliability referred to as

'Relative_CAIDI' is introduced. The *'Relative_CAIDI'* helps to identify the areas in the system those need reliability improvement.

In chapter 2 the test system used to illustrate the concepts of reliability evaluation is described in details form the production to the distribution parts. All the approach described in chapter 1 are applied on the well-known Roy Billinton Test System *(R.B.T.S)*, to give a real overview and more ideas on the robustness of the approach presented in this thesis. The chapter encloses one hand the results of the *HLII* analysis, on the other hand the distribution system assessment simulation results without considering the effect of the *HLII* on the distribution parts i.e., considering that the *HLII* level is *100 %* reliable. The chapter ends with comparison of reliability improvements for all the segments and load points for the Roy Billinton Test System.

Chapter 3 is devoted to the development of a data generator for calculating (mainly) the reliability, load flow, the static and dynamic stability of electrical grid network; and other constraints that may affect it, namely, short-circuit and lightning. Draw up of this generator is based on the theory of programming called "oriented objects" which is a software program using a definite bottom-up design like "messages" exchanged by called basic entities objects; this theory, which makes the behavior of an object, describes how this one changes state with the reception of messages of other objects and how it transmits itself the messages to the other objects. The work presented in chapter 3 is an attempt to put and to have a foot in the world of software industry; it is a path toward a realization (construction) of practical application in the electrical field.

In order to perform an overall power system reliability analysis (*HLIII* reliability evaluation), it was necessary to develop techniques for this purpose. It was necessary to have a complete test system with generation, transmission, and radial distribution system facilities, in order to illustrate the developed techniques. Chapter 4 presents the concepts of overall power system reliability evaluation. This chapter also presents the relative contributions of the overall *HLIII* indices from the *HLII* and the distribution functional zone. Techniques theories for this intention are presented; also the chapter introduces the *HLIII* indices calculation. At the end the results are revealed in a series of tables screening different indices for load points of the Roy Billinton Test System, and also indices for the whole system are depicted.

The thesis ends with a conclusion and some future research issues are identified.

Chapter 1

Reliability Evaluation In: Composite Generation and Transmission Systems, and in Distribution Systems

1.1. Introduction

Power system reliability assessment can be performed for two distinct periods: the past and the future [*2,3*]. Assessment of future system performance is valuable and can be used to predict how that system is expected to behave in the future, the benefits of alternate system designs, reinforcements, expansion plants and the related cost/worth/benefit of the alternatives. This chapter presents predictive indices at hierarchical level two *HLII*.

Generating capacity adequacy evaluation is primarily concerned with estimating the necessary generating capacity to satisfy the system load requirements. A basic objective in generating system planning is to determine the necessary generating capacity to satisfy the system demand in the presence of scheduled and unscheduled outages and unforeseen variations in the system load. A second equally important objective is the development of a suitable transmission network to carry the generated energy to the bulk load centers. This aspect must be dealt with in conjunction with the available generating facilities such that there is adequate transmission for the planned generation. Lastly, adequate distribution facilities must be designed in order to transport the available energy from the bulk load centers to the actual customer terminals. The basic concepts and indices for the evaluation for composite generation and transmission systems are presented in this chapter. The Roy Billinton test system is used to illustrate the concepts is presented [*32-34*].

1.2. Composite System Adequacy Assessment: [1,40]

Bulk adequacy evaluation techniques are concerned with the composite problem of assessing the generation and transmission facilities in regard to their ability to supply adequate, dependable and suitable electrical energy at the bulk load points [*35*]. A basic objective of bulk power system adequacy assessment is to provide quantitative outputs and evaluation added to the qualitative engineering judgments of the customer load demand at acceptable levels of quality and availability. Such assessment also is crucial and gives inputs to other studies and analysis like economic development for a cost/benefit analysis. There is, however, no consensus in the electric power industry as to which adequacy indices are the most appropriate. This can be constructed to simply reflect the actual complicity of the problem of *HLII* adequacy assessment or to indicate the variety of purposes for which these indices may be used. In order to make objective system design or planning decisions, it is therefore more appropriate to study a variety of adequacy indices which convey meaningful information regarding the performance of the system under investigation. Adequacy evaluation and planning at *HLII* is normally comprised of the following basic steps [*36*].

1. Evaluate the performance of the power network without removing any component. This can be designated as studying the performance of the base case system.
2. Make changes in the system configuration due to the outage(s) of various components.
3. Check the adequacy of the modified power system.
4. Take if necessary, corrective actions such as rescheduling of the generating units, line overloads alleviation, correction of bus voltages and load curtailment at buses.
5. Calculate the adequacy indices for the individual load buses and for the whole system.

Extensive work in the area of *HLII* adequacy evaluation has been done all around the world for the importance of this part of the power system in regards to the distribution system reliability assessment.

1.2.1. Reliability indices

The reliability indices determined in an *HLII* study can be grounded into two categories, namely load point indices and system indices [*37*]. The calculation of both this sets of indices is necessary to obtain a complete picture of the bulk power system adequacy i.e., these indices complement rather than substitute for each other. Individual loads points indices are necessary to identify the weak points in the system and to help establish optimum response to design changes, of the system under steady states condition. The individual load point indices can also be further divided into the relative contributions to bulk system unreliability associated with the generation and transmission functional zones. Overall system indices provide an appreciation of global *HLII* adequacy and can be used by planner and managers for comparing the adequacies of different systems. The severity of an outage event depends on the components under outage, their relative importance and their location in the network. An outage event may affect only a small area (bus) of the system or a large area (several buses). It is important to identify the areas of the system which have poor reliability and/or, are prone to disturbances. Such information cannot be obtained from the system indices, but is readily available from the individual load point values.

A wide range of *HLII* adequacy indices are provided from several references [*37,38*]. Some of the indices utilized in this these are described in this section. *HLII* adequacy indices are usually expressed and calculated on an annual basis. These indices obtained using the actual load variation over a year, are known as annual indices. However, indices can be calculated for any period such as a season, a month and also for a particular operating condition. Indices can also be calculated for a particular load level and expressed on an annual basis.

1.2.1.1. Load point indices

There are tree fundamental parameters in the evaluation of load point adequacy. These are the frequency, duration and severity associated failure events. The probability can be derived by multiplying the frequency and duration values. Computationally, however, it is often easier to compute the event probabilities and frequencies and use them to derive the durations. These basic indices can be defined for generation systems, composite systems distribution systems and at the *HLIII* system level. Additional indices can also be created from these basic values [*1,37,38, 40*].

a. Basic values

$$\boldsymbol{Probability\ of\ failure} = \sum_{j} \boldsymbol{P_j\, P_{kj}} \qquad (\mathbf{1.1})$$

$$\boldsymbol{Frequency\ of\ failure} = \sum_{j} \boldsymbol{F_j\, P_{kj}} \qquad (\mathbf{1.2})$$

Where: *j* is an outage condition in the network,

Pj : is the state probability of the outage event j,

Fj : is the frequency of occurrence of the outage event j,

Pkj: is the probability of load at bus k exceeding the maximum load that can be supplied at that bus during the outage event j.

$$\boldsymbol{Expected\ Number\ of\ load\ curtailments} = \sum_{j\in x,y} \boldsymbol{F_j} \qquad (\mathbf{1.3})$$

$$\boldsymbol{Expected\ load\ curtailed\ (ELCi)} = \sum_{j\in x,y} \boldsymbol{L_k\, F_j} \quad \boldsymbol{MW} \qquad (\mathbf{1.4})$$

$$\textit{Expected energy not supplied } (EENSi) = \sum_j L_{kj} D_{kj} F_j \quad \textbf{MWhr}$$

$$= \sum_{j\in x,y} 8760\, L_{kj} P_j \qquad (1.5)$$

$$\textit{Expected duration of load curtailment } (EDLCi) = \sum_{j\in x,y} D_{kj} F_j \quad (\textbf{hr})$$

$$= \sum_{j\in x,y} 8760\, P_j \quad (hr) \qquad (1.6)$$

Where: *j* є x includes all contingencies resulting in load curtailment at bus *k*,

j є *y* includes all contingencies resulting in isolation of bus *k*,

Lkj: is the load curtailment at bus *k* to alleviate line overloads arising due to outage event *j*, or load not supplied at an isolated bus k due to the outage event,

Dkj: is the duration in hours of the load curtailment arising due to the outage event *j*, or the duration in hours of the load curtailment at an isolated bus k due to the outage event *j*.

1.2.1.2. System indices:

a. Basic values:

$$\textit{Bulk Power Interruption Index } (BPII) = \sum_k \sum_{j\in x,y} F_j \quad (\textbf{hr}) \qquad (1.7)$$

$$\textit{Bulk Power Supply average MW curtailment } (BPACI) = \frac{\sum_k \sum_{j\in x,y} L_{kj} F_j}{L_s} \frac{MW}{MWyr} \quad (1.8)$$

$$\textit{Bulk Power Energy curtailment Index } (BPECI) = \frac{\sum_k \sum_{j\in x,y} 60\, L_{kj} D_{kj} F_j}{L_s} (\textit{System minutes}) \qquad (1.9)$$

$$\textit{Modified Bulk Power Energy Curtailment Index } (MBPECI) = \frac{\sum_k \sum_{j\in x,y} L_{kj} D_{kj} F_j}{8760 L_s} \qquad (1.10)$$

It should be also be appreciated that although the *HLII* indices add realism to the analysis by including bulk transmission, they steel are adequacy indicators and do not include the ability of the system to respond to transient disturbances.

1.2.2. Outage model

A component is on outage when it is unavailable to perform its intended function. A component outage, however, may or may not cause load interruption. Outage events may occur such that they are independent of other outages or where they are consequences of other failures within the system. These are classified as independent and dependent outages respectively. Simultaneous outages of two or more components are referred to as overlapping outages. The basic component model used in these applications is the two-state system represented in figure *1.1* in which the component is assumed to be either up or down. The rate of departure from the component up state to its down state is the component failure rate λ. The restoration of the component to its operating state is denoted by another transition rate termed the component repair rate μ. The actual restoration process could be high or low speed automatic re-closure, repair or simple replacement of the failed component by a spare. Different restoration rates are associated with each of these activities. The component availability/unavailability [*40*] is governed by both λ and μ.

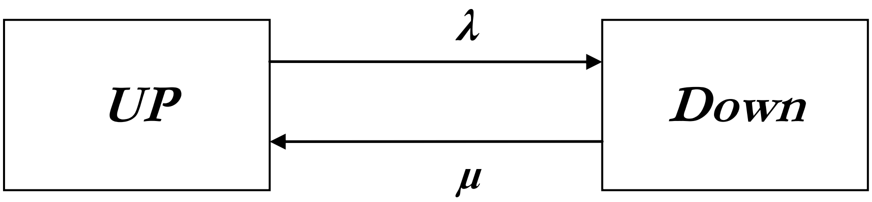

Figure 1.1 Two states model for single component on outage

Overlapping independent outages of two components can be modeled as shown in figure *1.2* the probabilities, frequencies and durations of the four states in which components can be obtained by a set of reliability simple equation [*1*]. This model can be extended to three or more components [*40*]. There are several failure modes which can be create dependence between the behavior if individual components [*3*]. It is therefore important to select the most appropriate model in order to ensure that the evaluation responds end reflects the true system behavior.

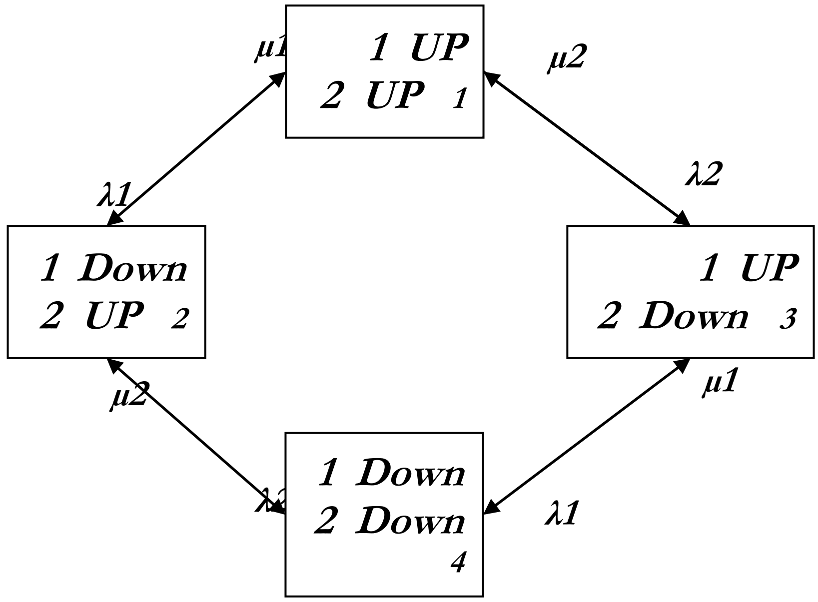

Figure 1.2 ***Model for overlapping independent outages of two components***

1.2.3. Three unit states space diagram

1.2.3.1 Fundamental development

The concepts can perhaps be most easily seen by using a simple numerical example. The system described in Table *1.1* contains the basic data required for the analysis. This section illustrates the development of a system model using the fundamental relationship as it will be shown. This is not a practical approach for large system analysis using a digital computer. If each unit can exist in two states, then there are 2^n states in the total system where n = number of elements i.e. $2^3 = 8$ in this case. The total number of states in the system of table *1.1* are enumerated in table *1.2*. These states can also be represented as a state transition diagram as shown in Figure *1.3*. This diagram enumerates all the possible system states and also shows the transition modes from one state to another. As an example, given that the system is in State *2* in which element *1* is down and the others are up, the system can transit to States *1, 5* or *6* in the following ways:

From State *2* to *1* if element *1* is repaired.

From State *2* to *5* if element *2* fails.

From State *2* to 6 if element *3* fails.

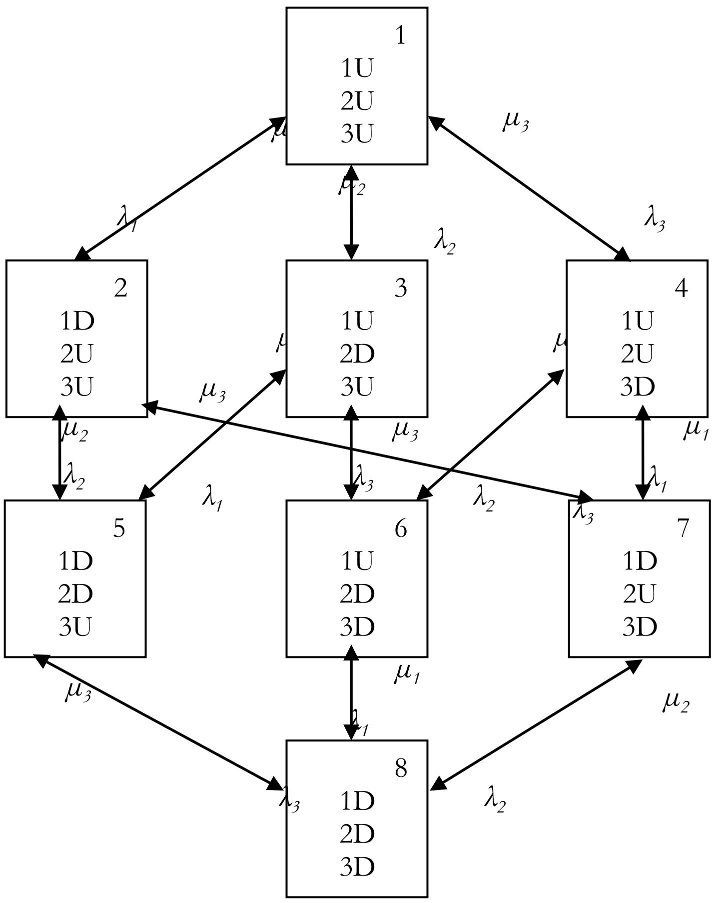

Figure: 1.3: Three-units state space diagram

Table 1.1 System data

Element no.	***Element Capacity (MW)***	***Failure rate λ (f/day)***	***Repair rate μ (r/day)***	***Availability A***	***Unavailability U***
1	*25*	*0.01*	*0.49*	*0.98*	*0.02*
2	*25*	*0.01*	*0.49*	*0.98*	*0.02*
3	*50*	*0.01*	*0.49*	*0.98*	*0.02*

For example, if the elements are generator units, so the last line is the information of the capacity out of service in the system. If the elements are transmission lines in parallel so the information will be the maximum megawatts which can be delivered to the load points.

The total rate of departure from State 2 is therefore the sum of the individual rates of departure $(\mu_1+\lambda_2+\lambda_3)$. The probabilities associated with each state in Table 1.2 can be easily calculated assuming event independence. The frequencies of encountering each state are obtained when the rate of departure or entry is the sum of the appropriate rates. The basic manipulations are shown in Table 1.3.

Table 1.2 Failure modes and effects

State number	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
Element No. 1	U	D	U	U	D	D	U	D
Element No. 2	U	U	D	U	D	U	D	D
Element No. 3	U	U	U	D	U	D	D	D
Capacity out:	*0*	*25*	*25*	*50*	*50*	*75*	*75*	*100*

Table 1.3 Generation model

State No.	***Capacity out***	***State Probability P***	***Departure rate***	***State frequency f (Occurrence/day***
1	*0*	*(0.98x0.98x0.98) = 0.941192*	*0.03*	*(0.941192)x(0.03) = 0.02823576*
2	*25*	*(0.02x0.98x0.98) = 0.019208*	*0.51*	*(0.019208)x(0.51) = 0.00979608*
3	*25*	*(0.98)(0.02x0.98) = 0.019208*	*0.51*	*(0.019208)x(0.51) = 0.00979608*
4	*50*	*(0.98)(0.98x0.02) = 0.019208*	*0.51*	*(0.019208)x(0.51) = 0.00979608*
5	*50*	*(0.02x0.02x0.98) = 0.000392*	*0.99*	*(0.000392)x(0.99) = 0.00038808*
6	*75*	*(0.02)(0.98x0.02) = 0.000392*	*(0.99*	*(0.000392)x(0.99) = 0.00038808*
7	*75*	*(0.98X0.02X0.02) = 0.000392*	*(0.99*	*(0.000392x0.99) = 0.00038808*
8	*100*	*(0.02)(0.02X0.02) = 0.000008*	*1.47*	*(0.000008)x(1.47) = 0.00001176*
		Total *= 1.000000*		

1.3. Numerical example for different configurations

1.3.1 Network configurations [40]

The total problem of assessing the adequacy of the generation and bulk power transmission systems in regard to providing a dependable and suitable supply at the terminal stations can be designated as composite system reliability evaluation. The analysis of the system for a reliability study depends on the system configuration, either simple radial generation transmission system and meshed configurations.

1.3.1.1. Radial configurations

One of the first major applications of composite system evaluation was the consideration of transmission elements in interconnected system generating capacity evaluation. The analysis at the load point L of the system shown in Figure *1.4* can be done using the loss of load expectation *(LOLE)*, loss of energy expectation *(LOEE)* or frequency and duration *(F&D)* techniques [40], the *(F&D)* was introduced in section *1.2.3* and is used in this thesis. The linking configuration between the generation source and the load point may not be of the simple series-parallel type shown in Figure *1.4* but could be a relatively complicated d.c transmission configuration where the transmission capability is dependent upon the availability of the rectifier and inverter bridges, the filters at each end and the associated pole equipment. The development of the transmission model may be relatively complex but once obtained can be combined with the generation model to produce a composite model at the load point.

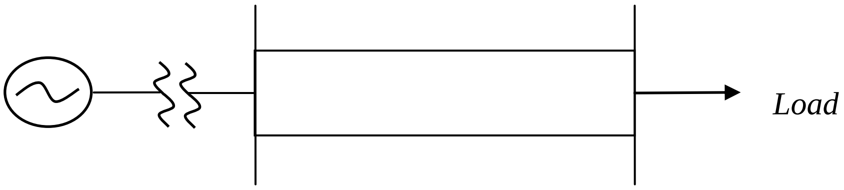

Figure 1.4 Simple radial generation transmission system

The progressive development of an equivalent model is relatively straightforward for a radial configuration such as that shown in Figure *1.4*. This approach, however, is not suitable for networked configurations including dispersed generation and load points. A more general approach is required which can include the ability of the system to maintain adequate voltage levels, line loadings and steady state stability limits.

A more general set of equations can be obtained directly from the probability condition theory. Respectively the probability and the frequency of failure are:

$$\boldsymbol{Q_k(Probability\ of\ failure) = \sum_j [P\ (B_j\ )P_{lj}]} \qquad \mathbf{(1.11)}$$

$$\boldsymbol{F_k(Frequency\ of\ failure) = \sum_j [F(B_j\ )P_{lj}]} \qquad \mathbf{(1.12)}$$

Where:

Bj = an outage condition in the transmission network.

Plj = Probability of load at bus *K* exceeding the maximum load that can be supplied at that bus without.

In this case, the generation outages are treated individually, as are the transmission outage events, and the generation schedule and resulting load flow are modified accordingly. It should be noted, however, that Equation (1.12) does not include a frequency component due to load model transitions. This could be included but it would require the assumption that all system loads transit from high to low load levels at the same time. Equation (1.12) also includes possible frequency components due to transitions between states each of which represent a failure condition.

Equations (1.11) and (1.12) are applied to the system shown in Figure *1.4* using the following data.

Generating units:	6 x40 MW units	λ= 0.01 f/day = 3.65 f/yr.
		μ = 0,49 r/day = 178.85 r/yr
		U=0.02
Transmission elements:	2 lines	λ = 0.5 f/yr
		r= 7.5 hours/repair
		U = 0.0004279
Load:		Peak load = 180MW

Where the basic element parameter used in the evaluation is the probability of finding that element on forced outage at some distant time in the future. This probability was defined in Engineering Systems as the unit unavailability, and historically in power system applications it is known as the unit forced outage rate (*FOR*). It is the ratio of two time values [*47*].

$$\boldsymbol{Unavailability\ (FOR) = U = \frac{\lambda}{\lambda + \mu} = \frac{r}{m + r} = \frac{r}{T} = \frac{f}{\mu}}$$

$$= \frac{\sum[\boldsymbol{down\ time}]}{\sum[\boldsymbol{down\ time}] + \sum[\boldsymbol{up\ time}]} \qquad (\mathbf{1.13})$$

$$\boldsymbol{Availability} = \boldsymbol{A} = \frac{\boldsymbol{\mu}}{\boldsymbol{\mu} + \boldsymbol{\lambda}} = \frac{\boldsymbol{m}}{\boldsymbol{m} + \boldsymbol{r}} = \frac{\boldsymbol{m}}{\boldsymbol{T}} = \frac{\boldsymbol{f}}{\boldsymbol{\lambda}}$$

$$= \frac{\sum[\boldsymbol{up\ time}]}{\sum[\boldsymbol{down\ time}] + \sum[\boldsymbol{up\ time}]} \qquad (\mathbf{1.14})$$

Where

λ = expected failure rate

μ = expected repair rate

m = mean time to failure = MTTF = 1/ λ

r = mean time to repair = MTTR = 1/ μ

m + r = mean time between failures = MTBF = *1/f*

f= cycle frequency = 1/*T*

T= cycle time = l/*f*

The load is represented by a straight-line load — duration curve from the 100% to the 70% load points. For the system shown on figure *1.4* the generating capacity model (capacity outage probability table) is shown in Table *1.4*, and the transmission capability model in Table *1.5*. The capability of each line is designated as X in Table *1.5*. The actual carrying capability will depend on the criterion of success at the load point. If a line rating can be nominally assigned the problem becomes one of transport rather than service quality and it becomes somewhat simpler.

Table 1.4 Generation system model

State	*Nº of generators on outage*	*Capacity available (MW)*	*Probability*	*Departure rate (occ/yr)*	*Frequency (occ/yr)*
1	*0*	*240*	*0.88584238*	*21.9*	*19.399948*
2	*1*	*200*	*0.10847049*	*197.1*	*21.379534*
3	*2*	*160*	*0.00553421*	*372.3*	*2.060386*
4	*3*	*120*	*0,00015059*	*547.5*	*0.082448*
5	*4*	*80*	*0.0000023*	*722.7*	*0.001666*
6	*5*	*40*	*0.00000002*	*897.9*	*0.000017*
7	*6*	*0*	*0.00000000*	*1073.1*	*0.000000*

Table 1.5 Transmission system model

State	*N° of lines on outage*	*Capacity available (MW)*	*Probability*	*Departure rate (occ/yr)*	*Frequency (occ/yr)*
1	0	2X	0.999144	1	0.999144
2	1	1X	0.000855	1168.5	0.999574
3	2	0X	1.8E-07	2336	0.000428

X = rating of each line in MW

Table 1.6 shows the composite state probabilities and frequencies assuming that the individual line-carrying capability X is *160 MW*. Equation *(1.12)* includes possible transitions between failure states and will therefore give an expected failure frequency at the load point which is slightly higher than that determined by creating the complete *21*-state Markov model and evaluating the frequency of transitions across a specified capacity boundary wall.

In this case transitions between failure states would not be included. The probability and frequency component for each state is weighted by the probability that the load will exceed the capability of that state to give the failure probability and frequency.

1.3.1.2. Meshed configuration [40]

The technique illustrated with the radial configuration can be applied to networked or meshed configuration this application is illustrated using the system shown in Figure *1.5*. Assume that the daily peak load curve for the period under study is a straight line from the *100%* to the *60%* point and that the load-duration curve is a straight line from the *100%* to the *40%* point. The peak load for the period is *110 MW*.

There is a range of possible solution techniques which can be used in this case. It should be fully appreciated that each approach involves different modeling techniques and therefore gives different load point reliability indices. The simplest approach is to assume that there are no transmission curtailment constraints and that continuity is the sole criterion. The next level is to use a transportation approach in which the line capability is pre-specified at some maximum value.

Table 1.6 State probabilities and frequencies

State	*State Condition*	*Cap avail (MW)*	*Probability*	*Frequency (occ/yr)*	*Plj*	*Failure Probability*	*Freq (occ/yr)*
1	0G 0L	240	0.88508444	20.268433	0.00000000	0.00000000	0.0000000
2	0G 1L	160	0.00075778	0.902061	0.37037038	0.00028066	0.3340970
3	0G 2L	0	0.00000016	0.000382	1.0000000	0.00000016	0.0003820
4	1G 0L	200	0.10837768	21.469619	0.00000000	0.00000000	0.0000000
5	1G 1L	1 60.00	0.00009279	0.126713	0.37037038	0.00003437	0.0469310
6	1G 2L	0	0.00000002	0.000050	1.00000000	0.00000002	0.0000500
7	2G 0L	160	0.00552947	2.064152	0.37037038	0.00204795	0.7645010
8	2G 1L	1 60.00	0.00000473	0.007294	0.37037038	0.00000175	0.0027020
9	2G 2L	0	0.0000000	0.000003	1.0000000	0.00000000	0.0000030
10	3G 0L	1 20.00	0.00015046	0.082528	1.0000000	0.00015046	0.0825280
11	3G 1L	1 20.00	0.00000013	0.000221	1.0000000	0.00000013	0.0002210
12	3G 2L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
13	4G 0L	80	0.0000023	0.001667	1.0000000	0.0000023	0.0016670
14	4G 1L	80	0.0000000	0.000004	1.0000000	0.00000000	0.0000040
15	4G 2L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
16	5G 0L	40	0.00000002	0.000017	1.0000000	0.00000002	0.0000170
17	5G 1L	40	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
18	5G 2L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
19	6G 0L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
20	6G 1L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
21	6G 2L	0	0.0000000	0.0000000	1.0000000	0.00000000	0.0000000
						0.00251783	1.233102

Line capacity = 160 MW

G = number of generators on outage

L= number of lines on outage

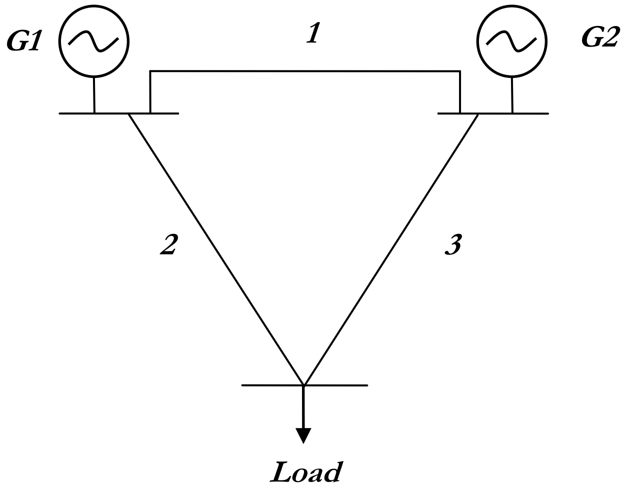

Figure 1.5 Simple network configuration

Table 1.7 Generation data

Plant	Number of units	Capacity. (MW)	Probability	λ(f/yr)	μ(r/yr)
1	4	20	0.01	1	99
2	2	30	0.05	3	57
Total	6	140			

Table 1.8 Transmission data

Line	Connected to		λ (f/yr)	r (hours)	Rating (MVA)
	Bus	Bus			
1	1	2	4	8	80
2	1	3	5	8	100
3	2	3	3	10	90

The transmission line availabilities (*A*) and unavailabilities (*U*) for the system in Figure *1.5* are given in Table 1.9 using the data from Table 1.8.

Table 1.9 Transmission line statistics

Line	Availability	Unavailability
1	0.99636033	0.00363967
2	0.99545455	0.00454545
3	0.99658703	0.00341297

If the assumption is made that there are no transmission line constraints and that connection to sufficient generating capacity is the sole criterion, then:

$Qs = 0.09807433$.

This value was calculated assuming that the load remains constant at the *110 MW* level for the entire year. This index can be designated as an annualized value i.e. expressed on an annual base. It can be compared with the value of *Pg=0.09803430* which is the probability of having *30 MW* or more out of service in the generation model. The *30 MW* outage state is considered to represent system failure as there would be some additional transmission loss in addition to the *110 MW* load. This annualized index is clearly not a true value of the system reliability as it does not account for the load variation. It is a simple and very useful index, however, for relating and comparing weaknesses in alternative system proposals.

Table 1.10 State probabilities and frequencies

State	***Line out***	***P(Bj)***	***Pg***	***Plj***	***Probability (System Failure)***
1	*0*	*0.98844633*	*0.09803430*	*0*	*0.09690164*
2	*1*	*0.00361076*	*0.09803430*	*0*	*0.00035398*
3	*2*	*0.00451345*	*0.09803430*	*0*	*0.00044247*
4	*3*	*0.00339509*	*0.09803430*	*0*	*0.00033185*
5	*1,2*	*0,00001649*	*1.0*	*0*	*0.00001649*
6	*1,3*	*0.00001237*	*1.0*	*0*	*0.00001237*
7	*2,3*	*0.00001546*	*1.0*	*1*	*0.00001546*
8	*1,2,3*	*0.00000006*	*1.0*	*1*	*0.00000006*
				annualized	*Qs = 0.09807433*

Table *1.10* shows the required transmission and generation state probabilities for the no transmission constraint case.

The load model can be included in the calculation, rather than assuming the load will remain at the *110 MW* peak value. Under these conditions the *Pg* and *Plj* values in Table 1.10 reduce because the contribution to *Qs* by lower load levels is less. This can be included using conditional probability.

The calculation of the expected frequency requires, in addition to the data shown in Table *1.10* the departure rates for each state. These values together with the state frequencies are shown in Table *1.11*.

Table 1.11 State frequencies

State	*Line out*	*Departure rate*	*F(Bj)*	*Failure Frequency (Occ/yr)*
1	0	12	11.861355%	1.16281973
2	1	1103	3.98266828	0.39043810
3	2	1102	4.97382190	0.48760515
4	3	885	2.99580465	0.29369161
5	1,2	2193	0.03616257	0.03616257
6	1,3	1976	0.02444312	0.02444312
7	2,3	1975	0.03053350	0.03053350
8	1,2,3	3066	0.00018396	0.00018396
			Annualized	F_s= 2.42587774

If transmission line overloads conditions result in transmission lines being removed from service, then the load point indices increase. This can be illustrated by assuming that overload occurs whenever line 2 or 3 is unavailable. Under these conditions, load must be curtailed, causing increased load point failures. In this case:

$Qs = 0.10520855$

$Fs = 9.61420753$ f/yr

1.4. State selection [40]

Equations (1.11) and (1.12) consider each generating unit and transmission line as a separate element, thereby increasing the flexibility of the approach but simultaneously increasing the number of states which must be considered. In this system there are 9 elements which represent a total of 512 states. It becomes necessary therefore to limit the number of states by selecting the contingencies which will be included. This can be done in several basic ways.

The most direct is to simply specify the contingency level, i.e. first order contingencies, second order contingencies etc. This can be modified by neglecting those contingencies which have a probability of occurrence less than a certain minimum value. An alternative method is to consider those outages which create severe conditions within the system. The intention in all methods is to curtail the list of events that can occur in a practical system. A useful approach is to consider those outage conditions which result from independent events and have a probability exceeding some minimum value and, in addition, to consider those outage conditions resulting from outage dependence such as common mode or station related events again having the same probability constraint. At this stage only independent overlapping outages are considered, the problems of outage dependence are not considered.

1.4.1. Application

The state selection process is illustrated by considering first and second order generating unit and transmission line outages in the system shown in Figure *1.5* and using Equations (1.11) and (1.12). The unavailability associated with a transmission line is normally much lower than that for a generating unit, and therefore a higher order contingency level should be used when generating units are considered. The combined generation and transmission states are shown in Table 1.12.

As in Table 1.10 it has been assumed that a loss of 30 MW will result in a load point failure due to the transmission loss added to the 110 MW load level.

The values in Table 1.12 are again for a constant load level of 110 MW and therefore are annualized values. The load model can be incorporated in the analysis, however, by considering the probability that the load will exceed the capability of each state. The *Plj* values in Table 1.12 will then be modified accordingly and the Qs and Fs indices will be on a periodic or annual base. The difference between Fs in Table 1.11 and Table 1.12 would be much smaller if the generation reserve margin were increased.

The effect of transmission line overloading can be illustrated by assuming, that overload occurs whenever lines 2 or 3 are unavailable. Under these conditions loads must be curtailed, causing increased load point failures.

Overloading can be eliminated by curtailing or dropping some load to alleviate the situation. Use of this technique therefore requires a load flow technique which can accommodate it. Load reduction can also be used in the case of an outage condition in the generation configuration provided, that the bus-bars at which load will be curtailed are pre-specified. This is clearly not a problem in a single load example.

1.4.2. System and load point indices

The system shown in Figure *1.5* is a very simple configuration. In a more practical network there are a number of load points and each point has a distinct set of reliability indices [37,39]. The basic parameters are the probability and frequency of Composite generation and transmission systems Table 1.13 Annualized load point indices failure at the individual load points, but additional indices can be created from these generic values. The individual load point indices can also be aggregated to produce system indices which include, in addition to consideration of generation adequacy, recognition of the need to move the generated energy through the transmission network to the customer load points. Table 1.13 lists a selection of load point indices which can be used.

Table 1.12 System Values

State B_j	***Elements out***	***Probability $P(B_j)$***	***Frequency $F(B_j)$ (occ/yr)***	***Plj***	***Failure***	
					Probability P_j	***Frequency F_j (occ/yr)***
1	—	*0.85692158*	*18.85227476*	*0*		
2	*G1*	*0.03462309*	*4.15477080*	*0*		
3	*G1.G1*	*0.00052449*	*0.11436062*	*1.0*	*0.00052449*	*0.11436062*
4	*G1,G2*	*0.00364454*	*0.63414996*	*1.0*	*0.00364454*	*0.63414996*
5	*G1.LI*	*0.00012648*	*0.15329376*	*0*		
6	*G1,L2*	*0.00015810*	*0.19145910*	*0*		
7	*G1,L3*	*0.00011857*	*0.11774001*	*0*		
8	*G2*	*0.09020227*	*6.85537252*	*1.0*	*0.09020227*	*6.85537252*
9	*G2, G2*	*0.00237374*	*0.30858620*	*1.0*	*0.00237374*	*0.30858620*
10	*G2,L1*	*0.00032951*	*0.38783327*	*1.0*	*0.00032951*	*0.38783327*
11	*G2,L2*	*0.00041188*	*0.48438029*	*1.0*	*0.00041188*	*0.48438029*
12	*G2,I3*	*0.00030891*	*0.29315559*	*1.0*	*0.00030891*	*0.29315559*
13	*L1*	*0.00313030*	*3.48402390*	*0*		
14	*L1,L2*	*0.00001430*	*0.03150290*	*1.0*	*0.00001430*	*0.03150290*
15	*L1, L3*	*0.00001072*	*0.02128992*	*1.0*	*0.00001072*	*0.02128992*
16	*L2*	*0.00391288*	*4.35112256*	*0*		
17	*L2,L3*	*0.00001340*	*0.02659900*	*1.0*	*0.00001340*	*0.02659900*
18	*L3*	*0.00293466*	*2.62652070*	*0*		
					Qs = *0.09783386*	*Fs =9.15723027*

Table 1.13 **Annualized load point indices**

Basic values	
	Probability of failure
	Expected frequency of failure
	Expected number of voltage violations
	Expected number of load curtailments
	Expected load curtailed
	Expected energy not supplied
	Expected duration of load curtailment
Maximum values	
	Maximum load curtailed
	Maximum energy curtailed
	Maximum duration of load curtailment
Average values	
	Average load curtailed
	Average energy not supplied
	Average duration of curtailment
Bus isolation values	
	Expected number of curtailments
	Expected load curtailed
	Expected energy not supplied
	Expected duration of load curtailment

It is important to appreciate that, if these indices are calculated for a single load level and expressed on a base of one year, they should be designated as annualized values. Annualized indices calculated at the system peak load level are usually much higher than the actual annual indices.

1.5. Distribution System Adequacy Assessment: [1, 40]

The economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service.

The power system is vulnerable [7] to system abnormalities such as control failures, protection or communication system failures, and disturbances, such as lightning, and human operational errors. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation.

This section presents a research efforts and a software implementation of a reliability analysis algorithm for electrical power distribution systems. This algorithm is used to study reliability improvements due to the addition of distributed generators *(DGs)*. This algorithm also takes into account system reconfigurations.

1.5.1 Distributed generators

When Thomas Edison built the *Pearl Street Power Station* to provide the first electric service to customers in *New York City*, he was essentially following a strategy that today would be called distributed generation – *building power generation within the localized area of use*. As the young industry grew, many industrial facilities built their own power plants both to serve their own needs and to sell to customers around them, another example of distributed generation. Rapid technological development led to larger and more efficient generating plants built farther and farther from the end-user. Large regional power transmission networks delivered this power to the local distribution systems and finally to the end-user. The industry was regulated so that these changes could occur efficiently without wasteful duplication of facilities, and the economic role of distributed generation became much more limited.

Since the *1970s*, however, large central nuclear and coal-fired power stations have become increasingly expensive and more difficult to site and to build. At the same time technological development has improved the cost and performance of smaller, modular power generation options -from *300* megawatt *(MW)* gas-fired combined cycle power plants down to individual customer generation of as little as a few kilowatts.

The industry is also restructuring to allow customers to competitively select the optimum combination of energy resources to meet their needs. [*9,10*]

What is distributed generation? [*11*],

Distributed generation or *(DG)* generally refers to small-scale *(typically 1KW –50MW)* electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include synchronous generators, but are not limited to them, it comprise induction generators, reciprocating engines, micro-turbines *(combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel)*, combustion gas turbines, fuel cells, solar photovoltaic, and wind turbines.

1.5.2. Distributed generation technologies [9,46]

Energy service providers and consumers can select from a wide range of distributed power generation technologies. Commercial technologies such as reciprocating engines and small combustion turbines already are used in a variety of applications from emergency power to combined heat and power. Emerging technologies such as fuel cells micro-turbines and photovoltaic will provide additional options for distributed power generation.

DGs (also known as Distributed Resources -DRs-) interconnected to the electric power system *EPS* [*11,12*] come in many forms including gas turbine driven synchronous generators, wind powered induction generators, fuel cells with inverter circuitry, and others.

The use of *DGs* is projected to grow. This growth is due to cost reductions available with *DGs*. The cost reductions may be the result of released system capacity or reductions in generation costs at peak conditions.

The systems considered in this part are radial operated [*24*] with respect to substations, and are reconfigurable.

1.5.3. Reliability assessment

The distribution system is that portion of the electric power system which links the bulk power source(s) to the consumer's facilities. Sub-transmission circuit, distribution substations, primary feeders, distribution transformers, secondary circuits and consumer connections all form different parts of an electric distribution system. Reliability evaluation in a distribution system, therefore, deals with how adequately these combined elements perform their intended function. Distribution system reliability evaluation techniques have been developed and enhanced in the last three decades [*15-18*, *25-27*]. The distribution system is an important part of the total electric system as it provides the final link between the bulk system and the customers. In many cases, these links are radial in nature and therefore susceptible to outage due to a single event. Outages in distribution systems tend to have localized effects to overall customer supply inadequacy. An electric distribution system can be generally classified into sub-transmission and radial/meshed segments.

Quantitative reliability evaluation is an essential aspect of distribution system planning. Distribution system reliability assessment can be divided into the two basic segments of measuring past system performance and predicting future performance. Most electric power utilities collect data on past system performance and evaluate appropriate indices. Predictive reliability evaluation is an attempt to estimate future performance at the actual customer load points. These predictions can also be aggregated to provide system performance indices. Two sets of reliability indices which are important for individual customer load points and for the overall distribution system are defined in the following sections. In this research, reliability analysis is not conducted on a complete power system and reliability evaluation of the distribution system part is conducted independently of the two other parts of the electric power system *(generation and transmission segments)*. This kind of analysis generally assumes that the other parts of the system are fully reliable and capable of performing their intended functions. [*40*]

1.5.4. Radial distribution systems

A distribution circuit normally uses primary or main feeders and lateral distributors. A main feeder originates from the sub-transmission substation and passes through the major load points and is constructed using single, parallel or meshed circuits. Any distribution systems used in practice have a single circuit main feeder and are referred to as radial systems. Other systems, although connected as meshed circuits, are normally operated as radial systems using normally open points. Radial systems are popular due to their simple design and generally low cost. The outage durations due to component failures are reduced by protection and switching action is termed as switching/restoration time. In some systems, there is provision for an alternate supply in the case of failure or due to a component maintenance outage. Fuse-gear, which clears the faults on the lateral distributor or the distribution transformer, is also normally present on a lateral distributor.

1.5.5. Definitions of performance indices

A basic problem in distribution system reliability assessment is measuring the efficacy of past service. A common solution consists of condensing the effects of service interruptions into *indices* of system performance, which are then used to make decisions. The Edison Electric Institute *(EEI)*, the Institute of Electrical and Electronics Engineers *(IEEE)*, and the Canadian Electric Association *(CEA)* have suggested a wide range of *performance indices*

[23]. These *indices* are generally yearly averages of interruption frequency or duration. They attempt to capture the magnitude of disturbances by load lost during each interruption.

System average interruption duration index *SAIDI* is the average interruption duration per customer served. It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served.

$$\boldsymbol{SAIDI = \frac{Sum\ of\ Customer\ interuption\ durations}{Total\ number\ of\ Customers}} \qquad (\mathbf{1.15})$$

Customer average interruption duration index *CAIDI* is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the number of customers experiencing one or more interruptions during a one-year period.

$$\boldsymbol{CAIDI = \frac{Sum\ of\ Customer\ interuption\ durations}{Total\ number\ of\ Customers\ interuptions}} \qquad (\mathbf{1.16})$$

These two performance indices express interruption statistics in terms of system customers. A customer here can be an individual, firm, or organization that purchases electric services at one location under one rate classification, contract or schedule. If service is supplied to a customer at more than one location, each location shall be counted as a separate customer.

1.5.6. Comparison of different system designs

Of paramount interest in any reliability study is ensuring a good quality of service to customers defined as a combination of availability of the energy supply and the quality of the energy available to the customers. In the following sections the reliability of the power supply for three kinds of situations are discussed and how reconfiguration and alternative sources improve the reliability of the power system.

A. Simple radial distribution system

Figure *1.6* shows a simple radial distribution system. In this system a single incoming power service is received and distributes power to the facility.

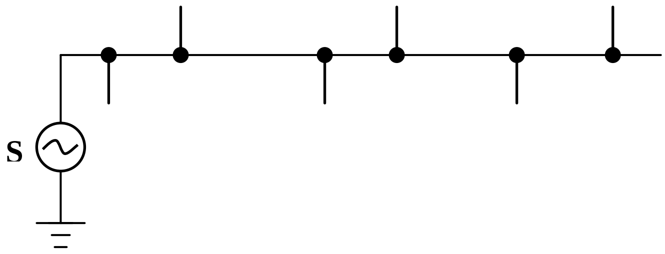

Figure 1.6 Simple Radial

There is no duplication of equipment and little spare capacity is typically included. Failure of any one component in the series path between the source and the load will result in a power interruption to at least all loads downstream of the failed component.

B. Alternative feed distribution arrangement

A second distribution arrangement is used for facilities requiring more reliable power. Figure *1.7* is a diagram representing this system arrangement. Part of the load is connected to one source and the other part of the load is connected to a second power source [*46*].

The circuits *(one circuit fed by S0 and the other fed by S1)* are tied together through a normally open tie-switch, with both power sources energized. The electrical equipment is designed to accommodate *100%* of the facility load. For instance, when a failure occurs in source *S0*, after the failure is isolated by opening the circuit breaker, the tie-switch is closed allowing the complete load to be served from a single source until the problem is corrected. Most customers can be restored immediately and do not have to wait until *S0* is repaired.

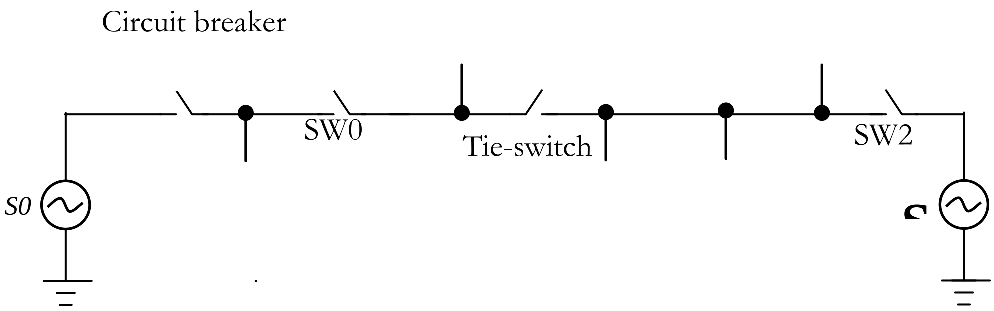

Figure 1.7 Alternative Feed Distribution

c. Alternative feed arrangement with DG

Reliability can be improved further by adding a *DG* into the circuit, as indicated in Figure *1.8*. In case the failure occurs on the left hand side of *SW0*, switch *SW0* is opened and *SW3* is closed, so that the *DG* can pick up the rest of the circuit, which was originally fed by *S0*. Without the *DG*, the power is drown from *S1*. Such operation might violate system constraints or degrade the quality of the power supply, especially when the customer load reaches a peak value.

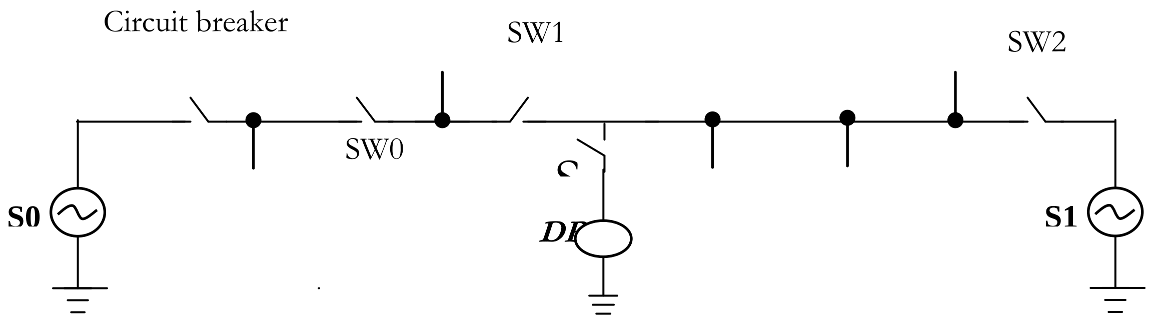

Figure 1.8 Alternative Feed Arrangements with *DG*

1.5.7. Switching operations

Reliability analysis for a power system also leads to more reliable and cost-effective operation, since power restoration analysis is a subset of the calculations performed for reliability analysis. Here switch operation time is assumed to be less than repair time, so loads that have lost power may be restored faster by appropriate switching operations, or reconfiguration of the system.

There are two kinds of switching operations of interest. One is isolating the failure point so that a load point of interest, which has lost power, may be re-supplied from the original source. The other is to again isolate the failure point and to feed a load point of interest from an alternate source, if an alternate source is available.

1.5.8. Reliability analysis components [28, 41,42]

1.5.8.1. Segment

In essence, there are two configurations in a distribution system. One consists of lines, transformers, and other components that are directly responsible for transmitting power from the distribution substation to customers. The second one consists of fuses, re-closers, circuit breakers, etc.

This interrelated network is designed to detect unusual conditions on the power delivery system and isolate the portions of system that are responsible for these conditions from the rest of the network. The location of protection or isolation components on the distribution system and their response to failures can have an important impact on the reliability indices. The distribution system is sectionalized into segments by these protection and isolation components. In the following sections, the power system is not modeled in terms of components but segments. A segment is a group of components, whose entry component is a switch or a protective device. This sectionalizing device *(re-closer, fuse, CB, switch …etc)* isolates groups of components into indivisible sections. Each segment has only one switch or protective device.

In Figure *1.9*, the only protection on the feeder is the station breaker. The failure of any of the components in this segment can cause an interruption at load point *1*. It is the same for the other load points (*2*, *3*, *4*, and *5*). No temporary restoration is possible. For this configuration, the reliability of all the load points (*1*,*2*, *3*, *4*, and *5*) is identical.

A segment's name is the same as that of its sectionalizing device *(re-closer, fuse, CB, switch …etc)*. In Figure *1.9*, there is only one segment, which is segment *B*. Breaker *B* and components *1*, *2*, *3*, *4*, and *5* all belong to segment *B*.

Modeling the power system in terms of segments speeds up the reliability index calculations. The algorithm can be programmed to run faster since only the sectionalizing devices are processed without processing the intermediate components

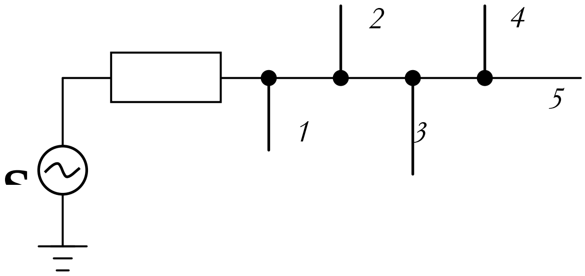

Figure 1.9 Sample Segment

1.5.8.2. Reliability analysis sets

In order to analyze the reliability of distribution systems, the Electric Power Research Institute *(EPRI)* defined sets [*28*] which are needed for calculating the reliability of a given load point. Figure *1.10* illustrates the relation among these sets.

In reliability analysis, the failure of all elements that can cause a loss of service to a particular load point must be considered. *(This load point will be presented in terms of a segment, which is the segment of interest S).* All system components are either located on the continuous path between the source and the segment of interest, or not located on the path. The failure of all continuous path components can cause an interruption at the load point.

The failure of components not in the path can also cause an interruption at the load point, unless the component is separated from the path by a protective device that responds automatically to the component failure. The effects of non-series elements and temporary restoration are now considered in the sets shown in Figure *1.10*, as will now be explained.

The *L* set, shown in Figure *1.10*, contains all segments within a circuit whose failure can cause loss of power to the segment of interest *S*. This *L* set includes all segments that are not separated from the continuous path between the source *(substation, generator, etc)* and the segment of interest *S* by an automatic protection device.

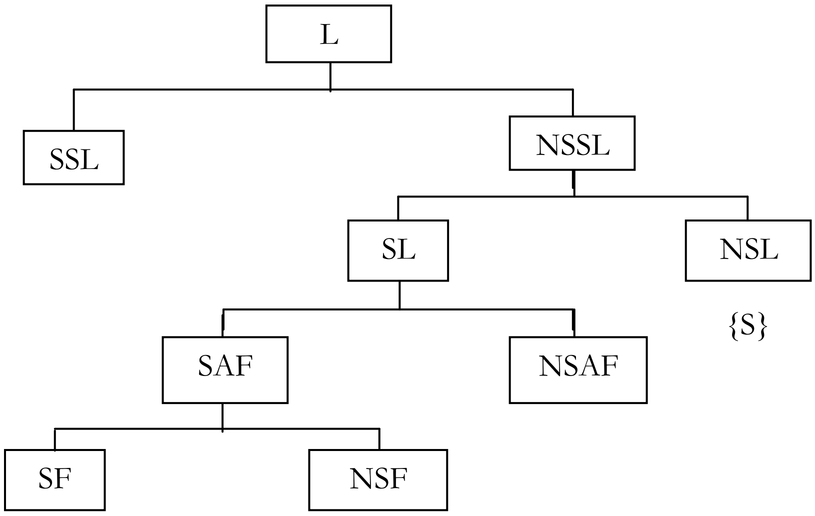

Figure 1.10 Reliability Analysis Sets

Now the *L* set is partitioned into the sets *SSL* and *NSSL*:

- The *SSL* set consists of the segments that may be isolated from the continuous path between *S* and the original source;
- The *NSSL* set consists of the segments that cannot be switched away from the continuous path between *S* and the original source.

The *SSL* set contains any segments separated from the continuous path by manually operated switches. If any element of this set fails, the segment of interest *S* can be temporarily restored from the original source before the failed component is repaired or replaced.

Examining those segments that cannot be separated from the continuous path, the set *NSSL* is further portioned into *SL* and *NSL*:

- The *SL* set consists of the segments that *can* be switched away from the segment of interest *S*, so that if the failure occurs in the *SL* set, *S* may be fed by an alternate source;
- The *NSL* set consists of the segments that *cannot* be switched away from the segment of interest *S*. That is the segment of interest itself, so this set only contains the element $\{S\}$.

If anything fails in the *NSL* set, all the components within that segment have to experience the full repair or replacement time of the failed component. Temporary restoration is not possible.

Considering the SL set, it can be divided into SAF and $NSAF$:

- For the SAF set, if the failed component lies in these segments, it is possible to restore power to S by an alternate source;
- For the $NSAF$ set, if the failed segment belongs to this set, the segment of interest S cannot be temporarily restored from an alternate feed.

The set SAF contains the segments that can be isolated from both the segment of interest S and the alternative source, which make the temporary restoration topologically possible. Sometimes, system constraints may limit the restoration options; the alternate source might not have the capacity to support the particular load point that of interest. So the set SAF is partitioned into SF and NSF:

- The SF set consists of all segments that *can* be isolated from S and an alternative source, allowing power to be restored to S from the alternative source *(for segments in this set, system constraint violations do not occur during the restoration)*;
- The NSF set consists of all segments which may be isolated from S and an alternative source, but for which it is *not* possible to restore power to S because of violating system constraints.

The set L, including all the segments for calculating the reliability indices, is decomposed into a number of sets as given by

$$L = SSL \cup NSSL \tag{1.17}$$

$$NSSL = SL \cup \{S\} \tag{1.18}$$

$$SL = SAF \cup NSAF \tag{1.19}$$

$$SAF = SF \cup NSF \tag{1.20}$$

Equations (*1.17*)-(*1.20*) yield

$$L = SSL \cup SF \cup \{S\} \cup NSAF \cup NSF \tag{1.21}$$

To sum up, if the failed component from the *L* set is placed in the *SSL* set, it is possible to restore power to the load point of interest *S* from the original source. If the failure occurs in the *SF* set, the power can be restored to *S* from an alternative source without violating system constrains. But, if the failed component locates in either {*S*} *NSAF* or *NSF* sets, the failed component must be completely repaired before power can be restored to *S*.

Several additional reliability analysis *(RA)* sets are used to calculate the sets of Equation *(1,21)*, as given by

SIC = a set of all the segments in the circuit;

SW = a set of all the sectionalizing devices in the circuit;

AF = a set of available alternate sources;

IS = a set of sectionalizing devices that will isolate the segment of interest *S* from the original sources;

NIS = a set of switches that do not isolate the original source from the segment of interest;

EC = a set of ending components for the circuit;

PD = a set of protective devices in the circuit that isolate a load point of interest from its source.

1.5.9. Approach to distribution systems reliability evaluation

1.5.9.1 Circuit model

Reliability analysis is complicated by a number of factors. One of these factors is the size of distribution systems. Large metropolitan areas may contain thousands of devices with several separate circuits supplied by different substations. Calculation of reliability for a system is an extensive logistical problem. Fundamental to reliability improvement is manipulation of large amounts of interrelated data. These data includes distribution system configuration, system fault protection, customer density, failure rate, and repair time [*29*]. The methods in which data are stored, displayed and modeled determine the effectiveness of the computerized method.

1.5.9.2 Pointers

The pointer [30] is a variable that holds the address of a data element; pointers permit the construction of linked lists of data elements in computer memory [31], pointers are used for all data objects. Applications share circuit information via pointers, and also use pointers to manipulate data objects hidden inside the applications.

In distribution systems, a single circuit model may contain thousands of components, and an entire system model consisting of hundreds of circuits may contain over a million components. With such large systems, modeling methods have a direct impact on the ability to perform engineering analysis.

Use of pointers in linked lists allows system interconnects and equipment parameters to be directly available for analysis without repetitive search algorithms. Intrinsic in the graphical creation of the circuits is the creation of linked lists. The program memory model links together sources and components of each circuit [32]. In this way, it is possible to trace from circuit to circuit, through an individual circuit, or through a particular branch of a circuit.

Application programmers defined objects; these objects are manipulated and accessed via pointers and indices into arrays of pointers. The links provided that pertain to component traces involved in reliability analysis are:

- *Forward Pointer*—forward direction for doubly linked list of circuit components.
- *Backward Pointer*— backward direction for doubly linked list of circuit components.
- *Feeder Path Pointer* — for a radial system, the feeder path pointer of a given component is the next component toward the reference substation that feeds the given component.
- *Brother Pointer* — a given component's brother pointer points to the first component connected in its forward path which is not fed by the given component. *(It is used to detect dead ends or physical jumps in connectivity).*

Because of these contained links and pointers, each component's data object is known as a *"trace"* structure.

Table *1.14* lists the elements in the trace component structure that are related to the reliability analysis module.

TABLE 1.14

Program Component Trace Structure Elements

ELEMENT NAME	DATA TYPE
Circuit Number	Short Integer
Substation Number	Short Integer
Equipment Index Number	Short Integer
Component type Number	Short Integer
Component Name	String
Forward Pointer	Pointer
Backward Pointer	Pointer
Feeder Path Pointer	Pointer
Brother Pointer	Pointer
Elements Added For Reliability Analysis Module	
Segment Pointer	Pointer
Forward Segment Pointer	Pointer
Backward Segment Pointer	Pointer
Feeder Path Segment Pointer	Pointer
.	.
.	.

Due to the large size of the trace structure only the elements, which are employed by the reliability analysis module are listed in Table *1.14*. Several segment trace pointers are included in the structure. The *Segment Pointer* is used to find the primary sectionalizing device *(re-closer, fuse, CB, switch ...etc)* for a component.

Sectionalizing devices in a circuit are linked in a doubly linked list via the *Forward Segment Pointer* and the *Backward Segment Pointer*. Sectionalizing devices are also linked with the *Feeder Path Segment Pointer*, which is similar to the *Feeder Path pointer* for components, except that only sectionalizing devices are processed.

1.5.9.3 Circuit traces

Circuit traces [*28*] are applied in determining the reliability analysis *(RA)* sets shown in Figure *1.10*. Circuit traces employ pointers and linked lists discussed previously. Circuit traces represent the order in which an algorithm processes the components of the system. As indicated earlier, a circuit analysis program must efficiently manage large quantities of system and equipment data. The pointers and linked lists compact the data storage and reduce algorithm execution time.

Here an overview of using circuit traces is provided. Figure *1.11* is an example circuit used to illustrate the application of circuit traces. Source *S0* is the original source of the circuit of interest, and *S1* is the alternate source. *S1* is separated from the circuit of interest by the normally open switch *SW25*.

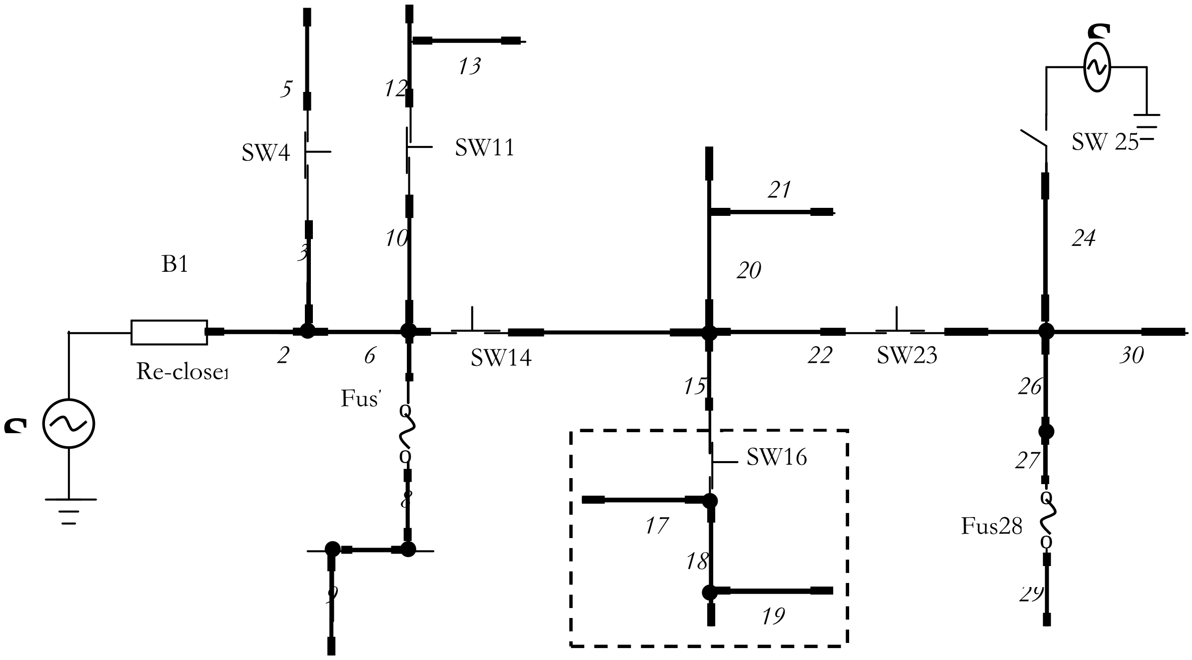

Figure 1.11 Sample Circuit: Modeled In Terms Of Segments

Each circuit trace represents a particular linked list tracing through the components of a circuit. Four types of component circuit traces will be applied. These traces, along with the notation used to indicate the trace, are defined as follows:

FTm = forward component trace beginning with component *m (if m is not specified, FT begins from the substation)*. *FT* in the example circuit is given by:

$$FT = 2 \rightarrow 3 \rightarrow SW4 \rightarrow 5 \rightarrow 6 \rightarrow 7 \rightarrow 8 \rightarrow \ldots\ldots \rightarrow Fus28 \rightarrow 29 \rightarrow 30 \quad (1.22)$$

BTm = backward component trace beginning with *m*; as illustrated by:

$$BT_{15} = SW14 \rightarrow 13 \rightarrow 12 \rightarrow SW11 \rightarrow \ldots \rightarrow Fus7 \rightarrow 6 \rightarrow 5 \rightarrow SW4 \rightarrow 3 \rightarrow 2 \rightarrow 1 \qquad (1.23)$$

FPTm = component *m*'s feeder path component trace, as illustrated by:

$$FPT_{15} = SW14 \rightarrow 6 \rightarrow 2 \rightarrow B1 \quad (1.24)$$

ECT = ending component trace, is given by:

$$ECT = 5 \rightarrow 9 \rightarrow 13 \rightarrow 17 \rightarrow 18 \rightarrow 19 \rightarrow 20 \rightarrow 21 \rightarrow 29 \rightarrow 30 \quad (1.25)$$

The circuit traces discussed above are basic circuit traces. For reliability analysis, it is more efficient to work with pointers to segments and to perform traces based on these pointers. The segment circuit traces used in this research are:

FSTm = forward segment trace from segment *m*, *(if m is not specified, the forward trace will begin with the substation)*. In the example circuit, *FST* is given by:

$$FST = SW4 \rightarrow Fus7 \rightarrow SW11 \rightarrow SW14 \rightarrow SW16 \rightarrow SW23 \rightarrow Fus28 \quad (1.26)$$

FPSTm = feeder path segment trace *(It is performed relative to a given segment m)*. For instance, tracing from the segment of interest, segment *SW16*, $FPST_{SW16}$ is given by:

$$FPST_{SW16} = SW14 \rightarrow B1 \quad (1.27)$$

AFT = alternative feed trace. In the example circuit, there is only one alternative source, so *AFT* is given by

$$AFT = SW25 \quad (1.28)$$

If there are more than one alternative feed for the circuit, then *AFT* would consist of the linked list of all alternative feeds.

1.5.10. Computer algorithm

1.5.10.1. General

This section presents the computer algorithm used to develop the reliability analysis *(RA)* sets. The algorithm is implemented with linked lists; the implementation is pulled off by using the *MATLAB* package.

A notation in terms of linked lists is introduced to describe the algorithm. A software design for implementing the algorithm is also discussed. Along with the presentation of the algorithm, the example circuit illustrated in Figure *1.11* is used to explain the development of the *RA* sets.

1.5.10.2 Algorithm

In what follows, it is assumed for the example circuit that the segment of interest is given by:

$$\{S\}=\{Sw16\} \qquad (1.29)$$

First a forward component trace *(FCT)* is conducted, beginning with the substation, so that the set *SW* and segment pointers can be determined. This can be expressed as

$$FCT \longrightarrow SW, pFSeg, pBSeg, pSeg \qquad (1.30)$$

Where

pFSeg = **p**ointer to **f**orward **seg**ment *(in the example circuit, segment B1's pFSeg pointer is pointed to segment SW14)*

pBSeg = **p**ointer to **b**ackward **seg**ment *(in the example circuit, segment SW14's pBseg pointer is pointed to segment B1)*

pSeg = pointer to segment device for component (in the example circuit, all the components in segment *SW16*, components *17*, *18* and *19*, have their *pSeg* pointed to *SW16*).

The expression *(1.30)* is read as the *Forward Component Trace (FCT)* yields the *SW* set and sets the pointers *pFSeg*, *pBSeg*, and *pSeg*. Note that the notation used here is always to have pointers begin with a small *'p'*.

For the example circuit,

$$SW=\{B1, SW4, Fu7, SW11, SW14, SW16, SW23, Fu28, SW25\} \qquad (1.31)$$

In the *FCT*, the ending components that make up the *EC* set can also defined, by using the following condition:

If a component's forward pointer points to its brother pointer [*20*], then this component is an ending component.

Thus,

$$FCT \rightarrow EC \qquad (1.32)$$

There is a set of pointers representing the list of existing alternate feeds, *AF*, which can be set up during the *FCT* as well. If a component's adjacent component, say component *A*, belongs to another circuit and is fed by another substation, it means the original circuit is connected to an alternative feed. Once such a component as *A* is found, the source for *A* can be traced via an *FPST*. In this way, all the available alternate sources can be collected. Thus:

$$FCT \rightarrow AF \qquad (1.33)$$

Note that for each segment stored in the *AF* set, there are two ending components. One corresponds to a component in the *EC* set, and the other component exists in the adjacent circuit.

Since *IS* consists of all the sectionalizing devices in the feeder path of *S*, a *FPSTs* can be used to obtain the *IS* set, as well as the *PD (protective device)* set, as given by:

$$FPSTs \rightarrow IS, PD \qquad (1.34)$$

For the segment of interest *S* in the example circuit:

$$IS=\{SW16, SW14, B1\} \qquad (1.35)$$

$$PD=\{B1\} \qquad (1.36)$$

The logic used to develop the L set is as follows:

- Perform an *FST,* when the *FST* encounters a segment whose primary protective device belongs to the *PD* set, this segment is in the *L* set.
- Otherwise, when the *FST* encounters a segment whose primary protective device does not belong to the *PD* set, the segment is not in the *L* set.

Thus,

$$FST \rightarrow L \qquad (1.37)$$

Following the steps described above, the *L* set for the segment of interest *S* is obtained.

$$L=\{B1, SW4, SW11, SW14, SW16, SW23\} \qquad (1.38)$$

The segments in the *SSL* set may be isolated from *S* and the original source, so that the power can be restored from the original source. *SSL* is given by the following set operations as:

$$SSL = L \cap NIS \qquad (1.39)$$

Where $NIS = SW - IS$.

Applying Equation *(1.39)* in the example circuit, and using expressions *(1.31)*, *(1.35)* and *(1.38)*, the result is:

$$SSL = \{SW4, SW11, SW23\} \qquad (1.40)$$

The *NSL* set has only one element – *the segment of interest S*. All the failed components in the segment of interest must be completely repaired before power can be restored to *S*.

The segments in the *SL* set can be switched away from the segment of interest *S*, so that if the failure occurs in the *SL* set, *S* may be fed from an alternative source. The *SL* set is given by the following set operation.

$$SL = L \cap IS - \{S\} \qquad (1.41)$$

In the example circuit, applying expressions *(3.8)*, *(3.14)* and *(3.17)*, this gives:

$$SL = \{B1, SW14\} \qquad (1.42)$$

If the failed component lies in the *SAF* set, it is possible to restore power to *S* when system constraints are not violated. The system constraints that are of interest here are the power handling capabilities of the equipment.

Of particular interest is the remaining power handling capability of each piece of equipment. In order to find the *SAF* set, we conduct feeder path segment traces both from an alternate source and the segment of interest *S*, $FPST_{AF}$ and $FPST_S$, respectively. When these traces encounter a common path, then the *SAF* set is not empty. The *SAF* set includes the segments in the common path except the first segment that the feeder path traces meet in the common path. Thus,

$$FPST_{AF}, FPST_S \rightarrow SAF \qquad (1.43)$$

In the example circuit,

$$SAF = \{B1\} \qquad (1.44)$$

The $NSAF$ set includes all the segments for which it is not possible to restore power to S from an alternative source. All the failed components in these segments must be completely repaired before restoring power to S.

The $NSAF$ set is given by set operation:

$$NSAF = SL - SAF \qquad (1.45)$$

In the example circuit, using expression *(3.21)* and *(3.23)*, this yields:

$$NSAF = \{SW14\} \qquad (1.46)$$

The segments in the SF set may be isolated from S and an alternative source, so that power can be restored to S from the alternative source without violating system constraints.

The NSF set includes all the segments which may be isolated from S and an alternative source, but for which it is not possible to restore power to S because of system constraint violations. All the failed components in these segments must be completely repaired before power can be restored to S.

To achieve the SF set, the power required by S must be compared to the minimum remaining capacity of the components along the feeder path from the alternative feed *(AF)*.

If there is more than one alternative feed in the system, the minimum capacities encountered in the feeder path component traces FPT_{AF} for all the available sources in the AF set must be compared. For instance, there are n alternative feeds in the system. Let:

C_{AFK} = *minimum remaining component power capacity in the* FPT_{AF} *for the* k^{th} *alternative feed,* $k=1,2,3\ldots n$. *(1.47)*

$$C_{AFm} = \max_{k}\{C_{AFK}\} \qquad (1.48)$$

Thus C_{AFm} represents the *greatest minimum* remaining capacity available among the alternative sources. For example, as demonstrated in Figure *1.12*, there are two alternative sources, AF_1 and AF_2. The segment of interest is marked as S. As indicated in the figure, the power required by S is *5 KW*. The numbers on the alternative feed components stand for the remaining capacity *(units of KW)* of the components.

According to Equation *(1.47)* and *(1.48)*,

$$C_{AF1} = min\{10, 5, 30\} = 5$$

$$C_{AF2} = min\{40, 20, 20, 10\} = 10$$

$$C_{AFm} = max\{C_{AF1}, C_{AF2}\} = max\{5, 10\} = 10$$

So
$$AF_m = AF_2 \qquad (1.49)$$

Even though the minimum remaining capacity on the feeder path from *AF1* is equal to the required power in S, pulling the power from *AF1* to S will fully utilize component *AF12*. Thus *AF2* is chosen since it has more remaining capacity on the feeder path.

In the general case, the segment of interest is not directly connected to the alternative feeds. So *FPT* traces in the circuit of interest are also required to determine remaining power handling capabilities. In essence, component traces from the segment of interest to all alternative sources are required to check power handling capacities. In summary, the circuit traces that yield the reliability analysis *(RA)* sets are shown in table *1.15*.

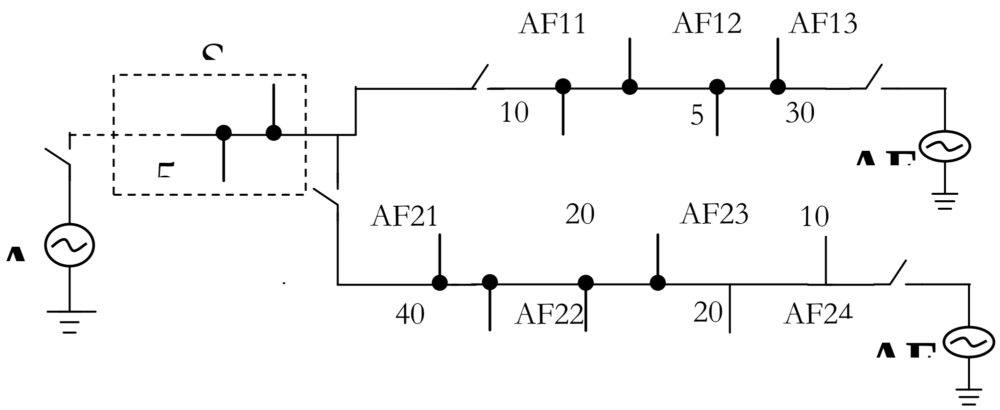

Figure 1.12 Illustrating Selection of Alternative Feed

Table 1.15

Summary of Traces Used To Develop The RA Sets

ALGORITHM STEPS	TRACES IN THE CIRCUIT MODEL
Step 1	$FCT \rightarrow SW, pFSeg, pBSeg, pSeg, EC, AF$
Step 2	$FPST_S \rightarrow IS, PD$
Step 3	$FST \rightarrow L$
Step 4	$FPST_{AF}, FPST_S \rightarrow SAF$
Step 5	$FPT_{AF} \rightarrow SF$ or NSF

In order to get the required power or remaining capacity of a component, a power flow needs to be calculated.

Once the power flow calculation is completed, then

$$FPT_{AF} \rightarrow SF \text{ or } NSF \quad (1.50)$$

In the example circuit, assuming system constraints are not violated,

$$SF = \{B1\} \quad (1.51)$$

1.5.11. Reliability indices

This analysis relies on two general classes of information to estimate the reliability; component reliability parameters and system structure. Using system structure and component performance data, the reliability of specific load points or the whole distribution system can be evaluated. The structure information is achieved by the circuit traces presented previously. In the following paragraphs the performance data is discussed.

Predictive reliability techniques suffer from data collection difficulties. Simplifying assumptions *(default values)* are required for practical analysis of distribution systems.

1.5.11.1 Functional characterization

The availability of component functionally is characterized by the following indices:

• *Annual Failure Rate* = the annual average frequency of failure,

• *Annual Down Time* = the annual outage duration experienced at a load point also known as unavailability U.

The failure rate for segment i, FR_i, is the sum of the failure rates of all the components contained in the segment i as given by

$$FR_i = \sum_{j=1}^{n} Fr_j \qquad (1.52)$$

Where: Fr_j = the failure rate for component j, and

n = the number of components in segment i.

The average repair time for a segment i, REP_i, can be calculated by

$$REP_i = \frac{\sum_{j=1}^{n} (Fr_j \times Rep_j)}{\sum_{j=1}^{n} Fr_j} \qquad (1.53)$$

Where

Fr_j = the failure rate for component j,

Rep_j = the average repair time for component j, and

n = the number of components in segment i.

These indices are computed for each segment in the feeder. All load points within a segment have the same failure rate and experience the same down time.

In the reliability analysis program, failure rates and repair times from field data are preferred. When this data is not available, default values are fetched from a table in the relational database, which has generic average failure rates and repair times for each type of device.

1.5.11.2 Reliability indices calculation

After finding the reliability analysis sets for the segment of interest S, reliability indices can be calculate. First assume there is a single failure incident.

The down time for the segment S, DT_s, is given by

$$DT_s = \sum_{\substack{i \in NSL, \\ NSAF, \\ NSF}} (FR_i \times REP_i) + \sum_{\substack{i \in SSL, \\ SF}} (FR_i \times SOT_i) \qquad (1.54)$$

Where,

SOT_i = switch operation time to re-supply segment S due to the failure of segment i.

Note that the reliability analysis algorithm presented here assumes that switch operations can always be performed faster than repairs.

The customer average interruption duration index *(CAIDI)* for a segment is the same as DT_s

$$CAIDI = DT_s \qquad (1.55)$$

Once the down time for each segment is calculated, and given the number of customers attached to each segment, the total customer down time, DTC, for a given circuit can be calculated by:

$$DTC = \sum_{i \in Circuit} (DT_i \times C_i) \qquad (1.56)$$

Where C_i = the number of customers attached to segment i.

Since the failure rate and down time is known at each segment on the feeder, the system index $SAIDI$ *(System Average Interruption Duration Index)* is then given by:

$$SAIDI = \frac{DTC}{\sum_{i \in Circuit} C_i} \qquad (1.57)$$

The average restoration time for segment S is computed as

$$RT_s = \frac{DT_s}{\sum_{i \in L} FR_i} \qquad (1.58)$$

1.5.11.3. Relative reliability index

A new measure of reliability referred to as *'Relative_CAIDI'* is introduced here. $Relative\_CAIDI_j$ helps to identify the areas that need improvement. $Relative\_CAIDI_j$ is given by:

$$Relative\_CAIDIj = \frac{CAIDI_{ckt}}{CAIDI_j} \qquad (1.59)$$

Where $CAIDI_{ckt}$ = average $CAIDI$ for the circuit of interest.

$CAIDI_j$ = $CAIDI$ for segment j.

Thus:

- If $Relative\_CAIDI_j = 1$, then the customers in segment j have average reliability
- If $Relative\_CAIDIj < 1$, then the reliability of the customers in segment j is less than average.
- If $Relative\_CAIDIj > 1$, then customers in segment j have reliability better than average.

Extra reliability indices [*44*] for the distribution system can exist such as the *ASAI* and *ASUI* as designated below:

Average service availability index, *ASAI:*

$$\boldsymbol{ASAI = \frac{customer\ hours\ of\ available\ service}{customer\ hours\ demanded}} \qquad (\mathbf{1.60})$$

Average service unavailability index *ASUI:*

$$\boldsymbol{ASUI = 1 - ASAI = \frac{customer\ hours\ of\ unavailable\ service}{customer\ hours\ demanded}} \qquad (\mathbf{1.61})$$

1.5.12. Distributed generator placement

In the evolving energy industry, emerging distributed generator technologies have the potential to provide attractive, practical, and economical generation options for energy companies and their customers.

Distributed resource technologies range in size from *3-10 KW* for residential systems to *50-500 KW* for commercial users to *1-50 MW* in the industrial market segment. Primary opportunities lie in using these technologies to

1. Improve the service and delivery of energy to end users
2. Support the operation and management of transmission and distribution systems.

This work does not consider the islanding of distributed generators *(that is the generator operating without substation supply)*.

A distributed generator is often placed at a substation because no further land purchases are needed. However, locating generators at substations, distributed generator acts only as a backup power source, which may not contribute significant reliability improvement as far as the entire system is concerned. Instead, generators located further out on a circuit can often significantly affect system reliability. It is necessary to evaluate the effects of different placements of distributed generators. It will be seen that locating the *DG* at the end of the circuit produces more reliability improvement than placing it at the substation.

1.5. Summary

The chapter in here presents the basic concepts associated with composite system adequacy assessment, also known as the *HLII* adequacy assessment. Reliability indices for load points and for all the entire system are initiated. States selection techniques are presented. Numerical examples are used to illustrate the application of the assessment techniques on the *HLII* level.

The chapter in addition, presents the concepts of the techniques used in distribution system reliability evaluation; reliability analysis component are introduced as reliability analysis sets, pointers, circuit traces and segments. At this stage of the work, it was assumed that the *HLII* level is *100%* reliable. Indices concerning load points and the complete distribution system are described. Distributed generation technologies are introduced, and used in here, for the improvement of distribution system reliability [43]. Moreover in this chapter, the computer algorithm components and concepts used for this purpose is presented in detail.

Chapter 2

Application To The "Roy Billinton Test System" R.B.T.S

2.1. Introduction

The concepts outlined in chapter 1 are utilized in this chapter to predict the reliability indices for overall power system. The test system used throughout this section to illustrate the basic concepts and procedures involved in the overall power system reliability analysis.

2.2. Test System

The application in this section uses the well-known *(R.B.T.S)*. The detailed descriptions of these systems are given in [*32-34*]. The *(R.B.T.S)* is an educational test system developed by the *Power Systems Research Group* at the University of Saskatchewan. The *(R.B.T.S)* is sufficiently small to permit the conduct of a large number of reliability studies with a reasonable solution time yet sufficiently detailed to reflect the actual complexities involved in a practical reliability analysis.

The single line diagram of the *(R.B.T.S)* is shown in Figure *2.1*. The *(R.B.T.S)* described has two generation buses, five load buses *(one of which is also a generation bus)*, nine transmission lines and eleven generating units. The total installed capacity is *240MW* with a system peak load of *185MW*. The transmission voltage level is *230KV*. The minimum and the maximum ratings of the generating units are *5 MW* and *40 MW* respectively. The detailed generator data, bus data and station data for this system are given here after.

The generating unit ratings and reliability data for the RBTS are shown in Table *2.1*.

Table 2.1 Generating unit reliability data

Unit size (MW)	Type	No of Units	U Forced outage rate	MTTF (hr)	λ/yr Failure rate	MTTR (hr)	μ/yr Repair rate	Scheduled maintenance (wk/yr)
05	hydro	2	0.010	4380	2	45	198	2
10	thermal	1	0.020	2190	4	45	196	2
20	hydro	4	0.015	3650	2.4	55	157.6	2
20	thermal	1	0.025	1752	5	45	195	2
40	hydro	1	0.020	2920	3	60	147	2
40	thermal	2	0.030	1460	6	45	194	2

Table 2.2 shows the basic transmission line reliability data. The permanent outage rate of a given transmission line is obtained using a value of 0.02 outages per year per kilometer.

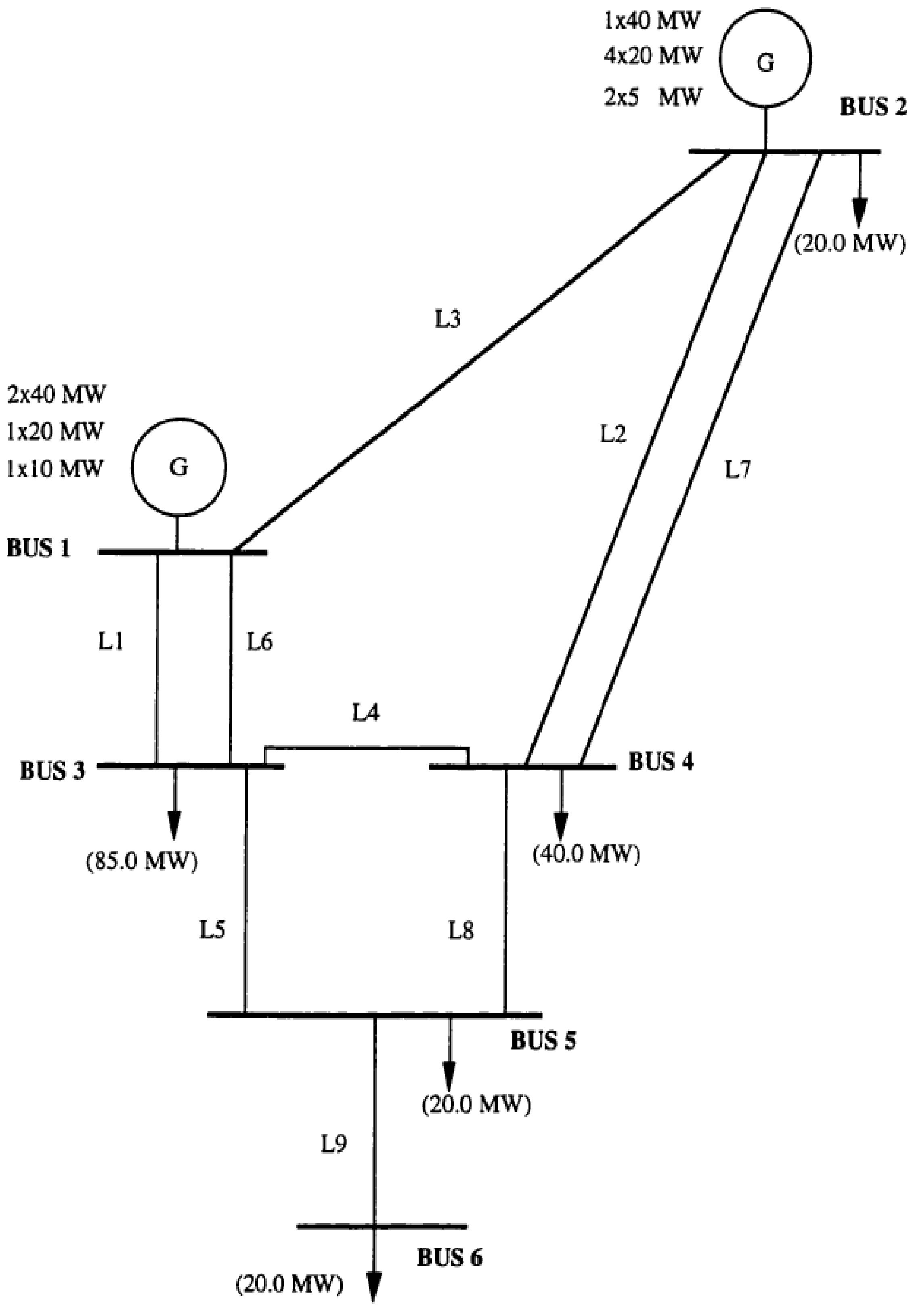

Figure ***2.1***: Single line diagram of The *R.B.T.S*

Table 2.2 Transmission line length and outage data

Line	*Buses*		*Length (Km)*	*Permanent Outage rate (λ/yr)*	*Outage Duration r (hr)*
	From	*To*			
1	*1*	*3*	*75*	*1.5*	*10.0*
2	*2*	*4*	*250*	*5.0*	*10.0*
3	*1*	*2*	*200*	*4.0*	*10.0*
4	*3*	*4*	*50*	*1.0*	*10.0*
5	*3*	*5*	*50*	*1.0*	*10.0*
6	*1*	*3*	*75*	*1.5*	*10.0*
7	*2*	*4*	*250*	*5.0*	*10.0*
8	*4*	*5*	*50*	*1.0*	*10.0*
9	*5*	*6*	*50*	*1.0*	*10.0*

2.3. HLII reliability indices for the R.B.T.S

Reliability studies and analysis are based on the probability theory, they are not made for having just numerical results for different system configuration, and based on these results the engineers will opt and select one system configuration because of the good probability percentage of that case. In fact and real applications, that numerical results obtained from the studies represent the other face of information contained in that numerical outcome, in another word, numerical calculation are the compressed form of the information for the system in case of study.

Reliability indices for the composite system in favor of the *R.B.T.S* at buses *2-6* are represented in tables *(2.3)-(2.7).*

The tables in here after, point up the indices either for every state in the analysis of the concerned bus (column: *1* to *14*) and the indices for the load connected to that bus (overall indices of the bus), (column: *15* to *17* and the last line of the tables).

The nine *(9)* first columns are reserved to the system states, they furnish information on all the possibilities for all the lines of the transmission system, it is like a logical code, each line can exist in to states (up or down) zeros *(0)* mean that the line is operational (up), i.e., there is no fault in that line; if it is one *(1)* i.e., the line is out of service because of a fault (down).

In addition the tables display the failure probability and the failure frequency for each state which can emerge from that system state. The *Pg* column presents the generation probability with respect to the load of the bus bar.

The tables outlined afterward are not truncated to a sensitive percentage level; they are just samples from the whole states of the system. The real number of the transmission line system states is *(2^9 = 512)*. These tables are put to give for the reader comprehensible ideas on the results and the evaluation of the reliability.

From the application on *R.B.T.S* the results in the tables below, it is find that the displayed results are not the complete results as it was introduced later, they are selected from the *(2^9 = 512)* states to be interpreted for the reader as examples. The discussion and the explanation of the whole resultants states *(2^9 = 512)* is done here after.

For a general view, it can be seen that Bus *2* is both a generation and a load bus and this proves to be the most reliable load bus in the network. Bus *3* is connected directly to Bus 1 by two transmission lines on separate circuits. Bus *4* is supplied by two lines. Bus 5 is supplied by a two transmission lines, while Bus *6* is supplied by only one line.

From the tables below (last line of the tables), the indices at Bus 2 are less sensitive to supply failure, as Bus 2 is also a generating bus. Similarly those at Bus 3, which is strongly connected to a generating bus, are also virtually insensitive in comparison with Bus 4. It can be seen that buses 3 and 4 have the same configuration and the sole difference is the length of lines (1 and 6) which is less than that of lines (*2* and *7*); this difference in line length affect the failure rate of the lines which is traduced in reliability in difference in failure rate and availability of the supply. On the other hand, Bus 5 and Bus 6 are extremely sensitive to the loss of power delivery at the load points. In another word, more the load is distant from the supply points then the reliability is more sensitive to the number of elements between the load point and the supply point, the raison is that additional elements indices (failure rates and unavailability) are used in the calculation.

Here after individual flash for the buses are made:

Apropos Bus 2, it can be observed on table 2.3 that whatever all the transmission lines are failed (line 2: in grey) and there is no way to bring power from Bus 1 it steel possible to supply the load point at Bus 2 form the plant connected at this bus itself, this is why Bus 2 is the more reliable in the network.

Because of having the same analysis of the results of the other buses 3, 4, 5 and 6 investigations for bus 6 are given in detail:

Table 2.7 spots that there are four *(4)* major cases:

First case: There is possibility to supply the load point from both stations, station 1 at bus *1*, and station *2* at Bus *2*. In this case there will be a failure at the load point *6* only and only if a failure of supplying electric power takes place.

This can be observed on the three first lines on table *2.7*.

In this case ***Pg***= *2.28E-14* (the probability of having power production less or equal to *20 MW* - having more than *220 MW* out of service) is used in the calculation.

In this case there are: *120* states on *512* total system states.

Second case: Bus *6* is isolated (there is no connectivity between the supply points and the load point at bus *6*), see the cases:

- Failure of line *9* alone
- Failure of lines *5* and *8*
- Failure of lines *1, 6, 2* and *7*.

In this case ***Pg***=*1* (*100%* probability of failure at bus *6*) is used in the calculation.

In this case there are: *344* states on *512* total system states.

Third case: The power plant at bus *1* is isolated (there is no connectivity between Bus *1* and the load point at bus *6*), see the cases:

- Failure of lines *1*, *6* and *3*
- Failure of lines *3*, *4* and *5*.

In this case there will be a failure at the load point *6* only if a failure of supplying electric power from the power plant at bus *2* occurs.

In this case ***Pg***=*1.04E-09* (the probability of having power production -from power plant at bus 2- less or equal to *20 MW* - having more than *110 MW* out of service), this probability is used in the calculation.

In this case there are: *24* states on *512* total system states.

Fourth case: The power plant at bus *2* is isolated (there is no connectivity between Bus *2* and the load point at bus *6*), see the cases:

- Failure of lines *3*, *2* and *7*
- Failure of lines *3*, *4* and *8*.

In this case there will be a failure at the load point *6* only if it is impossible to bring electric power from the power plant at bus *1*.

In this case ***Pg***=*4.01E-05* (the probability of having power production -from power plant at bus *1*- less or equal to *20 MW* - having more than *90 MW* out of service), this probability is used in the calculation.

In this case there are: *24* states on *512* total system states.

As said before bus *6* have the lowest reliability level in the network system, and this is because that Bus *6* will be completely isolated from the supply *344* times i.e., Bus 6 will be in an isolated state (failure state) *344* times on *512* states of the total system states, which represent *67.1875%* of the *512* states of the system where bus 6 will be isolated completely from the supply points, all the engineer work will be made on taking the necessary actions to study how to make these states (weak points) to not came out. This can be done for example by doing the necessary maintenance in time period, to provide an alternative feed to bus 6.

Behind this exposition of the results from the reliability analysis of the case study of *R.B.T.S*, it can be said that any kind of information needed for the system planning can be extract from this study, like the composition of system states failure of transmission lines, generator units states which lead to failure of supply, their failure rates, unavailability for every state, any kind of be details can be pulled out if it is required to find out the weak points in the system. And after the collection of information the engineers can take the necessary procedures to improve the reliability of the system.

Table 2.3: HLII Load points indices for the RBTS at Bus 2

States (0: in, 1: out) T.L Number									State Probability	State Frequency Occ/yr	Pg	Failure Probability	Failure Frequency Occ/yr	ELCi MW	EENSi MWh	EDLCi h
L1	L2	L3	L4	L5	L6	L7	L8	L9								
0	0	0	0	0	0	0	0	0	0.976354	20.50343	2.28E-14	2.23E-14	4.67E-13	6.47E-12	2.70E-09	1.95E-10
1	1	1	1	1	1	1	1	1	7.22E-25	5.69E-21	1.04E-09	7.50E-34	5.92E-30	7.39E-29	8.22E-29	6.57E-30
0	0	1	1	1	0	1	1	1	4.32E-17	2.27E-13	1.04E-09	4.49E-26	2.36E-22	2.95E-21	4.91E-21	3.93E-22
0	0	0	1	0	1	0	0	1	2.18E-09	5.76E-06	2.28E-14	4.96E-23	1.31E-19	1.82E-18	6.02E-18	4.35E-19
1	0	1	0	0	1	0	0	0	1.31E-08	3.45E-05	1.04E-09	1.36E-17	3.59E-14	4.48E-13	1.49E-12	1.19E-13
1	0	1	0	0	1	0	0	1	1.49E-11	5.24E-08	1.04E-09	1.55E-20	5.45E-17	6.81E-16	1.70E-15	1.36E-16
1	0	1	0	0	1	0	1	0	1.49E-11	5.24E-08	1.04E-09	1.55E-20	5.45E-17	6.81E-16	1.70E-15	1.36E-16
1	0	1	0	0	1	0	1	1	1.70E-14	7.47E-11	1.04E-09	1.77E-23	7.77E-20	9.71E-19	1.94E-18	1.55E-19
Unavailability at the bus is: U= 1.39E-10 h Failure Frequency is: λ= 9.55E-13 occ/yr									Total (results for the bus)=			2.30E-14	1.42E-12	1.91E-11	2.78E-9	2.01E-10

Table 2.4: HLII Load points indices for the RBTS at Bus 3

States (0: in, 1: out) T.L Number									State Probability	State Frequency Occ/yr	Pg	Failure Probability	Failure Frequency Occ/yr	ELCi MW	EENSi MWh	EDLCi h
L1	L2	L3	L4	L5	L6	L7	L8	L9								
0	0	0	0	0	0	0	0	0	0.976354	20.50343	5.10E-08	4.98E-08	1.05E-06	6.73E-05	2.81E-02	4.36E-04
1	0	0	0	0	1	0	0	0	2.86E-06	0.005065	5.10E-08	1.46E-13	2.58E-10	1.66E-08	8.23E-08	1.28E-09
1	0	0	1	0	1	0	0	0	3.27E-09	8.64E-06	5.10E-08	1.67E-16	4.41E-13	2.83E-11	9.39E-11	1.46E-12
1	0	0	1	1	1	0	0	0	3.73E-12	1.31E-08	1	3.73E-12	1.31E-08	1.12E-06	2.78E-06	3.27E-08
1	0	0	1	1	1	0	0	1	4.25E-15	1.87E-11	1	4.25E-15	1.87E-11	1.59E-09	3.17E-09	3.73E-11
1	0	0	1	1	1	0	1	0	4.25E-15	1.87E-11	1	4.25E-15	1.87E-11	1.59E-09	3.17E-09	3.73E-11
1	0	1	0	0	1	0	0	0	1.31E-08	3.45E-05	0.001587	2.07E-11	5.48E-08	2.99E-06	9.91E-06	1.82E-07
1	0	1	0	0	1	0	0	1	1.49E-11	5.24E-08	0.001587	2.37E-14	8.32E-11	4.54E-09	1.13E-08	2.07E-10
1	0	1	0	0	1	0	1	0	1.49E-11	5.24E-08	0.001587	2.37E-14	8.32E-11	4.54E-09	1.13E-08	2.07E-10
0	1	1	0	0	0	1	0	1	1.66E-10	5.82E-07	0.05957	9.87E-12	3.47E-08	1.55E-06	3.86E-06	8.65E-08
0	1	1	0	0	0	1	1	0	1.66E-10	5.82E-07	0.05957	9.87E-12	3.47E-08	1.55E-06	3.86E-06	8.65E-08
0	1	1	0	0	0	1	1	1	1.89E-13	8.29E-10	0.05957	1.13E-14	4.94E-11	2.20E-09	4.40E-09	9.87E-11
Unavailability is U= 3.83E-04 h Failure Frequency is: λ= 1.51E-05 occ/yr										Total (results for the bus)=		6.06E-8	2.75E-05	0.0013	0.0325	5.30E-04

Table 2.5: HLII Load points indices for the RBTS at Bus 4

States (0: in, 1: out)									State Probability	State Frequency Occ/yr	Pg	Failure Probability	Failure Frequency Occ/yr	ELCi MW	EENSi MWh	EDLCi h
T.L Number																
L1	L2	L3	L4	L5	L6	L7	L8	L9								
0	0	0	0	0	0	0	0	0	0.976354	20.50343	6.90E-12	6.73E-12	1.41E-10	4.17E-09	1.74E-06	5.90E-08
0	0	0	0	0	0	1	1	0	6.36E-06	0.011238	6.90E-12	4.39E-17	7.75E-14	2.29E-12	1.13E-11	3.84E-13
0	0	0	0	0	0	1	1	1	7.26E-09	1.92E-05	6.90E-12	5.01E-20	1.32E-16	3.90E-15	1.29E-14	4.39E-16
1	1	0	0	0	1	1	1	0	1.06E-13	4.67E-10	1	1.06E-13	4.67E-10	1.87E-08	3.73E-08	9.32E-10
1	1	0	0	0	1	1	1	1	1.21E-16	6.39E-13	1	1.21E-16	6.39E-13	2.56E-11	4.25E-11	1.06E-12
1	1	0	0	1	1	1	0	0	1.06E-13	4.67E-10	1	1.06E-13	4.67E-10	1.87E-08	3.73E-08	9.32E-10
1	0	1	0	0	1	0	0	0	1.31E-08	3.45E-05	2.70E-07	3.52E-15	9.31E-12	2.41E-10	8.00E-10	3.09E-11
1	0	1	0	0	1	0	0	1	1.49E-11	5.24E-08	2.70E-07	4.02E-18	1.41E-14	3.67E-13	9.13E-13	3.52E-14
1	0	1	0	0	1	0	1	0	1.49E-11	5.24E-08	2.70E-07	4.02E-18	1.41E-14	3.67E-13	9.13E-13	3.52E-14
0	1	1	0	1	0	1	0	0	1.66E-10	5.82E-07	0.000929	1.54E-13	5.40E-10	1.26E-08	3.15E-08	1.35E-09
0	1	1	0	1	0	1	0	1	1.89E-13	8.29E-10	0.000929	1.76E-16	7.71E-13	1.80E-11	3.59E-11	1.54E-12
0	1	1	0	1	0	1	1	0	1.89E-13	8.29E-10	0.000929	1.76E-16	7.71E-13	1.80E-11	3.59E-11	1.54E-12
Unavailability is U= 2.30E-06 h Failure Frequency is: λ= 8.36E-07 occ/yr									Total (results for the bus)=			3.21E-10	9.85E-07	3.34E-05	9.19E-05	2.81E-06

Table 2.6: HLII Load points indices for the RBTS at Bus 5

States (0: in, 1: out) T.L Number									State Probability	State Frequency Occ/yr	Pg	Failure Probability	Failure Frequency Occ/yr	ELCi MW	EENSi MWh	EDLCi h
L1	L2	L3	L4	L5	L6	L7	L8	L9								
0	0	0	0	0	0	0	0	0	0.976354	20.50343	2.28E-14	2.23E-14	4.67E-13	6.47E-12	2.70E-09	1.95E-10
0	1	0	0	0	0	0	0	1	6.36E-06	0.011238	2.28E-14	1.45E-19	2.56E-16	3.55E-15	1.76E-14	1.27E-15
1	1	0	1	1	1	0	0	1	2.43E-17	1.28E-13	2.28E-14	5.53E-31	2.91E-27	4.04E-26	6.71E-26	4.85E-27
0	0	0	0	1	0	0	1	0	1.27E-06	0.002252	1	1.27E-06	0.002252	0.045046	0.222814	0.011141
0	0	0	0	1	0	0	1	0	1.27E-06	0.002252	1	1.27E-06	0.002252	0.045046	0.222814	0.011141
1	1	0	1	0	1	1	0	0	1.06E-13	4.67E-10	1	1.06E-13	4.67E-10	9.33E-09	1.86E-08	9.32E-10
1	0	1	0	0	1	0	0	0	1.31E-08	3.45E-05	1.04E-09	1.36E-17	3.59E-14	4.48E-13	1.49E-12	1.19E-13
1	0	1	0	0	1	0	0	1	1.49E-11	5.24E-08	1.04E-09	1.55E-20	5.45E-17	6.81E-16	1.70E-15	1.36E-16
1	0	1	0	1	1	0	0	0	1.49E-11	5.24E-08	1.04E-09	1.55E-20	5.45E-17	6.81E-16	1.70E-15	1.36E-16
0	1	1	1	0	0	1	0	1	1.89E-13	8.29E-10	4.01E-05	7.58E-18	3.32E-14	3.32E-13	6.64E-13	6.64E-14
0	1	1	1	0	0	1	1	0	1.89E-13	8.29E-10	4.01E-05	7.58E-18	3.32E-14	3.32E-13	6.64E-13	6.64E-14
0	1	1	1	0	0	1	1	1	2.16E-16	1.14E-12	4.01E-05	8.65E-21	4.55E-17	4.55E-16	7.57E-16	7.57E-17
Unavailability is U= 0.0114 h Failure Frequency is: λ= 0.0023 occ/yr										Total (results for the bus)=		1.30E-06	0.0023	0.0465	0.2277	0.0114

Table 2.7: HLII Load points indices for the RBTS at Bus 6

States (0: in, 1: out)									State Probability	State Frequency Occ/yr	Pg	Failure Probability	Failure Frequency Occ/yr	ELCi MW	EENSi MWh	EDLCi h
T.L Number																
L1	L2	L3	L4	L5	L6	L7	L8	L9								
0	0	0	0	0	0	0	0	0	0.976354	20.50343	2.28E-14	2.23E-14	4.67E-13	6.47E-12	2.70E-09	1.95E-10
0	0	0	0	1	1	1	0	0	1.09E-08	2.88E-05	2.28E-14	2.48E-22	6.56E-19	9.08E-18	3.01E-17	2.17E-18
0	0	0	1	0	0	1	0	0	6.36E-06	0.011238	2.28E-14	1.45E-19	2.56E-16	3.55E-15	1.76E-14	1.27E-15
0	0	0	0	0	0	0	0	1	0.001114	0.998426	1	0.001114	0.998426	19.96852	195.228	9.761398
0	0	0	0	1	0	0	1	0	1.27E-06	0.002252	1	1.27E-06	0.002252	0.045046	0.222814	0.011141
1	1	0	0	0	1	1	0	0	9.32E-11	3.27E-07	1	9.32E-11	3.27E-07	6.55E-06	1.63E-05	8.17E-07
1	0	1	0	0	1	0	0	0	1.31E-08	3.45E-05	1.04E-09	1.36E-17	3.59E-14	4.48E-13	1.49E-12	1.19E-13
0	0	1	1	1	0	0	0	0	5.81E-09	1.53E-05	1.04E-09	6.03E-18	1.59E-14	1.99E-13	6.61E-13	5.29E-14
0	1	1	0	0	0	1	0	0	1.45E-07	0.000383	4.01E-05	5.82E-12	1.53E-08	1.53E-07	5.09E-07	5.09E-08
0	0	1	1	0	0	0	1	0	5.81E-09	1.53E-05	4.01E-05	2.33E-13	6.15E-10	6.15E-09	2.04E-08	2.04E-09
Unavailability is : U= 9.9977 h Failure Frequency is: λ= 1.0464 occ/yr									Total (results for the bus)=			0.0011	1.0464	20.9272	199.9539	9.9977

2.4. Distribution system reliability evaluation: Application on the R.B.T.S "Roy Billinton test system"

2.4.1. Development of distribution networks for The R.B.T.S

The *R.B.T.S* has *5* load bus bars *(BUS2-BUS-6)*. Two distribution networks were developed at the bus bars *2* and *4* [*32-34*]. The distribution network at the bus *3* of the *R.B.T.S* represents a typical industrial and large user distribution system with a peak load of *85MW*. Bus *3* has industrial, large users, office buildings, residential and commercial customers. The distribution network at the bus *5* represents a typical urban type network consisting of residential, government and industrial, office building, and commercial customers. The peak load of the distribution system at bus *5* is *20 MW*. The distribution network at bus *6* is a typical rural network with agricultural, small industrial, commercial and residential customers. The peak load of this network is *20 MW*. The distribution networks at buses *2, 3*, *4* *5* and *6* are shown in Figures *(2.2-6)*.

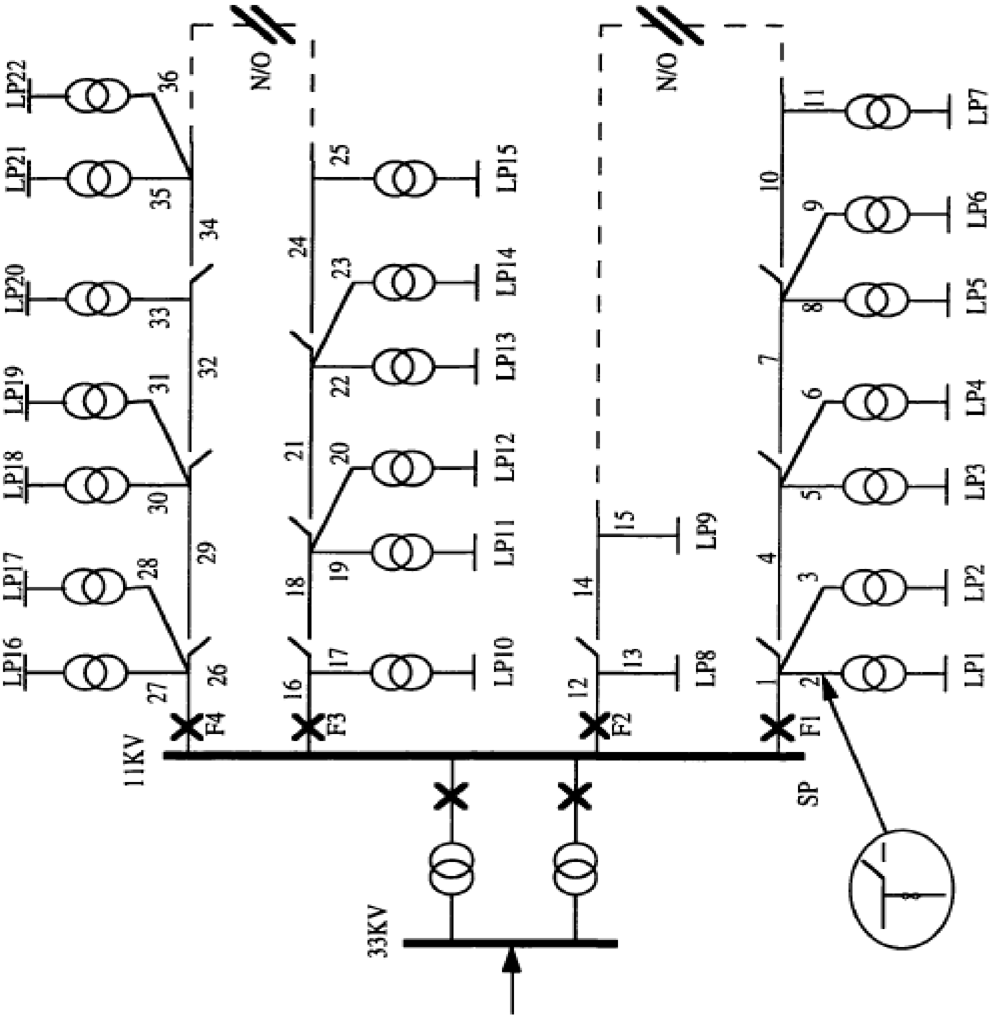

Figure *2.2*: Distribution network at bus *2*: *R.B.T.S*

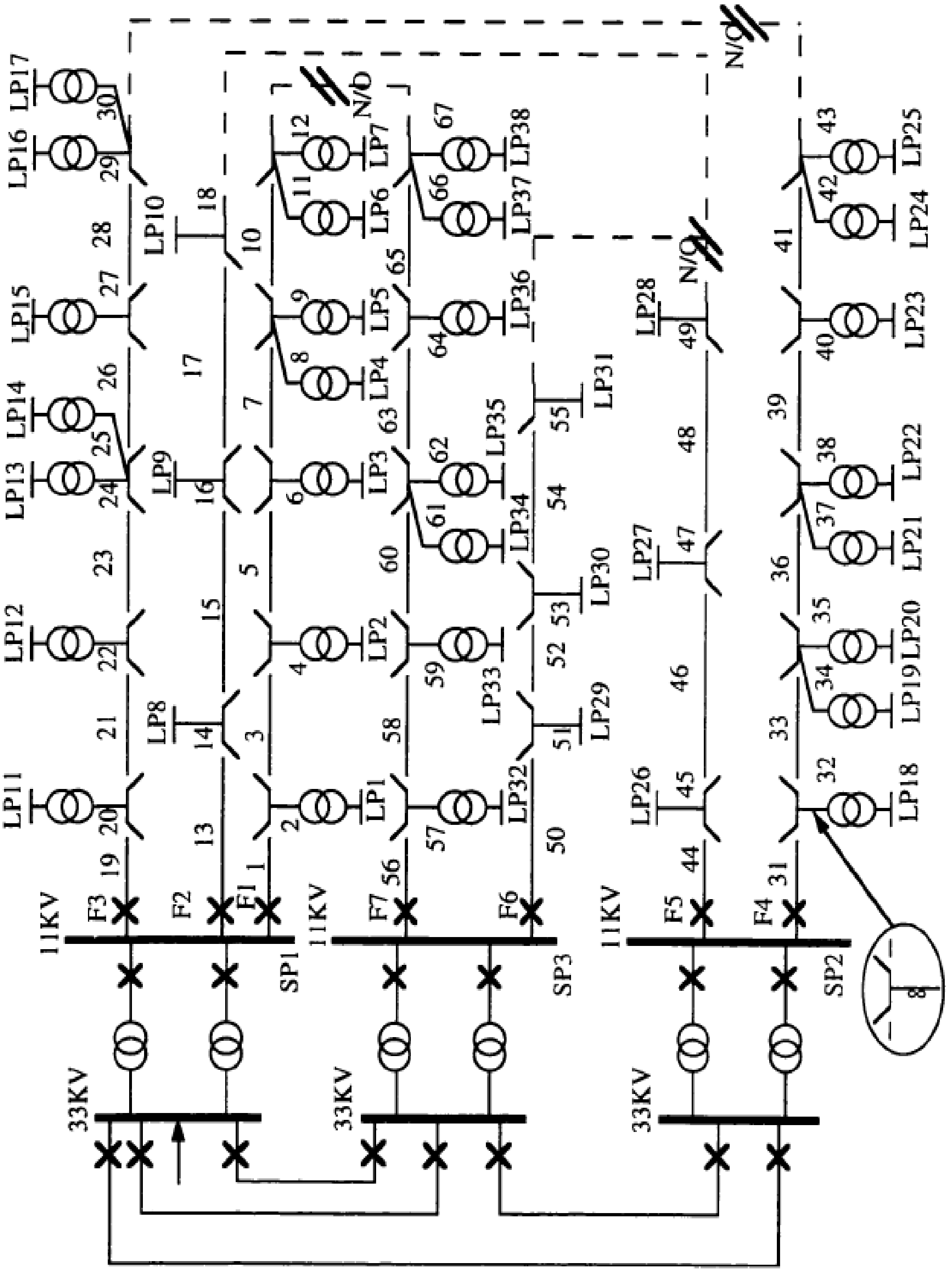

Figure *2.3*: Distribution network at bus *4*: *R.B.T.S*

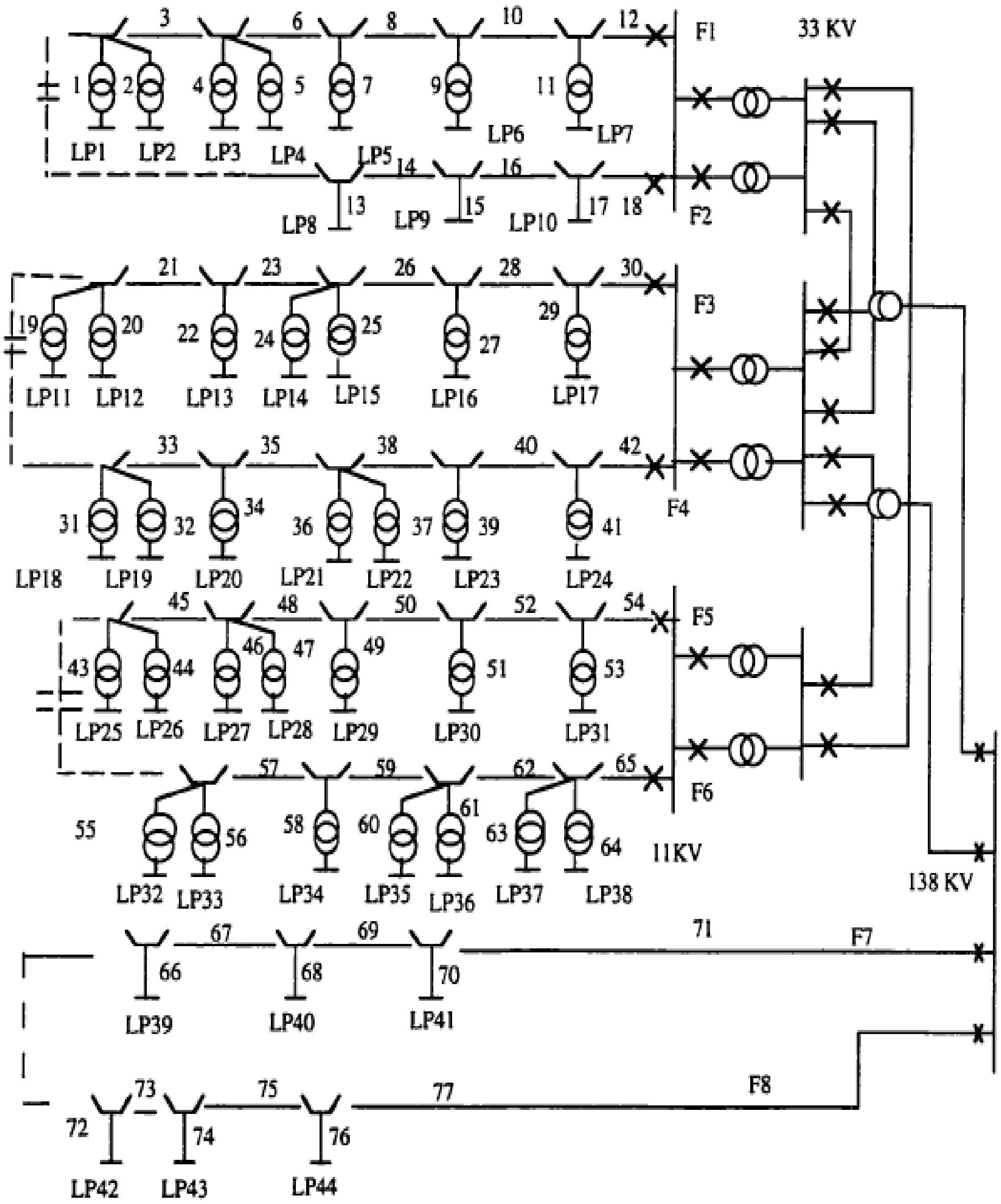

Figure *2.4.*: Distribution system at bus *3*: *R.B.T.S*

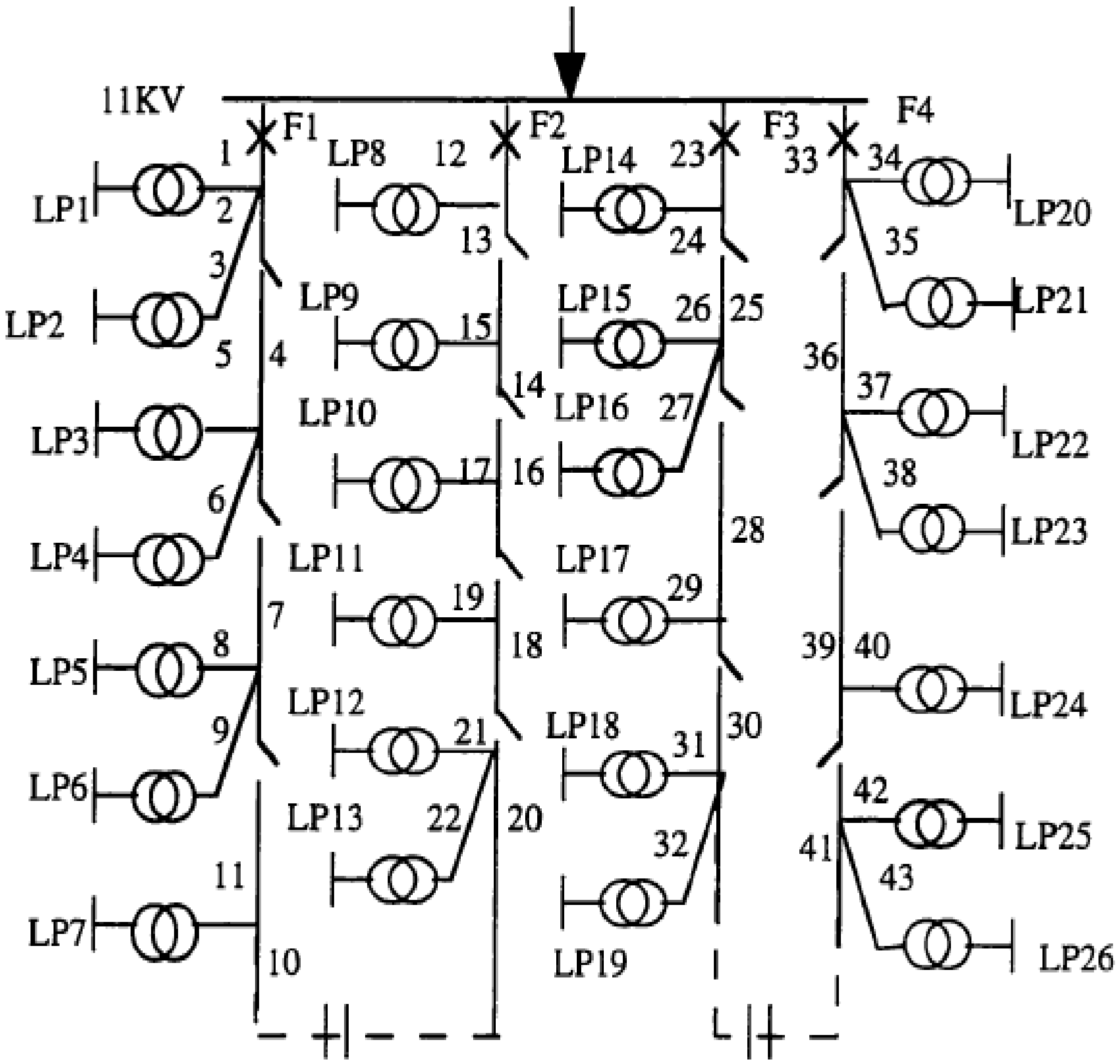

Figure ***2.5.***: Distribution system at bus *5*: *R.B.T.S*

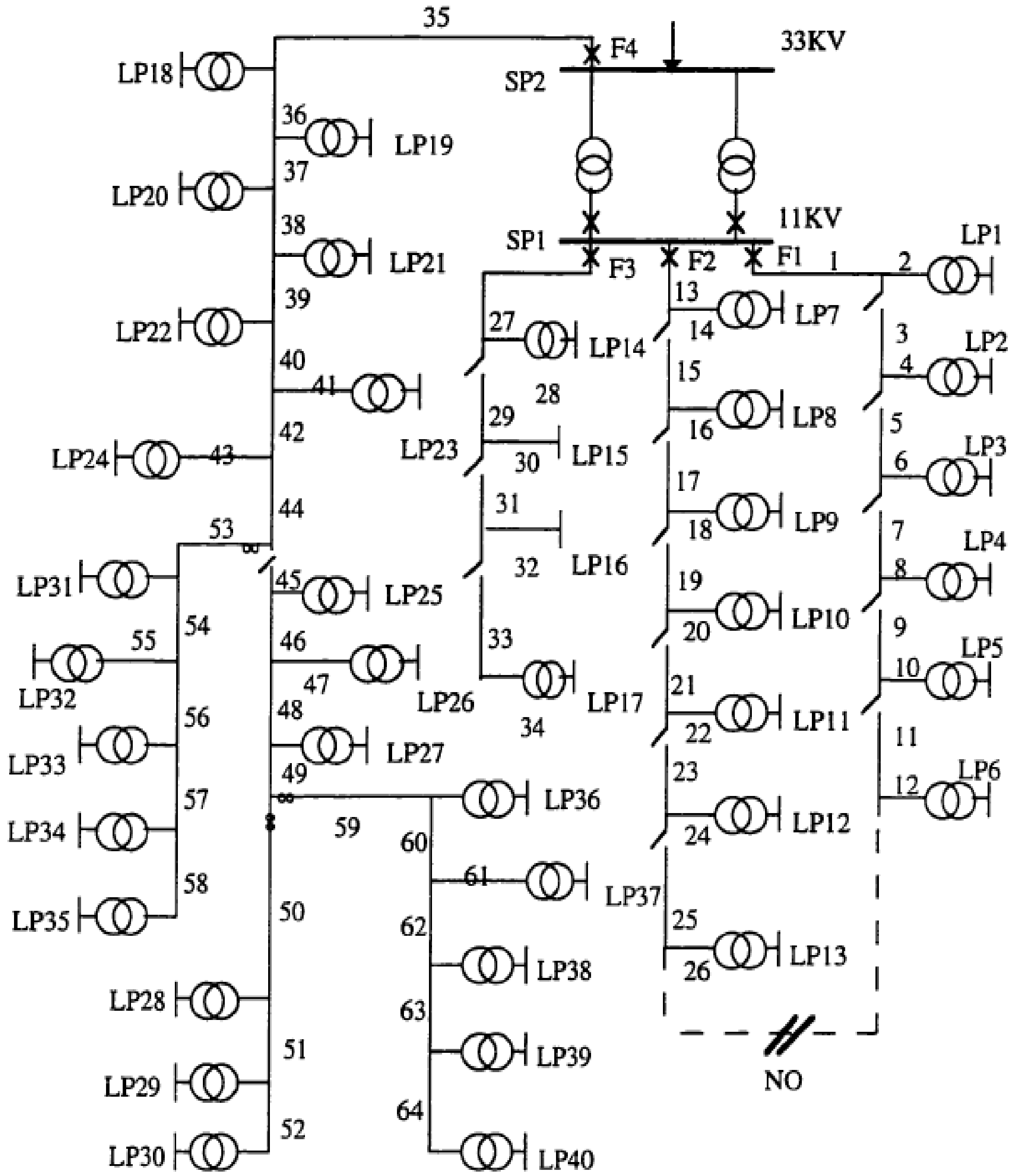

Figure *2.6.*: Distribution system at bus *6*: *R.B.T.S*

2.4.2 Customer data for the R.B.T.S

The customer data of the network shown in figure *2.1* at buses *3, 5,* and *6* are given in Tables *2.8*, *2.9* and *2.10*. The details of feeder data at buses *3*, *5* and *6* are given in Tables *2.11, 2.12* and *2.13*. The lengths of the feeder sections are presented in Table *2.14*. The design of the distribution networks for bus *3, 5,* and *6* of the *R.B.T.S* follow general utility principals and practices regarding topology, component ratings and loading levels [*1*].

TABLE 2.8

Customer Data For The R.B.T.S Bus 3

NUMBER OF LOAD POINTS	LOAD POINTS	CUSTOMER TYPE	NUMBER OF CUSTOMERS
15	*1,4-7,20,24,32,36.*	*Residential*	*250*
5	*11,12,13,18,25.*	*Residential*	*230*
4	*2,15,26,30.*	*Residential*	*190*
3	*39,40,44.*	*Large Users*	*1*
3	*41-43.*	*Large Users*	*1*
3	*8,9,10.*	*Small Industrial*	*1*
9	*3,16,17,19,28,29,31,37,38.*	*Commercial*	*15*
2	*14,27.*	*Office And Buildings*	*1*
		TOTAL	***5806***

TABLE 2.9

Customer Data For The R.B.T.S Bus 5			
Number of Load Points	*Load Points*	*Customer Type*	*Number of Customers*
4	1-2,20,21	Residential	210
4	4,6,15,25	Residential	240
5	26,9-11,13	Residential	195
5	3,5,8,17,23	Government and Inst	1
5	7,14,18,22,24	Commercial	15
3	12,16,19	Office Buildings	1
		Total	**2858**

TABLE 2.10

Customer Data For The R.B.T.S Bus 6			
Number of Load Points	*Load Points*	*Customer Type*	*Number of Customers*
3	1,3,9.	Residential	138
4	1,4,11,19.	Residential	126
2	5,6.	Residential	118
5	7,8,10,18,23.	Residential	147
3	12,13,22.	Residential	132
4	25,28,31,36.	Residential	79
4	27,29,33,39.	Residential	76
2	14,17.	Commercial	10
1	15.	Small	1
1	16.	Small	1
2	32,37.	Farm	1
3	20,30,34.	Farm	1
2	21,35.	Farm	1
2	24,40.	Farm	1
2	26,38.	Farm	1
		Total	**2938**

TABLE 2.11

FEEDER DATA FOR THE R.B.T.S BUS 3		
FEEDER NUMBER	LOAD POINTS	NUMBER OF CUSTOMERS
F1	1-7.	1455
F2	8-10.	3
F3	11-17.	681
F4	18-24.	1495
F5	25-31.	656
F6	32-38.	1280
F7	39-41.	3
F8	42-44.	3
	TOTAL	5806

TABLE 2.12

FEEDER DATA FOR THE R.B.T.S BUS 5		
FEEDER NUMBER	LOAD POINTS	NUMBER OF CUSTOMERS
F1	1-7.	917
F2	8-13.	782
F3	14-19	273
F4	20-26.	886
	TOTAL	2858

TABLE 2.13

FEEDER DATA FOR THE R.B.T.S BUS 6		
FEEDER NUMBER	LOAD POINTS	NUMBER OF CUSTOMERS
F1	1-6.	764
F2	7-13.	969
F3	14-17.	22
F4	18-40.	1183
	TOTAL	2938

TABLE 2.14

FEEDER TYPES AND LENGTH FOR THE R.B.T.S

Feeder Type	Length (Km)	Feeder Section Numbers
Bus 3		
1	0.6	1 2 3 7 11 12 15 21 22 29 30 31 36 40 42 43 48 49 50 56 58 61 64 67 70 72 76.
2	0.8	4 8 9 13 16 19 20 25 26 32 35 37 41 46 47 51 53 57 60 62 65 68 71 75 77.
3	0.9	5 6 10 14 17 18 23 24 27 28 33 34 38 39 44 45 52 54 55 59 63 66 69 73 74.
Bus 5		
1	0.5	1 6 9 13 14 18 21 25 27 31 35 36 39 42.
2	0.65	4 7 8 12 15 16 19 22 26 28 30 33 37 40.
3	0.8	2 3 5 10 11 17 20 23 24 29 32 34 38 41 43.
Bus 6		
1	0.6	2 3 8 9 12 13 17 19 20 24 25 28 31 34 41 47.
2	0.75	1 5 6 7 10 14 15 22 23 26 27 30 33 43 61.
3	0.8	4 11 16 18 21 29 32 35 55.
4	0.9	38 44.
5	1.6	37 39 42 49 54 62.
6	2.5	36 40 52 57 60.
7	2.8	35 46 50 56 59 64.
8	3.2	45 51 53 58 63.
9	3.5	48.

Table 2.15

Component Reliability Data For The R.B.T.S Distribution system

Component Type	Failure Rate(f/yr-km)	Repair Time (hr)	Switch Op-Time (hr)
Transformers			
33/11 Kv	0.015	--	1.0
LV	0.015	200	1.0
Breakers			
33 Kv	0.002	4.0	1.0
11 Kv	0.006	4.0	1.0
Bus Bars			
33 Kv	0.001	2.0	1.0
11 Kv	0.001	2.0	1.0
Lines			
33 Kv	0.046	8.0	2.0

11 Kv	*0.065*	*5.0*	*1.0*

The Following comments relate to the design of distribution networks at buses *3*,*5*and *6*:

- All feeders are operated as radial feeders but some are connected as a mesh through normally open sectionalizing points. Following an outage on feeder, the topology permits the sectionalizing points to be moved and customers to be supplied from alternative supply points.
- The main and lateral sections of the radial feeders utilize overhead lines.
- Disconnects, fuses, alternative supply and transformer repair are utilized for the reliability analysis of the radial feeders at all the buses.
- The fuse gear and disconnects in the radial feeders are assumed to be *100%* reliable.
- The alternative supply and the distributed generator are assumed to be *100%* available for all studies on the *R.B.T.S* i.e. the concept of expectation is not used in this research.
- Large users at bus *3* are supplied from bulk power supply points, *i.e.*, *138 Kv*.

The failure rates and repair durations of the various distribution components such as transformers, breakers, bus bars, and feeder sections follow the same data as presented in [*29*].

2.4.3. Distribution system reliability indices

Segment indices for segments at buses *2-6* are represented in Tables (*2.16)-(2.20)*. On one hand segment indices include segment load point failure rate and segment load point repair time *(Seg_LP_FR, Seg_LP_REP),* i.e. the failure and repair rates of the load connected to this segment, segment annual down time *(Seg_DTs)* and relative costumer average interruption duration index *(Rel_CAIDI)*. On the other hand, system indices include *SAIDI* and *CAIDI*; these indices provide a relative measure for a group of load points attached to a certain segment or for the entire distribution system. In these tables, the indices are evaluated for two cases one with *DG* and the other without *DG* (Base case) interconnected to the system showing how the reliability is improved by use of distributed resources as shown in the tables (*2.16)-(2.20)*. Note that, indices for the feeders *6* and *7* of bus *3* and feeder *4* of bus *6* were not set because of data unavailability.

From the results obtained, it can be seen that there is a patent improvement in reliability indices viewing the contribution of distributed generators for the research purpose, this reliability enhancement can be remarked for both segment and system indices i.e. *Seg_DTs*, *Rel_CAIDI*, *SAIDI*, *Sys_CAIDI*.

Concerning the first segment index *(Seg_DTs)*, it is screened on the tables that the failure rates of all the segments do not change, that the indices of the two or three first segment closer to the original source do not change because load transfer cannot recover any load lost and to bring the system to the no violated state, and that the greatest effect occurs for the segments furthest from the original supply point and nearest to the *DG* interconnection point.

A propos the results related to the *Relative_CAIDI* index, it was defined as an indicator for reliability improvement need for a certain segment or load point, it is clear on the tables and for the total results, that it is always greater than *1* before and after the *DG* interconnection giving the information of no need of reliability improvement which means that all segments do not require a step up of reliability, which is not completely true, the justification is, the concept related to the present theory applied here *(i.e. the reliability analysis sets was based on modeling the system in terms of segments and not in terms of components)*. So in this way, groups of component are processed without processing the intermediate components, but at least this index gives as a right significance, by having a relative sense with respect to the whole system and not to see if it is greater or less than one. It can be seen that, for the segments or load points farthest from the source have *Relative_CAIDI* less than those are closer to the source, also it is clear on the tables that using the *DG* intervention, this index is enhanced compared with the latest i.e. those segments closer to the source, and this is apparent by comparing the results before and after the *DG* intervention.

TABLES 2.16

Application To Roy Billinton Test System						
Bus 2/Feeder:1 Of The RBTS						
Without DG (Base case)						
Segment_Name	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**Rel_CAIDI**	**SAIDI**	**Sys_CAIDI**
SW1	0.25625	1.4107	0.3615	34.202	3.677	12.364
SW3	0.31025	11.463	3.5565	3.4765		
SW6	0.25625	14.002	3.588	3.446		
SW9	0.25625	2.2668	0.58088	21.285		
SW11	0.32325	11.882	3.8409	3.2191		
SW14	0.31025	12.17	3.7759	3.2745		
SW17	0.25625	3.1229	0.80025	15.45		
SW19	0.32325	12.561	4.0602	3.0452		
SW22	0.32	12.638	4.044	3.0574		
SW25	0.25625	3.8078	0.97575	12.671		
SW27	0.32325	13.104	4.2358	2.919		
Bus 2/Feeder:1 Of The RBTS						
With DG						
Segment_Name	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**Rel_CAIDI**	**SAIDI**	**Sys_CAIDI**
SW1	0.25625	1.4107	0.3615	33.333	3.584	12.05
SW3	0.31025	11.463	3.5565	3.3881		
SW6	0.25625	14.002	3.588	3.3584		
SW9	0.25625	1.3561	0.3475	34.676		
SW11	0.32325	11.16	3.6075	3.3402		
SW14	0.31025	11.418	3.5425	3.4015		
SW17	0.25625	1.3561	0.3475	34.676		
SW19	0.32325	11.16	3.6075	3.3402		
SW22	0.32	11.223	3.5912	3.3553		
SW25	0.25625	1.1849	0.30363	39.686		
SW27	0.32325	11.024	3.5636	3.3813		

Bus 2/Feeder:2 Of The RBTS						
Without DG (Base case)						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.09175*	*3.0436*	*0.27925*	*15.619*	*0.627*	*4.3617*
SW3	*0.14375*	*3.7513*	*0.53925*	*8.0885*		
SW5	*0.09175*	*4.9564*	*0.45475*	*9.5915*		
SW7	*0.14375*	*4.9722*	*0.71475*	*6.1025*		

Bus 2/Feeder:2 Of The RBTS						
With DG						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.09175*	*3.0436*	*0.27925*	*12.713*	*0.51*	*3.55*
SW3	*0.14375*	*3.7513*	*0.53925*	*6.5832*		
SW5	*0.09175*	*2.4128*	*0.22138*	*16.036*		
SW7	*0.14375*	*3.3487*	*0.48138*	*7.3747*		

Bus 2/Feeder:3 Of The RBTS						
Without DG (Base case)						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.1925*	*1.7123*	*0.32963*	*44.506*	*3.725*	*14.67*
SW3	*0.2465*	*14.299*	*3.5246*	*4.1622*		
SW6	*0.1925*	*2.9279*	*0.56363*	*26.028*		
SW8	*0.25625*	*14.858*	*3.8074*	*3.8531*		
SW11	*0.2595*	*14.735*	*3.8236*	*3.8367*		
SW14	*0.1925*	*3.8396*	*0.73913*	*19.848*		
SW16	*0.25625*	*15.543*	*3.9829*	*3.6833*		
SW19	*0.2595*	*15.411*	*3.9991*	*3.6684*		
SW22	*0.1925*	*4.9792*	*0.9585*	*15.305*		
SW24	*0.2465*	*16.85*	*4.1535*	*3.532*		

Bus 2/Feeder:3 Of The RBTS

With DG						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.1925*	*1.7123*	*0.32963*	*42.558*	*3.562*	*14.028*
SW3	*0.2465*	*14.299*	*3.5246*	*3.98*		
SW6	*0.1925*	*1.7156*	*0.33025*	*42.477*		
SW8	*0.25625*	*13.947*	*3.574*	*3.925*		
SW11	*0.2595*	*13.835*	*3.5903*	*3.9073*		
SW14	*0.1925*	*1.4117*	*0.27175*	*51.621*		
SW16	*0.25625*	*13.719*	*3.5155*	*3.9903*		
SW19	*0.2595*	*13.61*	*3.5318*	*3.972*		
SW22	*0.1925*	*1.6396*	*0.31563*	*44.445*		
SW24	*0.2465*	*14.242*	*3.5106*	*3.9959*		

Bus 2/Feeder:4 Of The RBTS

Without DG (Base case)						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.1925*	*1.7883*	*0.34425*	*42.978*	*3.715*	*14.795*
SW3	*0.25625*	*14.002*	*3.588*	*4.1235*		
SW6	*0.2465*	*14.358*	*3.5393*	*4.1803*		
SW9	*0.1925*	*2.9279*	*0.56363*	*26.25*		
SW11	*0.2465*	*15.248*	*3.7586*	*3.9363*		
SW14	*0.2595*	*14.735*	*3.8236*	*3.8694*		
SW17	*0.1925*	*4.0675*	*0.783*	*18.895*		
SW19	*0.2595*	*15.58*	*4.043*	*3.6595*		
SW22	*0.1925*	*4.9792*	*0.9585*	*15.436*		
SW24	*0.25625*	*16.399*	*4.2023*	*3.5208*		
SW27	*0.2595*	*16.256*	*4.2185*	*3.5072*		

Bus 2/Feeder:4 Of The RBTS

With DG						
Segment_Name	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***Rel_CAIDI***	***SAIDI***	***Sys_CAIDI***
SW1	*0.1925*	*1.7883*	*0.34425*	*40.984*	*3.542*	*14.109*
SW3	*0.25625*	*14.002*	*3.588*	*3.9322*		
SW6	*0.2465*	*14.358*	*3.5393*	*3.9863*		
SW9	*0.1925*	*1.6396*	*0.31563*	*44.701*		
SW11	*0.2465*	*14.242*	*3.5106*	*4.0188*		
SW14	*0.2595*	*13.779*	*3.5756*	*3.9458*		
SW17	*0.1925*	*1.6396*	*0.31563*	*44.701*		
SW19	*0.2595*	*13.779*	*3.5756*	*3.9458*		
SW22	*0.1925*	*1.4117*	*0.27175*	*51.918*		
SW24	*0.25625*	*13.719*	*3.5155*	*4.0133*		
SW27	*0.2595*	*13.61*	*3.5318*	*3.9948*		

Application To Roy Billinton Test System

Bus 3/Feeder:1 Of The RBTS							
Without DG (Base case)							
LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.251	1.255	0.315	41.796	4.091	13.166
	SW3	0.251	1.255	0.315	41.796		
LP1	SW4	0.305	11.508	3.51	3.7509		
	SW7	0.251	2.3038	0.57825	22.768		
	SW9	0.251	2.3038	0.57825	22.768		
LP2	SW10	0.318	12.07	3.8383	3.4301		
	SW13	0.251	3.2361	0.81225	16.209		
	SW15	0.251	3.2361	0.81225	16.209		
LP3	SW16	0.305	13.139	4.0073	3.2855		
	SW19	0.251	4.2849	1.0755	12.241		
	SW21	0.251	4.2849	1.0755	12.241		
LP4	SW22	0.3245	13.461	4.368	3.0141		
LP5	SW25	0.318	13.634	4.3355	3.0367		
	SW28	0.251	4.9841	1.251	10.524		
	SW30	0.251	4.9841	1.251	10.524		
LP6	SW31	0.305	14.577	4.446	2.9612		
LP7	SW34	0.305	14.577	4.446	2.9612		

Bus 3/Feeder:1 Of The RBTS							
With DG							
LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.251	1.255	0.315	34.218	3.349	10.779
	SW3	0.251	0.5	0.1255	85.885		
LP1	SW4	0.305	10.887	3.3205	3.2461		
	SW7	0.251	1.5488	0.38875	27.726		
	SW9	0.251	0.5	0.1255	85.885		
LP2	SW10	0.318	10.646	3.3855	3.1837		
	SW13	0.251	1.4323	0.3595	29.982		
	SW15	0.251	0.5	0.1255	85.885		
LP3	SW16	0.305	10.887	3.3205	3.2461		
	SW19	0.251	1.5488	0.38875	27.726		
	SW21	0.251	0.5	0.1255	85.885		
LP4	SW22	0.3245	10.533	3.418	3.1535		
LP5	SW25	0.318	10.646	3.3855	3.1837		
	SW28	0.251	1.1992	0.301	35.809		
	SW30	0.251	0.5	0.1255	85.885		
LP6	SW31	0.305	10.887	3.3205	3.2461		
LP7	SW34	0.305	10.887	3.3205	3.2461		

Bus 3/Feeder:2 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	*0.173*	*2.1026*	*0.36375*	*10.569*	*0.857*	*3.8444*
	SW3	*0.173*	*2.1026*	*0.36375*	*10.569*		
LP8	*SW4*	*0.2315*	*2.8348*	*0.65625*	*5.8582*		
	SW6	*0.173*	*3.4552*	*0.59775*	*6.4315*		
	SW8	*0.173*	*3.4552*	*0.59775*	*6.4315*		
LP9	*SW9*	*0.212*	*3.7394*	*0.79275*	*4.8495*		
	SW11	*0.173*	*4.9769*	*0.861*	*4.4651*		
	SW13	*0.173*	*4.9769*	*0.861*	*4.4651*		
LP10	*SW14*	*0.225*	*4.9822*	*1.121*	*3.4295*		

Bus 3/Feeder:2 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	*0.173*	*2.1026*	*0.36375*	*4.1412*	*0.336*	*1.5064*
	SW3	*0.173*	*0.5*	*0.0865*	*17.415*		
LP8	*SW4*	*0.2315*	*1.6371*	*0.379*	*3.9746*		
	SW6	*0.173*	*1.8526*	*0.3205*	*4.7*		
	SW8	*0.173*	*0.5*	*0.0865*	*17.415*		
LP9	*SW9*	*0.212*	*1.3278*	*0.2815*	*5.3512*		
	SW11	*0.173*	*2.0217*	*0.34975*	*4.307*		
	SW13	*0.173*	*0.5*	*0.0865*	*17.415*		
LP10	*SW14*	*0.225*	*1.54*	*0.3465*	*4.3474*		

Bus 3/Feeder:3 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	*0.251*	*1.255*	*0.315*	*43.704*	*4.331*	*13.767*
	SW3	*0.251*	*1.255*	*0.315*	*43.704*		
LP11	*SW4*	*0.305*	*11.508*	*3.51*	*3.9222*		
	SW7	*0.251*	*2.3038*	*0.57825*	*23.808*		
	SW9	*0.251*	*2.3038*	*0.57825*	*23.808*		
LP12	*SW10*	*0.3245*	*11.928*	*3.8708*	*3.5566*		
	SW13	*0.251*	*3.2361*	*0.81225*	*16.949*		
	SW15	*0.251*	*3.2361*	*0.81225*	*16.949*		
LP13	*SW16*	*0.318*	*12.806*	*4.0723*	*3.3807*		
LP14	*SW19*	*0.3245*	*12.649*	*4.1048*	*3.3539*		
	SW22	*0.251*	*4.2849*	*1.0755*	*12.8*		
	SW24	*0.251*	*4.2849*	*1.0755*	*12.8*		
LP15	*SW25*	*0.305*	*14.002*	*4.2705*	*3.2237*		
	SW28	*0.251*	*4.9841*	*1.251*	*11.005*		
	SW30	*0.251*	*4.9841*	*1.251*	*11.005*		
LP16	*SW31*	*0.318*	*14.186*	*4.511*	*3.0518*		
LP17	*SW34*	*0.318*	*14.186*	*4.511*	*3.0518*		

Bus 3/Feeder:3 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.251	1.255	0.315	33.99	3.369	10.707
	SW3	0.251	0.5	0.1255	85.314		
LP11	SW4	0.305	10.887	3.3205	3.2245		
	SW7	0.251	1.5488	0.38875	27.542		
	SW9	0.251	0.5	0.1255	85.314		
LP12	SW10	0.3245	10.533	3.418	3.1325		
	SW13	0.251	1.4323	0.3595	29.783		
	SW15	0.251	0.5	0.1255	85.314		
LP13	SW16	0.318	10.646	3.3855	3.1626		
LP14	SW19	0.3245	10.533	3.418	3.1325		
	SW22	0.251	1.5488	0.38875	27.542		
	SW24	0.251	0.5	0.1255	85.314		
LP15	SW25	0.305	10.887	3.3205	3.2245		
	SW28	0.251	1.1992	0.301	35.571		
	SW30	0.251	0.5	0.1255	85.314		
LP16	SW31	0.318	10.646	3.3855	3.1626		
LP17	SW34	0.318	10.646	3.3855	3.1626		

Bus 3/Feeder:4 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.251	1.255	0.315	40.255	4.007	12.68
	SW3	0.251	1.255	0.315	40.255		
LP18	SW4	0.318	11.242	3.575	3.5469		
	SW7	0.251	1.9542	0.4905	25.852		
	SW9	0.251	1.9542	0.4905	25.852		
LP19	SW10	0.3245	11.658	3.783	3.3519		
	SW13	0.251	3.003	0.75375	16.823		
	SW15	0.251	3.003	0.75375	16.823		
LP20	SW16	0.318	12.622	4.0137	3.1592		
LP21	SW19	0.305	12.947	3.9488	3.2112		
	SW22	0.251	3.9353	0.98775	12.838		
	SW24	0.251	3.9353	0.98775	12.838		
LP22	SW25	0.3245	13.19	4.2803	2.9625		
	SW28	0.251	4.9841	1.251	10.136		
	SW30	0.251	4.9841	1.251	10.136		
LP23	SW31	0.318	14.186	4.511	2.811		
LP24	SW34	0.305	14.577	4.446	2.8521		

Bus 3/Feeder:4 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.251	1.255	0.315	33.911	3.376	10.682
	SW3	0.251	0.5	0.1255	85.115		
LP18	SW4	0.318	10.646	3.3855	3.1552		
	SW7	0.251	1.1992	0.301	35.488		
	SW9	0.251	0.5	0.1255	85.115		
LP19	SW10	0.3245	10.533	3.418	3.1252		
	SW13	0.251	1.5488	0.38875	27.478		
	SW15	0.251	0.5	0.1255	85.115		

LP20	SW16	0.318	10.646	3.3855	3.1552		
LP21	SW19	0.305	10.887	3.3205	3.217		
	SW22	0.251	1.4323	0.3595	29.713		
	SW24	0.251	0.5	0.1255	85.115		
LP22	SW25	0.3245	10.533	3.418	3.1252		
	SW28	0.251	1.5488	0.38875	27.478		
	SW30	0.251	0.5	0.1255	85.115		
LP23	SW31	0.318	10.646	3.3855	3.1552		
LP24	SW34	0.305	10.887	3.3205	3.217		

Bus 3/Feeder:5 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2575	1.5767	0.406	33.049	4.314	13.418
	SW3	0.2575	1.5767	0.406	33.049		
LP25	SW4	0.3245	11.297	3.666	3.6601		
	SW7	0.2575	2.599	0.66925	20.049		
	SW9	0.2575	2.599	0.66925	20.049		
LP26	SW10	0.3245	12.109	3.9293	3.4149		
	SW13	0.2575	3.2806	0.84475	15.884		
	SW15	0.2575	3.2806	0.84475	15.884		
LP27	SW16	0.3115	12.969	4.0397	3.3215		
	SW19	0.2575	3.9621	1.0203	13.152		
	SW21	0.2575	3.9621	1.0203	13.152		
LP28	SW22	0.3245	13.19	4.2803	3.1348		
LP29	SW25	0.3245	13.19	4.2803	3.1348		
	SW28	0.2575	4.9845	1.2835	10.454		
	SW30	0.2575	4.9845	1.2835	10.454		
LP30	SW31	0.331	13.825	4.576	2.9322		
LP31	SW34	0.3115	14.377	4.4785	2.9961		

Bus 3/Feeder:5 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2575	1.5767	0.406	25.846	3.374	10.493
	SW3	0.2575	0.5	0.12875	81.501		
LP25	SW4	0.3245	10.443	3.3888	3.0965		
	SW7	0.2575	1.5223	0.392	26.769		
	SW9	0.2575	0.5	0.12875	81.501		
LP26	SW10	0.3245	10.443	3.3888	3.0965		
	SW13	0.2575	1.1816	0.30425	34.489		
	SW15	0.2575	0.5	0.12875	81.501		
LP27	SW16	0.3115	10.67	3.3238	3.1571		
	SW19	0.2575	1.1816	0.30425	34.489		
	SW21	0.2575	0.5	0.12875	81.501		
LP28	SW22	0.3245	10.443	3.3888	3.0965		
LP29	SW25	0.3245	10.443	3.3888	3.0965		
	SW28	0.2575	1.5223	0.392	26.769		
	SW30	0.2575	0.5	0.12875	81.501		
LP30	SW31	0.331	10.336	3.4213	3.0671		
LP31	SW34	0.3115	10.67	3.3238	3.1571		

Bus 3/Feeder:6 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2185	1.635	0.35725	40.715	4.059	14.545
	SW3	0.2185	1.635	0.35725	40.715		
LP32	SW4	0.2725	13.036	3.5522	4.0947		
LP33	SW7	0.292	12.499	3.6498	3.9853		
	SW10	0.2185	2.7059	0.59125	24.601		
	SW12	0.2185	2.7059	0.59125	24.601		
LP34	SW13	0.2725	13.894	3.7862	3.8417		
LP35	SW16	0.2855	13.489	3.8513	3.7768		
	SW19	0.2185	3.9108	0.8545	17.022		
	SW21	0.2185	3.9108	0.8545	17.022		
LP36	SW22	0.2725	14.861	4.0495	3.5919		
	SW25	0.2185	4.9817	1.0885	13.363		
	SW27	0.2185	4.9817	1.0885	13.363		
LP37	SW28	0.2725	15.719	4.2835	3.3957		
LP38	SW31	0.292	15.003	4.381	3.3201		

Bus 3/Feeder:6 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2185	1.635	0.35725	33.472	3.337	11.958
	SW3	0.2185	0.5	0.10925	109.45		
LP32	SW4	0.2725	12.126	3.3042	3.6189		
LP33	SW7	0.292	11.65	3.4017	3.5152		
	SW10	0.2185	1.5709	0.34325	34.837		
	SW12	0.2185	0.5	0.10925	109.45		
LP34	SW13	0.2725	12.126	3.3042	3.6189		
LP35	SW16	0.2855	11.801	3.3693	3.5491		
	SW19	0.2185	1.7048	0.3725	32.101		
	SW21	0.2185	0.5	0.10925	109.45		
LP36	SW22	0.2725	12.126	3.3042	3.6189		
	SW25	0.2185	1.5709	0.34325	34.837		
	SW27	0.2185	0.5	0.10925	109.45		
LP37	SW28	0.2725	12.126	3.3042	3.6189		
LP38	SW31	0.292	11.65	3.4017	3.5152		

TABLES 2.18

Application To Roy Billinton Test System

Bus 4/Feeder:1 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2445	1.4545	0.35563	36.891	4.0018	13.119
	SW3	0.2445	1.4545	0.35563	36.891		
LP1	SW4	0.2985	11.895	3.5506	3.695		
	SW7	0.2445	2.4116	0.58963	22.25		
	SW9	0.2445	2.4116	0.58963	22.25		
LP2	SW10	0.30825	12.436	3.8334	3.4224		
	SW13	0.2445	3.3686	0.82363	15.929		
	SW15	0.2445	3.3686	0.82363	15.929		
LP3	SW16	0.2985	13.463	4.0186	3.2647		
	SW19	0.2445	4.2658	1.043	12.579		
	SW21	0.2445	4.2658	1.043	12.579		
LP4	SW22	0.3115	13.814	4.303	3.0489		
LP5	SW25	0.30825	13.907	4.2867	3.0605		
	SW28	0.2445	4.9836	1.2185	10.767		
	SW30	0.2445	4.9836	1.2185	10.767		
LP6	SW31	0.3115	14.377	4.4785	2.9294		
LP7	SW34	0.30825	14.476	4.4623	2.9401		

Bus 4/Feeder:1 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2445	1.4545	0.35563	30.881	3.3499	10.982
	SW3	0.2445	0.5	0.12225	89.834		
LP1	SW4	0.2985	11.113	3.3173	3.3106		
	SW7	0.2445	1.4571	0.35625	30.827		
	SW9	0.2445	0.5	0.12225	89.834		
LP2	SW10	0.30825	10.92	3.366	3.2627		
	SW13	0.2445	1.4571	0.35625	30.827		
	SW15	0.2445	0.5	0.12225	89.834		
LP3	SW16	0.2985	11.113	3.3173	3.3106		
	SW19	0.2445	1.3972	0.34163	32.147		
	SW21	0.2445	0.5	0.12225	89.834		
LP4	SW22	0.3115	10.858	3.3823	3.247		
LP5	SW25	0.30825	10.92	3.366	3.2627		
	SW28	0.2445	1.2178	0.29775	36.884		
	SW30	0.2445	0.5	0.12225	89.834		
LP6	SW31	0.3115	10.858	3.3823	3.247		
LP7	SW34	0.30825	10.92	3.366	3.2627		

Bus 4/Feeder:2 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.147	2.1871	0.3215	12.355	0.76892	3.972
	SW3	0.147	2.1871	0.3215	12.355		
LP8	SW4	0.186	2.7769	0.5165	7.6903		
	SW6	0.147	3.7789	0.5555	7.1503		
	SW8	0.147	3.7789	0.5555	7.1503		
LP9	SW9	0.19575	4.083	0.79925	4.9697		
	SW11	0.147	4.9728	0.731	5.4337		
	SW13	0.147	4.9728	0.731	5.4337		
LP10	SW14	0.199	4.9799	0.991	4.0081		

Bus 4/Feeder:2 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.147	2.1871	0.3215	4.9234	0.30642	1.5829
	SW3	0.147	0.5	0.0735	21.536		
LP8	SW4	0.186	1.4435	0.2685	5.8952		
	SW6	0.147	2.0918	0.3075	5.1475		
	SW8	0.147	0.5	0.0735	21.536		
LP9	SW9	0.19575	1.6207	0.31725	4.9893		
	SW11	0.147	1.6939	0.249	6.3569		
	SW13	0.147	0.5	0.0735	21.536		
LP10	SW14	0.199	1.6759	0.3335	4.7462		

Bus 4/Feeder:3 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.23475	1.4941	0.35075	37.574	3.9177	13.179
	SW3	0.23475	1.4941	0.35075	37.574		
LP11	SW4	0.30175	11.966	3.6108	3.6499		
	SW7	0.23475	2.2417	0.52625	25.043		
	SW9	0.23475	2.2417	0.52625	25.043		
LP12	SW10	0.2985	12.63	3.77	3.4957		
	SW13	0.23475	3.2386	0.76025	17.335		
	SW15	0.23475	3.2386	0.76025	17.335		
LP13	SW16	0.2985	13.414	4.004	3.2915		
LP14	SW19	0.28875	13.698	3.9552	3.332		
	SW22	0.23475	4.2354	0.99425	13.255		
	SW24	0.23475	4.2354	0.99425	13.255		
LP15	SW25	0.2985	14.198	4.238	3.1097		
	SW28	0.23475	4.983	1.1698	11.266		
	SW30	0.23475	4.983	1.1698	11.266		
LP16	SW31	0.2985	14.786	4.4135	2.9861		
LP17	SW34	0.28875	15.116	4.3647	3.0194		

Bus 4/Feeder:3 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.23475	1.4941	0.35075	32.177	3.355	11.286
	SW3	0.23475	0.5	0.11737	96.154		
LP11	SW4	0.30175	11.193	3.3774	3.3417		
	SW7	0.23475	1.2476	0.29288	38.535		
	SW9	0.23475	0.5	0.11737	96.154		
LP12	SW10	0.2985	11.26	3.3611	3.3578		
	SW13	0.23475	1.4968	0.35137	32.12		
	SW15	0.23475	0.5	0.11737	96.154		
LP13	SW16	0.2985	11.26	3.3611	3.3578		
LP14	SW19	0.28875	11.471	3.3124	3.4072		
	SW22	0.23475	1.4968	0.35137	32.12		
	SW24	0.23475	0.5	0.11737	96.154		
LP15	SW25	0.2985	11.26	3.3611	3.3578		
	SW28	0.23475	1.2476	0.29288	38.535		
	SW30	0.23475	0.5	0.11737	96.154		
LP16	SW31	0.2985	11.26	3.3611	3.3578		
LP17	SW34	0.28875	11.471	3.3124	3.4072		

Bus 4/Feeder:4 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.251	1.488	0.3735	33.974	3.953	12.689
	SW3	0.251	1.488	0.3735	33.974		
LP18	SW4	0.31475	11.492	3.6173	3.508		
	SW7	0.251	2.4203	0.6075	20.888		
	SW9	0.251	2.4203	0.6075	20.888		
LP19	SW10	0.305	12.467	3.8025	3.3371		
LP20	SW13	0.31475	12.236	3.8512	3.2948		
	SW16	0.251	3.3526	0.8415	15.079		
	SW18	0.251	3.3526	0.8415	15.079		
LP21	SW19	0.31475	12.979	4.0852	3.1061		
LP22	SW22	0.305	13.234	4.0365	3.1436		
	SW25	0.251	4.2849	1.0755	11.798		
	SW27	0.251	4.2849	1.0755	11.798		
LP23	SW28	0.31475	13.723	4.3192	2.9378		
	SW31	0.251	4.9841	1.251	10.143		
	SW33	0.251	4.9841	1.251	10.143		
LP24	SW34	0.31475	14.28	4.4947	2.8231		
LP25	SW37	0.305	14.577	4.446	2.8541		

Bus 4/Feeder:4 Of The RBTS							
With DG							
LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.251	1.488	0.3735	28.818	3.3531	10.764
	SW3	0.251	0.5	0.1255	85.766		
LP18	SW4	0.31475	10.705	3.3693	3.1947		
	SW7	0.251	1.4323	0.3595	29.94		
	SW9	0.251	0.5	0.1255	85.766		
LP19	SW10	0.305	10.887	3.3205	3.2416		
LP20	SW13	0.31475	10.705	3.3693	3.1947		
	SW16	0.251	1.4323	0.3595	29.94		
	SW18	0.251	0.5	0.1255	85.766		
LP21	SW19	0.31475	10.705	3.3693	3.1947		
LP22	SW22	0.305	10.887	3.3205	3.2416		
	SW25	0.251	1.4323	0.3595	29.94		
	SW27	0.251	0.5	0.1255	85.766		
LP23	SW28	0.31475	10.705	3.3693	3.1947		
	SW31	0.251	1.1992	0.301	35.759		
	SW33	0.251	0.5	0.1255	85.766		
LP24	SW34	0.31475	10.705	3.3693	3.1947		
LP25	SW37	0.305	10.887	3.3205	3.2416		

Bus 4/Feeder:5 Of The RBTS							
Without DG (Base case)							
	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.14375	2.2252	0.31988	12.202	0.74292	3.9032
LP26	SW3	0.14375	2.2252	0.31988	12.202		
	SW4	0.1925	2.9279	0.56363	6.9252		
	SW6	0.14375	3.4461	0.49538	7.8794		
LP27	SW8	0.14375	3.4461	0.49538	7.8794		
	SW9	0.19575	3.8589	0.75538	5.1673		
	SW11	0.14375	4.9722	0.71475	5.461		
LP28	SW13	0.14375	4.9722	0.71475	5.461		
	SW14	0.18275	4.9781	0.90975	4.2905		

Bus 4/Feeder:5 Of The RBTS							
With DG							
	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.14375	2.2252	0.31988	5.0062	0.30479	1.6014
LP26	SW3	0.14375	0.5	0.071875	22.28		
	SW4	0.1925	1.6396	0.31563	5.0736		
	SW6	0.14375	1.7209	0.24738	6.4734		
LP27	SW8	0.14375	0.5	0.071875	22.28		
	SW9	0.19575	1.6954	0.33188	4.8252		
	SW11	0.14375	2.0261	0.29125	5.4982		
LP28	SW13	0.14375	0.5	0.071875	22.28		
	SW14	0.18275	1.4603	0.26687	6.0004		

Bus 4/Feeder:6 Of The RBTS							
Without DG (Base case)							
LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.15675	1.9888	0.31175	12.202	0.757	3.804
	SW3	0.15675	1.9888	0.31175	12.202		
LP29	SW4	0.19575	2.5888	0.50675	7.5067		
	SW6	0.15675	3.4817	0.54575	6.9703		
	SW8	0.15675	3.4817	0.54575	6.9703		
LP30	SW9	0.2055	3.8418	0.7895	4.8183		
	SW11	0.15675	4.9745	0.77975	4.8785		
	SW13	0.15675	4.9745	0.77975	4.8785		
LP31	SW14	0.19575	4.9796	0.97475	3.9026		

Bus 4/Feeder:6 Of The RBTS							
With DG							
LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.15675	1.9888	0.31175	4.6685	0.28963	1.4554
	SW3	0.15675	0.5	0.078375	18.57		
LP29	SW4	0.19575	1.3966	0.27338	5.3238		
	SW6	0.15675	1.9928	0.31238	4.6592		
	SW8	0.15675	0.5	0.078375	18.57		
LP30	SW9	0.2055	1.5675	0.32212	4.5181		
	SW11	0.15675	1.9928	0.31238	4.6592		
	SW13	0.15675	0.5	0.078375	18.57		
LP31	SW14	0.19575	1.3966	0.27338	5.3238		

Bus 4/Feeder:7 Of The RBTS							
Without DG (Base case)							
LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.238	1.4806	0.35238	37.625	3.9863	13.258
	SW3	0.238	1.4806	0.35238	37.625		
LP32	SW4	0.305	11.844	3.6124	3.6702		
	SW7	0.238	2.218	0.52788	25.116		
	SW9	0.238	2.218	0.52788	25.116		
LP33	SW10	0.305	12.419	3.7879	3.5001		
	SW13	0.238	3.1397	0.74725	17.742		
	SW15	0.238	3.1397	0.74725	17.742		
LP34	SW16	0.292	13.501	3.9423	3.3631		
LP35	SW19	0.305	13.139	4.0073	3.3085		
	SW22	0.238	4.0614	0.96663	13.716		
	SW24	0.238	4.0614	0.96663	13.716		
LP36	SW25	0.292	14.252	4.1616	3.1858		
	SW28	0.238	4.9832	1.186	11.179		
	SW30	0.238	4.9832	1.186	11.179		
LP37	SW31	0.305	14.577	4.446	2.982		
LP38	SW34	0.292	15.003	4.381	3.0263		

			Bus 4/Feeder:7 Of The RBTS				
			With DG				
LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	*0.238*	*1.4806*	*0.35238*	*31.689*	*3.3573*	*11.166*
	SW3	*0.238*	*0.5*	*0.119*	*93.834*		
LP32	*SW4*	*0.305*	*11.079*	*3.379*	*3.3046*		
	SW7	*0.238*	*1.2374*	*0.2945*	*37.916*		
	SW9	*0.238*	*0.5*	*0.119*	*93.834*		
LP33	*SW10*	*0.305*	*11.079*	*3.379*	*3.3046*		
	SW13	*0.238*	*1.4217*	*0.33838*	*33*		
	SW15	*0.238*	*0.5*	*0.119*	*93.834*		
LP34	*SW16*	*0.292*	*11.349*	*3.314*	*3.3694*		
LP35	*SW19*	*0.305*	*11.079*	*3.379*	*3.3046*		
	SW22	*0.238*	*1.4217*	*0.33838*	*33*		
	SW24	*0.238*	*0.5*	*0.119*	*93.834*		
LP36	*SW25*	*0.292*	*11.349*	*3.314*	*3.3694*		
	SW28	*0.238*	*1.4217*	*0.33838*	*33*		
	SW30	*0.238*	*0.5*	*0.119*	*93.834*		
LP37	*SW31*	*0.305*	*11.079*	*3.379*	*3.3046*		
LP38	*SW34*	*0.292*	*11.349*	*3.314*	*3.3694*		

TABLES 2.19

Application To Roy Billinton Test System

Bus 5/Feeder:1 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.173	1.4263	0.24675	63.769	3.6156	15.735
LP1	SW3	0.24	14.611	3.5068	4.487		
LP2	SW6	0.24	14.611	3.5068	4.487		
	SW9	0.173	2.5253	0.43688	36.017		
LP3	SW11	0.24	15.404	3.6969	4.2563		
LP4	SW14	0.2205	16.324	3.5994	4.3716		
	SW17	0.173	3.6243	0.627	25.096		
LP5	SW19	0.23025	16.67	3.8382	4.0995		
LP6	SW22	0.2205	17.186	3.7895	4.1522		
	SW25	0.173	4.9769	0.861	18.275		
LP7	SW27	0.24	17.171	4.121	3.8182		

Bus 5/Feeder:1 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.173	1.4263	0.24675	61.246	3.4726	15.112
LP1	SW3	0.24	14.611	3.5068	4.3095		
LP2	SW6	0.24	14.611	3.5068	4.3095		
	SW9	0.173	1.599	0.27663	54.632		
LP3	SW11	0.24	14.736	3.5366	4.2731		
LP4	SW14	0.2205	15.597	3.4391	4.3943		
	SW17	0.173	1.599	0.27663	54.632		
LP5	SW19	0.23025	15.148	3.4879	4.3329		
LP6	SW22	0.2205	15.597	3.4391	4.3943		
	SW25	0.173	1.8526	0.3205	47.153		
LP7	SW27	0.24	14.919	3.5805	4.2208		

Bus 5/Feeder:2 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.2055	1.4933	0.30688	43.078	3.5053	13.22
LP8	SW3	0.253	13.713	3.4694	3.8104		
	SW6	0.2055	1.2117	0.249	53.091		
LP9	SW8	0.26275	13.169	3.4603	3.8204		
	SW11	0.2055	1.4252	0.29288	45.138		
LP10	SW13	0.2725	13.038	3.5529	3.7208		
	SW16	0.2055	1.2117	0.249	53.091		
LP11	SW18	0.26275	13.169	3.4603	3.8204		
	SW21	0.2055	1.6387	0.33675	39.257		
LP12	SW23	0.253	13.831	3.4993	3.7779		
LP13	SW26	0.26275	13.503	3.548	3.726		

Bus 5/Feeder:2 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.2055	1.4933	0.30688	43.078	3.5053	13.22
LP8	SW3	0.253	13.713	3.4694	3.8104		
	SW6	0.2055	1.2117	0.249	53.091		
LP9	SW8	0.26275	13.169	3.4603	3.8204		
	SW11	0.2055	1.4252	0.29288	45.138		
LP10	SW13	0.2725	13.038	3.5529	3.7208		
	SW16	0.2055	1.2117	0.249	53.091		
LP11	SW18	0.26275	13.169	3.4603	3.8204		
	SW21	0.2055	1.6387	0.33675	39.257		
LP12	SW23	0.253	13.831	3.4993	3.7779		
LP13	SW26	0.26275	13.503	3.548	3.726		

Bus 5/Feeder:3 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.173	1.9335	0.3345	48.125	3.7071	16.098
LP14	SW3	0.24	14.977	3.5945	4.4785		
	SW6	0.173	2.7789	0.48075	33.485		
LP15	SW8	0.23025	16.035	3.692	4.3602		
LP16	SW11	0.2205	16.523	3.6433	4.4186		
	SW14	0.173	3.8779	0.67088	23.995		
LP17	SW16	0.24	16.379	3.9309	4.0953		
	SW19	0.173	4.9769	0.861	18.697		
LP18	SW21	0.2205	18.247	4.0235	4.001		
LP19	SW24	0.24	17.171	4.121	3.9063		

Bus 5/Feeder:3 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.173	1.9335	0.3345	44.82	3.4525	14.992
LP14	SW3	0.24	14.977	3.5945	4.1709		
	SW6	0.173	1.3454	0.23275	64.414		
LP15	SW8	0.23025	14.958	3.444	4.3532		
LP16	SW11	0.2205	15.398	3.3953	4.4157		
	SW14	0.173	1.599	0.27663	54.197		
LP17	SW16	0.24	14.736	3.5366	4.2391		
	SW19	0.173	1.599	0.27663	54.197		
LP18	SW21	0.2205	15.597	3.4391	4.3593		
LP19	SW24	0.24	14.736	3.5366	4.2391		

Bus 5/Feeder:4 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.16325	1.7504	0.28575	59.817	3.7607	17.093
LP20	SW3	0.23025	15.4	3.5458	4.8206		
LP21	SW6	0.21075	16.362	3.4483	4.9569		
	SW9	0.16325	2.6462	0.432	39.566		
LP22	SW11	0.2205	16.523	3.6433	4.6916		
LP23	SW14	0.23025	16.035	3.692	4.6297		
	SW17	0.16325	3.5421	0.57825	29.559		
LP24	SW19	0.2205	17.186	3.7895	4.5105		
	SW22	0.16325	4.9755	0.81225	21.044		
LP25	SW24	0.21075	18.86	3.9748	4.3003		
LP26	SW27	0.23025	17.686	4.0723	4.1974		

Bus 5/Feeder:4 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.16325	1.7504	0.28575	55.786	3.5072	15.941
LP20	SW3	0.23025	15.4	3.5458	4.4957		
LP21	SW6	0.21075	16.362	3.4483	4.6229		
	SW9	0.16325	1.3959	0.22787	69.954		
LP22	SW11	0.2205	15.597	3.4391	4.6351		
LP23	SW14	0.23025	15.148	3.4879	4.5703		
	SW17	0.16325	1.3959	0.22787	69.954		
LP24	SW19	0.2205	15.597	3.4391	4.6351		
	SW22	0.16325	1.9334	0.31562	50.505		
LP25	SW24	0.21075	16.504	3.4781	4.5832		
LP26	SW27	0.23025	15.529	3.5756	4.4582		

TABLES 2.20

Application To Roy Billinton Test System

Bus 6/Feeder:1 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.28025	1.3327	0.3735	32.139	4.0772	12.004
LP1	SW3	0.33425	10.676	3.5685	3.3638		
	SW6	0.28025	1.959	0.549	21.865		
LP2	SW8	0.34725	10.969	3.809	3.1514		
	SW11	0.28025	2.7417	0.76838	15.622		
LP3	SW13	0.344	11.663	4.0121	2.9919		
	SW16	0.28025	3.5245	0.98775	12.153		
LP4	SW18	0.33425	12.514	4.1827	2.8698		
	SW21	0.28025	4.1508	1.1633	10.319		
LP5	SW23	0.344	12.811	4.407	2.7238		
	SW26	0.28025	4.9857	1.3973	8.591		
LP6	SW28	0.33425	13.739	4.5922	2.6139		

Bus 6/Feeder:1 Of The RBTS

With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.28025	1.3327	0.3735	28.159	3.5723	10.517
LP1	SW3	0.33425	10.676	3.5685	2.9473		
	SW6	0.28025	1.1262	0.31562	33.322		
LP2	SW8	0.34725	10.297	3.5756	2.9414		
	SW11	0.28025	1.2828	0.3595	29.255		
LP3	SW13	0.344	10.475	3.6032	2.9188		
	SW16	0.28025	1.2828	0.3595	29.255		
LP4	SW18	0.33425	10.634	3.5545	2.9589		
	SW21	0.28025	1.1262	0.31563	33.322		
LP5	SW23	0.344	10.347	3.5594	2.9548		
	SW26	0.28025	1.335	0.37413	28.112		
LP6	SW28	0.33425	10.678	3.5691	2.9468		

Bus 6/Feeder:2 Of The RBTS

Without DG (Base case)

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	Rel_CAIDI	SAIDI	Sys_CAIDI
	SW1	0.3095	1.1123	0.34425	32.554	4.1622	11.207
LP7	SW3	0.37325	9.6129	3.588	3.1234		
	SW6	0.3095	1.8211	0.56363	19.883		
LP8	SW8	0.3765	10.156	3.8236	2.9309		
	SW11	0.3095	2.3881	0.73913	15.162		
LP9	SW13	0.3765	10.622	3.9991	2.8023		
	SW16	0.3095	2.9552	0.91463	12.253		
LP10	SW18	0.3635	11.306	4.1096	2.727		
	SW21	0.3095	3.7112	1.1486	9.7567		
LP11	SW23	0.37325	11.768	4.3924	2.5514		
	SW26	0.3095	4.42	1.368	8.1921		
LP12	SW28	0.3635	12.553	4.563	2.456		
	SW31	0.3095	4.9871	1.5435	7.2607		
LP13	SW33	0.37325	12.826	4.7873	2.341		

Bus 6/Feeder:2 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.3095	1.1123	0.34425	28.056	3.5871	9.6584
LP7	SW3	0.37325	9.6129	3.588	2.6919		
	SW6	0.3095	1.2088	0.37413	25.816		
LP8	SW8	0.3765	9.6524	3.6341	2.6577		
	SW11	0.3095	1.067	0.33025	29.246		
LP9	SW13	0.3765	9.5359	3.5903	2.6902		
	SW16	0.3095	1.067	0.33025	29.246		
LP10	SW18	0.3635	9.6981	3.5252	2.7398		
	SW21	0.3095	1.2561	0.38875	24.845		
LP11	SW23	0.37325	9.7321	3.6325	2.6589		
	SW26	0.3095	1.2088	0.37413	25.816		
LP12	SW28	0.3635	9.8188	3.5691	2.7061		
	SW31	0.3095	1.067	0.33025	29.246		
LP13	SW33	0.37325	9.5754	3.574	2.7024		

Bus 6/Feeder:3 Of The RBTS

Without DG (Base case)

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.1925	1.7123	0.32963	44.023	3.5722	14.511
LP14	SW3	0.2465	14.299	3.5246	4.117		
	SW6	0.1925	2.9279	0.56363	25.746		
LP15	SW8	0.24125	3.3466	0.80738	17.973		
	SW10	0.1925	3.8396	0.73913	19.633		
LP16	SW12	0.2445	4.0864	0.99913	14.524		
	SW14	0.1925	4.9792	0.9585	15.139		
LP17	SW16	0.2465	16.85	4.1535	3.4937		

Bus 6/Feeder:3 Of The RBTS

With DG

LP Nbr	*Segment_Name*	*Seg_LP_FR*	*Seg_LP_REP*	*Seg_DTs*	*Rel_CAIDI*	*SAIDI*	*Sys_CAIDI*
	SW1	0.1925	1.7123	0.32963	40.029	3.2481	13.195
LP14	SW3	0.2465	14.299	3.5246	3.7435		
	SW6	0.1925	1.7156	0.33025	39.953		
LP15	SW8	0.24125	2.3793	0.574	22.987		
	SW10	0.1925	1.4117	0.27175	48.554		
LP16	SW12	0.2445	2.1748	0.53175	24.813		
	SW14	0.1925	1.6396	0.31563	41.804		
LP17	SW16	0.2465	14.242	3.5106	3.7585		

2.5. Summary

This chapter here presents the application of the entire theories and techniques described and discussed in the previous chapter. The test system of Roy Billinton *(R.B.T.S)* used throughout this thesis is described in this chapter. The test system used throughout this thesis to illustrate the basic concepts and procedures involved in the overall power system reliability analysis. The concepts outlined in chapter 1 are utilized in this chapter to predict the reliability indices for overall power system.

The reliability indices for the Roy Billinton test system *(R.B.T.S)* are found calculated. The results for the *HLII* level are screened out on tables *2.3-7*. The distribution system reliability indices for the distribution system are screened out on tables *2.16-20*. These results calculated in this chapter are utilized for the overall power system reliability assessment in chapter 4, after considering the effects of all the hierarchical levels on each other.

Chapter 3

A DATA GENERATOR FOR DISTRIBUTION SYSTEM RELIABILITY EVALUATION

3.1. Introduction

This section is devoted to the development of a data generator for calculating (mainly) the reliability, load flow, the static and dynamic stability of electrical grid network; and other constraints that may affect it, namely, short-circuit and lightning. Draw up of this generator is based on the theory of programming called "oriented objects" which is a software program using a definite bottom-up design like "messages" exchanged by called basic entities objects; this theory, which makes the behavior of an object, describes how this one changes state with the reception of messages of other objects and how it transmits itself the messages to the other objects.

After having traced the necessary diagram, this data generator permits to obtain automatically all information on each object (bus, lines, transformers, etc) necessary for calculating and analyzing different events happening in a grid network; this “graphical” information is collected in the forms of matrix. The studied case, in this section, has twenty seven information on each object.

Object-oriented programming (OOP) is a programming paradigm that uses "objects" – data structures consisting of data fields and methods together with their interactions – to design applications and computer programs. Programming techniques may include features such as information hiding, data abstraction, encapsulation, modularity, polymorphism, and inheritance.

The object-oriented modeling has four main components: abstraction, encapsulation, modularity and hierarchy. Without this conceptual framework, the program is not object-oriented even though the language is object-oriented programming

Object Oriented Analysis (OOA) aims at understanding the system that must grow and develop a logic model of the system. This model is based on natural objects from the application domain. These objects contain data and have their own behavior from which one can express the behavior of the entire system [48].

The need to model power systems to simulate the operation probably goes back to the origins of electrical networks themselves. The first simulators were analogue simulators where scale models of networks could help to predict or know the system behavior.

They have to cover certain needs such as development or test equipment control and protection works.

Many analogue simulators of this generation, operating in real time are always used. Today, there is growing talk of digital simulators.

The problems that the software's of electrical networks must solve, often involve highly complex components which hide a multitude of requirements.

Today, electric power network are increasingly complex. The first ask is about perfectly, and on line, covering the loads power demands. In parallel, the control of functioning disrupted systems and the design of protection safe and selective contribute to increase this complexity [49].

So, functioning of electric power network is already difficult to define, yet we must add requirements (non functional) such as ease of use and maintainability of its software. The complexity of the problem itself causes so complex software with real time constraint.

The complexity of software usually comes from how users and developers see things. The experts of electrical networks are finding it hard to provide a precise expression of their needs in a form that developers (computers scientist) can include. This misunderstanding is not due to either users or developers, but rather the fact that it is a multidisciplinary filed (electrical and computer science) and each one of them is lacking competence in the other field. In addition, this complexity is increased by the fact that software specifications often change during development. Therefore, according to the literature, a vast majority of power system software are developed by people in electrical power systems themselves [8].

3.2. Object-oriented methods used

The method used is that proposed by James Rumbaugh and Michael Blaha, called Object Modeling Technique (OMT) applies to all processes of software development, from analysis to implementation. This method uses three different views, each one of them is capturing important aspects of software, and these three views are:

- The object model that represents the static aspect of software (definitions of classes, inheritance relationships, aggregation ...).
- The dynamic model shows the behaviour of software over time.
- The functional model that takes into account the aspect function transformation of software.

Each model contains references to entities of other models, so they are not completely independent. The proposed methodology is independent of programming languages and uses a standard graphical notation for all phases [50].

The three models separate a system into a set of views that are manipulated and evolve throughout the development cycle (analysis, design and implementation for OMT).

Objects are considered basic components that must capture the elements of reality that the analyst considers important for an application.

The dynamic model describes the temporal aspects, workflows and events that cause state changes within a class. The role of the dynamic model is to present different aspects of control system. This is reflected in the graphical notation by state diagrams and sequence of events.

The functional model describes the changes made by the system on the functions made, and this without worrying about how this is done or when it occurs. The functional model is represented with diagrams of data streams. It shows the dependencies between input and output of this process responsible for carrying out specific functions of the software.

The OMT method seems fairly comprehensive to approach a wide class of problems.

3.3. General structure of the developed tool

To reap the benefits of TOO (Theory Oriented Object), an object-oriented modeling according to OMT was developed for designing software components involved in the development process. The strategy for design of electrical power system simulators has led to four major parts, (see Figure 3.1). The main parts are:

1. A graphical editor is specially developed to visualize the single line diagrams of electrical networks with windows of dialog boxes. It uses graphic symbols to represent elements of the power system such as bus, transmission lines, loads, generators...
2. A visual database is developed for the user to make entering and editing data in a flexible screen. The data are related the single-line diagram and applications to execute
3. Applications that simulate the operation of an electrical network, applications being made in this tool are the generator matrix of data and calculation of reliability.

All parts are developed using Microsoft Visual Studio 2008 version 9.0 with the programming language *C++*. The material used is an Intel *PC IV*.

To implement the functionality of the GUI, tools are developed using two hierarchies of objects, one derived from the TForm object in Microsoft Visual Studio 2008 to represent the windows themselves and the other derived object TGraphicControl Microsoft Visual Studio 2008 to represent the graphical elements on the windows.

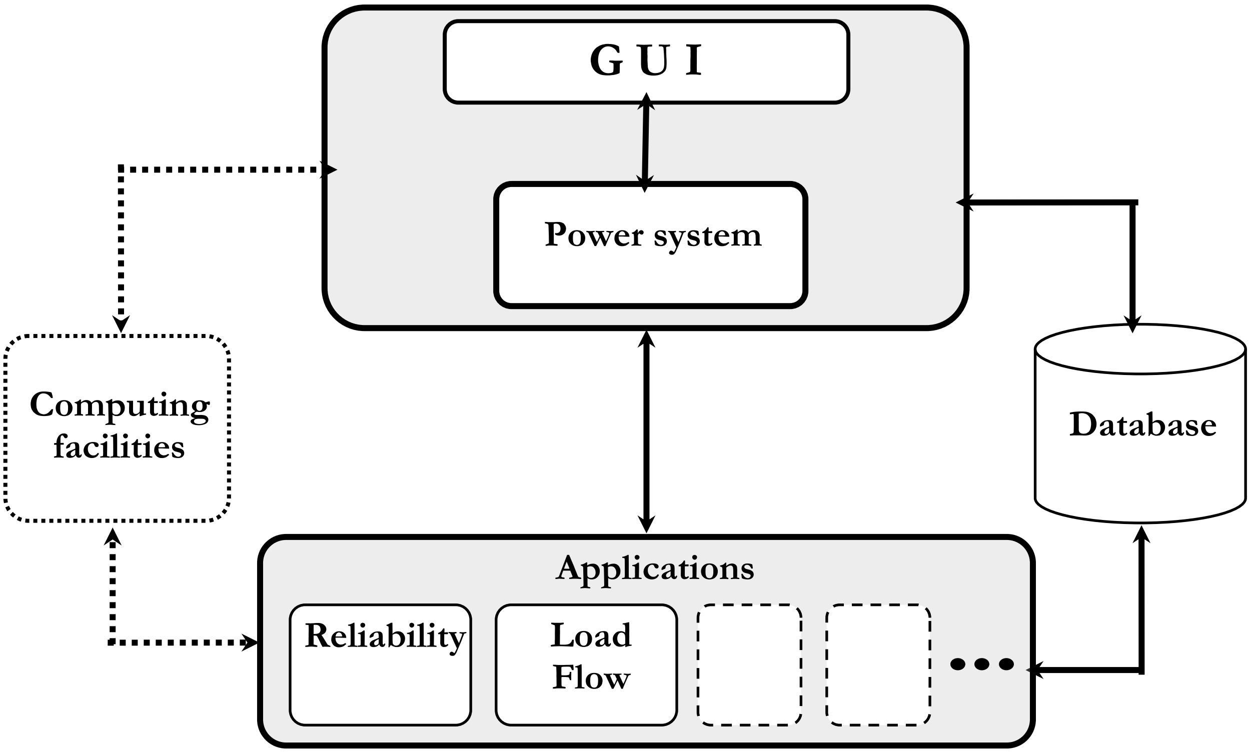

Figure 3.1 **General Structure**

3.4. Principle of operation of the data generator

The operation of our data generator has been designed in the most flexible way, after opening a new page in the graphical editor that looks good to different publishers known in the literature; it contains 21 tabs as can be seen in Figure 3.2.

Figure 3.2. **General Structure of the toolbar and commands of the publisher.**

In the new page we can easily draw any electrical network pattern, either, high medium or low voltage. Once the scheme is realized, we must initialize the end of the line to know the main branch, which allows us subsequently to know the addresses of other branches.

In Figure 3.3, we present a scheme of radial network at high voltage (Un = 60kV), where the load represents the end of the line.

Figure 3.3 **Classical radial network, L = 80 km et Un = 60kV.**

The program is launched by a simple click on the Startup tab, and then the necessary response to the data collection is almost instantaneous, this collection is composed of three very important results from which one can calculate any processes involved in the network. The results obtained by the program are:

- The numbering of all elements and their connections to our network.
- The transfer of the numbers into an array containing all the information about each element of the network (27 information for each network element).
- The transformation of this array of different matrices that are used as data generator of our electrical network.

3.5. Study and analysis of the obtained result

Let us start with the first results obtained by the program and that is the numbering of all elements and their connections in the existing network to explore, we will use the radial network above.

Figure 3.4 **Traditional radial network, numbered, L = 80 km and Un = 60kV**

One can see in Figure 3.4 that the pattern, and after launching the program, has been numbered from 1 to 19 which is equivalent to 10 elements plus 9 links. To be clear, we summarize the results in the table below:

Table 3.1 **Summary**

Network Elements	**Connections between elements**
1: Power station (Source)	2 : Connection between source 1 and Disconnector 3
3: Disconnector	4 : Connection between Disconnector 3 and Breaker 5
5: Breaker	6 : Connection between Breaker 5 and Transformer 7
7: Transformer	8 : Connection between Transformer 7 and Disconnector 9
9: Disconnector	10 : Connection between Disconnector 9 and Disconnector 11 (Transmission line)
11: Disconnector	12: Connection between Disconnector11 and Breaker13.
13: Breaker	14: Connection between Breaker 13 and Transformer 15.
15: Transformer	16: Connection between Transformer 15 and Disconnector 17.
17: Disconnector	18: Connection between Disconnector 17 and the load 19 (Consumer).
19: Load (point)	

After this numbering, the program transforms it into a large table of data with more precision and detail. This table is divided into 5 small tables which contain 19 elements with their details as they are shown below.

Table 3.2 (Element before the considered one)

Résultats

N° Elem	Elem Avant 1	Elem Avant 2	Elem Avant 3	Elem Avant 4	Elem Avant 5
1	0	0	0	0	0
2	1	0	0	0	0
3	2	0	0	0	0
4	3	0	0	0	0
5	4	0	0	0	0
6	5	0	0	0	0
7	6	0	0	0	0
8	7	0	0	0	0
9	8	0	0	0	0
10	9	0	0	0	0
11	10	0	0	0	0
12	11	0	0	0	0
13	12	0	0	0	0
14	13	0	0	0	0
15	14	0	0	0	0
16	15	0	0	0	0
17	16	0	0	0	0
18	17	0	0	0	0
19	18	0	0	0	0

Consider in Table 3.2 “Elem. Avant x” as the element before the x element.

The first column contains the number of each item and the numbers of linking elements, the columns from 1 to 5 contain each element above. For example, line 4 reads as follows: the element 4 has three elements before it, which are the elements *1*, *2* and *3*, see table *2*.

Table 3.3 **(Element after the considered one)**

Elem Apres 1	Elem Apres 2	Elem Apres 3	Elem Apres 4	Elem Apres 5	Type Elem
2	0	0	0	0	1
3	0	0	0	0	13
4	0	0	0	0	12
5	0	0	0	0	13
6	0	0	0	0	10
7	0	0	0	0	13
8	0	0	0	0	3
9	0	0	0	0	13
10	0	0	0	0	12
11	0	0	0	0	13
12	0	0	0	0	12
13	0	0	0	0	13
14	0	0	0	0	10
15	0	0	0	0	13
16	0	0	0	0	3
17	0	0	0	0	13
18	0	0	0	0	12
19	0	0	0	0	13
0	0	0	0	0	5

Consider in Table 3.3 “Elem. Apres x” as the element after the x element.

The columns from 1 to 5 contain each of the next elements and column 6 contains the number type of element (Disconnector, bus, batteries ...) see below:

Table 3.4 type of element

Element	***Number type***
Generator	*1*
Transformer	*3*
Connection	*13*
Breaker	*10*
Disconnector	*12*
Fuse	*11*
Load	*5*
Compensator	*2*
Emergency source	*4*

Table 3.5 **(Probability of failure according to the branch and source)**

Num Branche	Source Sec...	Def/An
0	0	0,01
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,001
0	0	0,01
0	0	0,0001

The 1st column contains the number of branch, the 2nd contains the number of emergency source and the 3rd contains the probability of failure of the element per year [51,52].

Table 3.6 **(Security elements that comes before)**

SwishCom	Elem Sec Av1	Elem Sec Av2	Elem Sec Av3	Elem Sec Av4	Elem Sec Av5
0	0	0	0	0	0
0	0	0	0	0	0
3	0	0	0	0	0
3	3	0	0	0	0
5	0	0	0	0	0
5	5	0	0	0	0
5	0	0	0	0	0
5	0	0	0	0	0
9	0	0	0	0	0
9	9	0	0	0	0
11	0	0	0	0	0
11	11	0	0	0	0
13	0	0	0	0	0
13	13	0	0	0	0
13	0	0	0	0	0
13	0	0	0	0	0
17	0	0	0	0	0
17	17	0	0	0	0
17	0	0	0	0	0

Consider in Table 5 "Elem. Sec Av x" as the security element before the x element. The first column contains the number of security element that precedes the other security elements; the columns from 1 to 5 contain each element of security above. For example, on line 4, always reads as follows: the element 4 is preceded by the element number 3 of security i.e. the element 4 which is a link is preceded by a disconnector which is a security element numbered as 3.

With regard to Table 5, the columns from 1 to 5 contain each element of the following security. For example, on line 4, always reads as follows: the element 4 is pursued by the security element number 5 i.e. the element 4 which is a link, is preceded by a Breaker, which is a security element numbered as 5.

Table 3.7 **(Security elements that comes after)**

Elem Sec Ap1	Elem Sec Ap2	Elem Sec Ap3	Elem Sec Ap4	Elem Sec Ap5	Boucles
0	0	0	0	0	0
3	0	0	0	0	0
0	0	0	0	0	0
5	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
9	0	0	0	0	0
0	0	0	0	0	0
11	0	0	0	0	0
0	0	0	0	0	0
13	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
17	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Consider in Table 6 "Elem. Sec Ap x" as the security element after the x element. The columns from 1 to 5 contain each element of security above. Column 6 shows the number of loops that may exist in the network.

Finally the Tables 1 to 5 will process in several matrices in text format that will contain all data necessary to study various phenomena in electrical power systems.

3.6. Interpretation of matrices

Our software transforms the tables in different matrices in number of ten; each matrix contains information on network elements in order to study its reliability, stability and influence of different phenomena that may affect its operation. We start with the most important matrix:

The matrix (*FPCT*) is composed of 19 rows by 19 columns (the number of network elements) indicates the path by which each element of the network is fed [53,54,55].

Table 3.8: FPCT (Feeder Path Component Trace) Matrix

1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	6	5	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
8	7	6	5	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0
9	8	7	6	5	4	3	2	1	0	0	0	0	0	0	0	0	0	0
10	9	8	7	6	5	4	3	2	1	0	0	0	0	0	0	0	0	0
11	10	9	8	7	6	5	4	3	2	1	0	0	0	0	0	0	0	0
12	11	10	9	8	7	6	5	4	3	2	1	0	0	0	0	0	0	0
13	12	11	10	9	8	7	6	5	4	3	2	1	0	0	0	0	0	0
14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	0	0	0
16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	0	0
17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	0
18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

To interpret the matrix FCTP we take as examples three lines, the 4th element means: to supply element 4 by the electric current this last must go through the elements 1, 2 and 3 (1.power source, 2.connection, 3.disconnector)

For the 6th element, to feed the 6th element; the current must be going through items 1, 2, 3, 4 and 5 (1.Power source, 2.Connection, 3.Disconnector, 4.Connection, 5.Breaker).

Finally line 12, to supply the element 12, the current must go through items 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 (1.Power source, 2.Connection, 3.disconnector, 4.Connection, 5.Breaker, 6.Connection, 7.Transformer, 8.Connection, 9.disconnector, 10.Connection, 11.disconnector).

The matrix (FPST) is composed of 6 rows and 6 columns (the number of protection elements in the network) indicates the path by which each element of protection in the power grid is supplied [53,54,55].

Table 3.9: FPST (Feeder Path Segment Trace) Matrix

3	*0*	*0*	*0*	*0*	*0*
5	*3*	*0*	*0*	*0*	*0*
9	*5*	*3*	*0*	*0*	*0*
11	*9*	*5*	*3*	*0*	*0*
13	*11*	*9*	*5*	*3*	*0*
17	*13*	*11*	*9*	*5*	*3*

The table 3.9 presents the paths feeding each element of protection of electrical network [53,54,55].

Table 3.10: FST (Forward Segment Trace) Matrix

5	9	11	13	17	0
9	11	13	17	0	0
11	13	17	0	0	0
13	17	0	0	0	0
17	0	0	0	0	0
0	0	0	0	0	0

Rank numbers of all elements of network protection downstream, BST (Backword Segment Trace) Matrix [53,54,55].

Table 3.11: BST (Backward Segment Trace) Matrix

0	0	0	0	0	0
3	0	0	0	0	0
5	3	0	0	0	0
9	5	3	0	0	0
11	9	5	3	0	0
13	11	9	5	3	0

Classification numbers of all elements of network protection upstream SW (Switch) Matrix

Table 3.12: Ending Component Trace

3	5	9	11	13	17

The number of protection elements ECT (Ending Component Trace) Matrix [53,54,55].

Table 3.13: (Ending Component) Matrix

19

The end elements number of the lines.

3.7. Summary

The work we have done is just the beginning of a very important work.
The programming method with "object oriented" allowed us to achieve multifunctional software that we have called data generator. With this software, we can draw any pattern network with all the necessary components.

One of the major advantages of this software is the real-time operation that is to say, whenever the scheme of a network changes, all information generated by the matrices of the software will change and adjusted.

The operation of our data generator is valid for any type of network (radial, looped or meshed) and any voltage level (*LV*, *MV* or *HV*).

Thus, with information collected by the program, we can study and analyze reliability; stability (dynamic and static) and load flow, as we can calculate different types of short-circuit.

Chapter 4

Overall Power System Reliability Assessment

4.1. Overall power system (HLIII) adequacy evaluation [58]

HLIII adequacy evaluation includes all three segments of an electric power system in an overall assessment of actual consumer load point adequacy. The primary adequacy indices at *HLIII* are the expected failure rate λ**,** the average duration of failure and the annual unavailability *U* of the customer load points**.** Individual customer *HLIII* indices can also be aggregated with the customer average connected load and the number of customers at each load point to obtain the *HLIII* system adequacy indices. These *HLIII* indices are the system average interruption frequency index *(SAIFI)*, the system average interruption duration index (*SAIDI*), the customer average interruption duration index (*CAIDI*) and the average service availability index (*ASAI*). Analysis of customer failure statistics [*40,44*] indicates that the distribution functional zone makes the greatest individual contribution to overall customer supply unavailability. The indices available in here are performance parameters obtained from historical event reporting. This section illustrates the prediction of similar indices.

4.2. Hierarchical level three (HLIII) indices

The *HLIII* adequacy assessment presented in this section includes the independent outages of generating units**,** transmission lines, and distribution element failures. The method utilized in this research is divided into three steps.

The computer program was used to obtain the probability, expected frequency and duration of each contingency at *HLII* that leads to load curtailment for each system bus.

1. At the sub transmission system level, the impact of all outages was obtained in terms of average failure rate and average annual outage time at each distribution system supply point.
2. At the radial distribution level, the effects due to outages of system components such as primary main/laterals/low voltage transformers, etc. were considered. A more detailed description of the three step procedure is as follows:

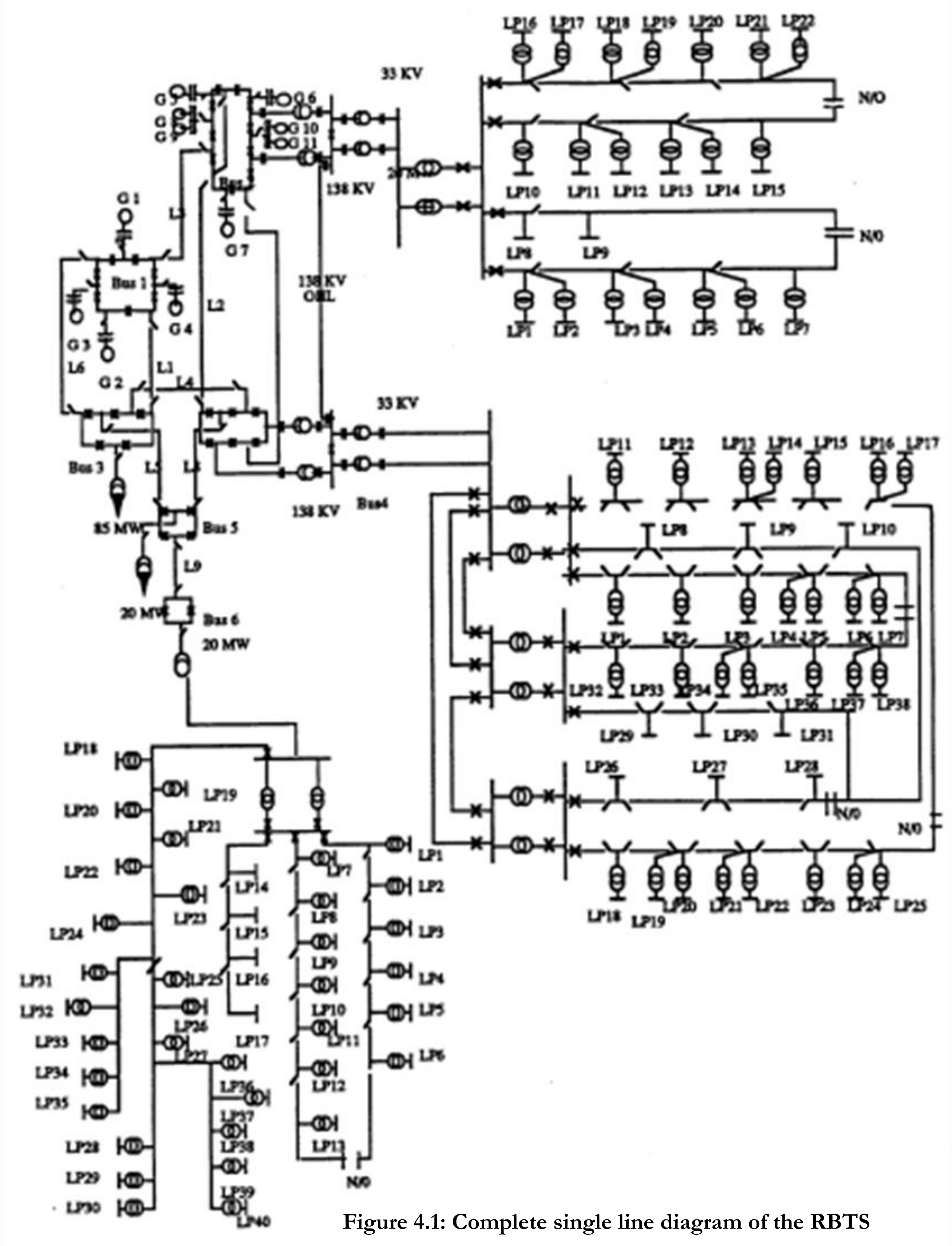

Figure 4.1: Complete single line diagram of the RBTS

Step *1*

a.) The computer program is used to generate, for a specified load level, the following parameters at each load bus.

λ_{kj}= frequency (occ/yr) of contingency *j* at bus *k* and

U_{kj} = duration (Hrs) of contingency *j* at bus *k*.

If the contingency results in load curtailment, a basic question is: then how would the electric utility distribute this interrupted load among its customers. It is obvious that different power utilities will take different actions based on their experience, judgments and other criteria. A policy that combines the average load curtailed at a bus, alleviation and isolation indices is used in here to modify the adequacy indices, probability and frequency at each load bus. This research considers, for each contingency *j*, the load curtailed L_{tj} at a bus *k* is assumed to be shared proportionately across all the customers. For each contingency *j* that leads to load curtailment of L_{tj}, the ratio of L_{tj} to bus peak load is determined. The failure probability and failure frequency at each bus k are modified using this ratio. The failure probability and frequency due an isolation case is not modified as the isolation affects all the customers.

For alleviation:

$$\lambda_{k,j,p} = \lambda_{k,j} \frac{L_{k,j}}{Peak\ load\ of\ k} \qquad (4.1)$$

$$U_{k,j,p} = U_{k,j} \frac{L_{k,j}}{Peak\ load\ of\ k} \qquad (4.2)$$

For Isolation:

$$\lambda_{k,j,p} = \lambda_{k,j} \qquad (4.3)$$

$$U_{k,j,p} = U_{k,j} \qquad (4.4)$$

Step *2*

Having obtained the expected failure frequency and duration for each customer due to all contingencies resulting from the composite generation and transmission system, the next step is to consider the effects of outages in the distribution networks up to the customer supply points. Any outage event that causes isolation of a distribution supply point involves all the customers connected at that point. Continuity of supply is assumed to be the sole criterion and therefore all load points at a supply point are completely isolated due to outage of the supply point. For every event j

$$\lambda_{k,j,p} = \lambda_{k,j} \qquad (4.5)$$

$$U_{k,j,p} = U_{k,j} \qquad (4.6)$$

Step *3*

The final contribution to the individual customer load point indices comes from the radial distribution networks. For a given configuration, the outage events contributing ***to*** the isolation of load point p can be aggregated from each event added as in Step **2.** The HLIII indices at load point p associated with bus *k* are as follows:

$$\boldsymbol{HL\ III\ \lambda_{k,p} = \sum_{i=1}^{3} (\lambda_{k,p})_i \quad f/yr} \qquad (\mathbf{4.7})$$

$$\boldsymbol{HL\ III\ U_{k,p} = \sum_{i=1}^{3} (U_{k,p})_i \quad h/yr} \qquad (\mathbf{4.8})$$

$$\boldsymbol{HL\ III\ r_{k,p} = \sum_{i=1}^{3} \frac{HL\ III\ U_{k,p}}{HL\ III\ \lambda_{k,p}} \quad h} \qquad (\mathbf{4.9})$$

Where

i = step number.

The failure probability and frequency were obtained for each load bus of the *R.B.T.S* using Step 1.

4.3. HLIII reliability indices for the R.B.T.S

The complete results of the *HLIII* reliability assessment are calculated for the load points at buses *3, 4, 5* and *6*. The load points at Bus *2* were not calculated because of the negligible results in the *HLII* assessment. Tables *4.1-4* present the *HLIII* indices at buses *3, 4, 5* and *6*. The tables display the results of the distribution system for every feeder of each bus of the Roy Billinton test system *(R.B.T.S)*, the tables below put on view the results of the assessment of *HLIII* for two cases, on one hand they display the results without the effect of distributed generation and on the other hand they show the results with distributed generators, showing the consequences of introducing *DGs* in the system.

The tables below display in addition indices for all the segments in the system at each bus of the *R.B.T.S*. Furthermore as well as individual indices, it is screened on the tables indices for the whole buses system like, System average interruption duration index *(SAIDI),* Customer average interruption duration index *(Sys_CAIDI),* Average service availability index *(ASAI),* and Average service unavailability index *(ASUI)*.

Tables *4.1-4 (*without *DG)* display that there is a contribution of the *HLII* in the evaluation of *HLIII* indices if the results in this chapter for load points are compared with those of chapter *2*, it can be seen that there is an augmentation in the indices both individual and of the system (augmentation in load point failure rate, down time -unavailability-, *SAIDI, Sys_CAIDI, ASAI* and *ASUI*). Also it can be seen that the unavailability contribution from the various zones is different for different customers, tables *4.1* and *4.2 (without DG)* show that the distribution system contribution to the *HLIII* indices is small for buses *3* and *4*. It can be seen from Tables *4.4* that the distribution system contribution to the *HLIII* indices is significant for bus *6*, the obvious reason is that customers at bus *6* are supplied through a single circuit transmission line and through a single *230/33 kv* transformer, i.e. no alternative feed for Bus *6* is available.

Herein this research, an effort for reliability improvement is achieved by using distributed generations *(DGs)* technologies. The introduction of these technologies was made in chapter *1*. As well as the results 'without distribution generator' are screened out on the tables, the results 'with distribution generator' are also displayed confirming moreover the role of introducing (interconnecting) a distributed generator to the system.

It is clear on all tables *4.1-4* without *DG* and with *DG* results, that there is a patent difference between the reliability indices either for load point and the whole system. It is visible that reliability indices were improved after the *DGs* are introduced to the system. From the *ASAI* index, continuity of service also was improved if a comparison between without and with *DG* results is done.

The integration of the distributed source is done at the end of each feeder of the Roy Billinton test system *(R.B.T.S)*. A distributed generator is frequently placed at a substation if no further land purchases are possible. However, locating generators at substations, distributed generator acts only as a backup power source, which may not contribute significantly in reliability improvement as far as the entire system is concerned. Instead, generators located further out on a circuit can often significantly affect the system reliability, which is confirmed herein this thesis.

Table 4.1. HLIII Load points indices for the RBTS at Bus 3

Bus 3/Feeder:1 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.251015081	1.254939316	0.3150087	4.0908489	13.165145	0.999533008	0.000467
	SW3	0.251015081	1.254939316	0.3150087				
LP1	SW4	0.305015081	11.50765622	3.5100087				
	SW7	0.251015081	2.303681085	0.5782587				
	SW9	0.251015081	2.303681085	0.5782587				
LP2	SW10	0.318015081	12.06958073	3.8383087				
	SW13	0.251015081	3.23589599	0.8122587				
	SW15	0.251015081	3.23589599	0.8122587				
LP3	SW16	0.305015081	13.13806741	4.0073087				
	SW19	0.251015081	4.284637759	1.0755087				
	SW21	0.251015081	4.284637759	1.0755087				
LP4	SW22	0.324515081	13.46011002	4.3680087				
LP5	SW25	0.318015081	13.6330286	4.3355087				
	SW28	0.251015081	4.983798938	1.2510087				
	SW30	0.251015081	4.983798938	1.2510087				
LP6	SW31	0.305015081	14.57635694	4.4460087				
LP7	SW34	0.305015081	14.57635694	4.4460087				

Bus 3/Feeder:1 With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.251015081	1.254939316	0.3150087	3.349099759	10.778053	0.999617683	0.0003823
	SW3	0.251015081	0.500004596	0.1255087				
LP1	SW4	0.305015081	10.88637546	3.3205087				
	SW7	0.251015081	1.548746364	0.3887587				
	SW9	0.251015081	0.500004596	0.1255087				
LP2	SW10	0.318015081	10.64574889	3.3855087				
	SW13	0.251015081	1.432219501	0.3595087				
	SW15	0.251015081	0.500004596	0.1255087				
LP3	SW16	0.305015081	10.88637546	3.3205087				

	SW19	0.251015081	1.548746364	0.3887587
	SW21	0.251015081	0.500004596	0.1255087
LP4	SW22	0.324515081	10.53266518	3.4180087
LP5	SW25	0.318015081	10.64574889	3.3855087
	SW28	0.251015081	1.199165775	0.3010087
	SW30	0.251015081	0.500004596	0.1255087
LP6	SW31	0.305015081	10.88637546	3.3205087
LP7	SW34	0.305015081	10.88637546	3.3205087

Bus 3/Feeder:2 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.173015081	2.102468132	0.3637587	0.856675361	3.8442067	0.999902206	9.779E-05
	SW3	0.173015081	2.102468132	0.3637587				
LP8	SW4	0.231515081	2.834626113	0.6562587				
	SW6	0.173015081	3.454951387	0.5977587				
	SW8	0.173015081	3.454951387	0.5977587				
LP9	SW9	0.212015081	3.73916181	0.7927587				
	SW11	0.173015081	4.97649505	0.8610087				
	SW13	0.173015081	4.97649505	0.8610087				
LP10	SW14	0.225015081	4.981926941	1.1210087				

Bus 3/Feeder:2 With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.173015081	2.102468132	0.3637587	0.335675361	1.5062946	0.999961681	3.832E-05
	SW3	0.173015081	0.500006668	0.0865087				
LP8	SW4	0.231515081	1.637079936	0.3790087				
	SW6	0.173015081	1.852489923	0.3205087				
	SW8	0.173015081	0.500006668	0.0865087				
LP9	SW9	0.212015081	1.327776745	0.2815087				
	SW11	0.173015081	2.02155033	0.3497587				
	SW13	0.173015081	0.500006668	0.0865087				
LP10	SW14	0.225015081	1.539935424	0.3465087				

Bus 3/Feeder:3 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI

	SW1	*0.251015081*	*1.254939316*	*0.3150087*	*4.331324611*	*13.766272*	*0.999505557*	*0.0004944*
	SW3	*0.251015081*	*1.254939316*	*0.3150087*				
LP11	*SW4*	*0.305015081*	*11.50765622*	*3.5100087*				
	SW7	*0.251015081*	*2.303681085*	*0.5782587*				
	SW9	*0.251015081*	*2.303681085*	*0.5782587*				
LP12	*SW10*	*0.324515081*	*11.92797784*	*3.8708087*				
	SW13	*0.251015081*	*3.23589599*	*0.8122587*				
	SW15	*0.251015081*	*3.23589599*	*0.8122587*				
LP13	*SW16*	*0.318015081*	*12.80539489*	*4.0723087*				
LP14	*SW19*	*0.324515081*	*12.64905372*	*4.1048087*				
	SW22	*0.251015081*	*4.284637759*	*1.0755087*				
	SW24	*0.251015081*	*4.284637759*	*1.0755087*				
LP15	*SW25*	*0.305015081*	*14.00097556*	*4.2705087*				
	SW28	*0.251015081*	*4.983798938*	*1.2510087*				
	SW30	*0.251015081*	*4.983798938*	*1.2510087*				
LP16	*SW31*	*0.318015081*	*14.18488922*	*4.5110087*				
LP17	*SW34*	*0.318015081*	*14.18488922*	*4.5110087*				

Bus 3/Feeder:3 With DG

LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.251015081*	*1.254939316*	*0.3150087*	*3.368598705*	*10.706435*	*0.999615457*	*0.0003845*
	SW3	*0.251015081*	*0.500004596*	*0.1255087*				
LP11	*SW4*	*0.305015081*	*10.88637546*	*3.3205087*				
	SW7	*0.251015081*	*1.548746364*	*0.3887587*				
	SW9	*0.251015081*	*0.500004596*	*0.1255087*				
LP12	*SW10*	*0.324515081*	*10.53266518*	*3.4180087*				
	SW13	*0.251015081*	*1.432219501*	*0.3595087*				
	SW15	*0.251015081*	*0.500004596*	*0.1255087*				
LP13	*SW16*	*0.318015081*	*10.64574889*	*3.3855087*				
LP14	*SW19*	*0.324515081*	*10.53266518*	*3.4180087*				
	SW22	*0.251015081*	*1.548746364*	*0.3887587*				
	SW24	*0.251015081*	*0.500004596*	*0.1255087*				
LP15	*SW25*	*0.305015081*	*10.88637546*	*3.3205087*				

	SW28	0.251015081	1.199165775	0.3010087				
	SW30	0.251015081	0.500004596	0.1255087				
LP16	SW31	0.318015081	10.64574889	3.3855087				
LP17	SW34	0.318015081	10.64574889	3.3855087				

Bus 3/Feeder:4 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.251015081	1.254939316	0.3150087	4.006995316	12.67976	0.99954258	0.0004574
	SW3	0.251015081	1.254939316	0.3150087				
LP18	SW4	0.318015081	11.24163258	3.5750087				
	SW7	0.251015081	1.954100495	0.4905087				
	SW9	0.251015081	1.954100495	0.4905087				
LP19	SW10	0.324515081	11.6574203	3.7830087				
	SW13	0.251015081	3.002842264	0.7537587				
	SW15	0.251015081	3.002842264	0.7537587				
LP20	SW16	0.318015081	12.6211269	4.0137087				
LP21	SW19	0.305015081	12.94627361	3.9488087				
	SW22	0.251015081	3.935057169	0.9877587				
	SW24	0.251015081	3.935057169	0.9877587				
LP22	SW25	0.324515081	13.18986064	4.2803087				
	SW28	0.251015081	4.983798938	1.2510087				
	SW30	0.251015081	4.983798938	1.2510087				
LP23	SW31	0.318015081	14.18488922	4.5110087				
LP24	SW34	0.305015081	14.57635694	4.4460087				

Bus 3/Feeder:4 With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.251015081	1.254939316	0.3150087	3.375508694	10.68148	0.999614668	0.0003853
	SW3	0.251015081	0.500004596	0.1255087				
LP18	SW4	0.318015081	10.64574889	3.3855087				
	SW7	0.251015081	1.199165775	0.3010087				
	SW9	0.251015081	0.500004596	0.1255087				
LP19	SW10	0.324515081	10.53266518	3.4180087				
	SW13	0.251015081	1.548746364	0.3887587				

	SW15	0.251015081	0.500004596	0.1255087
LP20	SW16	0.318015081	10.64574889	3.3855087
LP21	SW19	0.305015081	10.88637546	3.3205087
	SW22	0.251015081	1.432219501	0.3595087
	SW24	0.251015081	0.500004596	0.1255087
LP22	SW25	0.324515081	10.53266518	3.4180087
	SW28	0.251015081	1.548746364	0.3887587
	SW30	0.251015081	0.500004596	0.1255087
LP23	SW31	0.318015081	10.64574889	3.3855087
LP24	SW34	0.305015081	10.88637546	3.3205087

Bus 3/Feeder:5 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.257515081	1.576640453	0.4060087	4.314234761	13.417307	0.999507507	0.0004925
	SW3	0.257515081	1.576640453	0.4060087				
LP25	SW4	0.324515081	11.29688236	3.6660087				
	SW7	0.257515081	2.598910679	0.6692587				
	SW9	0.257515081	2.598910679	0.6692587				
LP26	SW10	0.324515081	12.10824681	3.9293087				
	SW13	0.257515081	3.280424163	0.8447587				
	SW15	0.257515081	3.280424163	0.8447587				
LP27	SW16	0.311515081	12.9679394	4.0397087				
	SW19	0.257515081	3.96213181	1.0203087				
	SW21	0.257515081	3.96213181	1.0203087				
LP28	SW22	0.324515081	13.18986064	4.2803087				
LP29	SW25	0.324515081	13.18986064	4.2803087				
	SW28	0.257515081	4.984207873	1.2835087				
	SW30	0.257515081	4.984207873	1.2835087				
LP30	SW31	0.331015081	13.82416982	4.5760087				
LP31	SW34	0.311515081	14.37653895	4.4785087				

Bus 3/Feeder:5 With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.257515081	1.576640453	0.4060087	3.373945889	10.493001	0.999614846	0.0003852

	SW3	*0.257515081*	*0.50000448*	*0.1287587*
LP25	*SW4*	*0.324515081*	*10.44268477*	*3.3888087*
	SW7	*0.257515081*	*1.522274705*	*0.3920087*
	SW9	*0.257515081*	*0.50000448*	*0.1287587*
LP26	*SW10*	*0.324515081*	*10.44268477*	*3.3888087*
	SW13	*0.257515081*	*1.181517964*	*0.3042587*
	SW15	*0.257515081*	*0.50000448*	*0.1287587*
LP27	*SW16*	*0.311515081*	*10.66981632*	*3.3238087*
	SW19	*0.257515081*	*1.181517964*	*0.3042587*
	SW21	*0.257515081*	*0.50000448*	*0.1287587*
LP28	*SW22*	*0.324515081*	*10.44268477*	*3.3888087*
LP29	*SW25*	*0.324515081*	*10.44268477*	*3.3888087*
	SW28	*0.257515081*	*1.522274705*	*0.3920087*
	SW30	*0.257515081*	*0.50000448*	*0.1287587*
LP30	*SW31*	*0.331015081*	*10.33580912*	*3.4213087*
LP31	*SW34*	*0.311515081*	*10.66981632*	*3.3238087*

Bus 3/Feeder:6 Without DG

LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.218515081*	*1.634938387*	*0.3572587*	*4.059309475*	*14.544739*	*0.999536609*	*0.0004634*
	SW3	*0.218515081*	*1.634938387*	*0.3572587*				
LP32	*SW4*	*0.272515081*	*13.03490684*	*3.5522087*				
LP33	*SW7*	*0.292015081*	*12.49869932*	*3.6498087*				
	SW10	*0.218515081*	*2.705802691*	*0.5912587*				
	SW12	*0.218515081*	*2.705802691*	*0.5912587*				
LP34	*SW13*	*0.272515081*	*13.89357492*	*3.7862087*				
LP35	*SW16*	*0.285515081*	*13.48898517*	*3.8513087*				
	SW19	*0.218515081*	*3.910525032*	*0.8545087*				
	SW21	*0.218515081*	*3.910525032*	*0.8545087*				
LP36	*SW22*	*0.272515081*	*14.85975998*	*4.0495087*				
	SW25	*0.218515081*	*4.981389335*	*1.0885087*				
	SW27	*0.218515081*	*4.981389335*	*1.0885087*				
LP37	*SW28*	*0.272515081*	*15.71842805*	*4.2835087*				

LP38	SW31	0.292015081	15.00267958	4.3810087

Bus 3/Feeder:6 With DG

LP Nbr	ent_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.218515081	1.634938387	0.3572587	3.337109085	11.957054	0.999619051	0.0003809
	SW3	0.218515081	0.500005279	0.1092587				
LP32	SW4	0.272515081	12.12486546	3.3042087				
LP33	SW7	0.292015081	11.64908567	3.4017087				
	SW10	0.218515081	1.570869583	0.3432587				
	SW12	0.218515081	0.500005279	0.1092587				
LP34	SW13	0.272515081	12.12486546	3.3042087				
LP35	SW16	0.285515081	11.80080815	3.3693087				
	SW19	0.218515081	1.704727621	0.3725087				
	SW21	0.218515081	0.500005279	0.1092587				
LP36	SW22	0.272515081	12.12486546	3.3042087				
	SW25	0.218515081	1.570869583	0.3432587				
	SW27	0.218515081	0.500005279	0.1092587				
LP37	SW28	0.272515081	12.12486546	3.3042087				
LP38	SW31	0.292015081	11.64908567	3.4017087				

Table 4.2. HLIII Load points indices for the RBTS at Bus 4

Bus 4/Feeder:1 Without DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.244500836	1.454514704	0.3556301	4.00180006	13.119349	0.999543174	0.0004568
	SW3	0.244500836	1.454514704	0.3556301				
LP1	SW4	0.298500836	11.89477428	3.5506001				
	SW7	0.244500836	2.411566648	0.5896301				
	SW9	0.244500836	2.411566648	0.5896301				
LP2	SW10	0.308250836	12.43597622	3.8334001				
	SW13	0.244500836	3.368618593	0.8236301				
	SW15	0.244500836	3.368618593	0.8236301				
LP3	SW16	0.298500836	13.46260909	4.0186001				
	SW19	0.244500836	4.265834341	1.0430001				
	SW21	0.244500836	4.265834341	1.0430001				
LP4	SW22	0.311500836	13.81376732	4.3030001				
LP5	SW25	0.308250836	13.90653185	4.2867001				
	SW28	0.244500836	4.983623299	1.2185001				
	SW30	0.244500836	4.983623299	1.2185001				
LP6	SW31	0.311500836	14.37716869	4.4785001				
LP7	SW34	0.308250836	14.47619778	4.4623001				

Bus 4/Feeder:1 With DG

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
	SW1	0.244500836	1.454514704	0.3556301	3.349928242	10.982277	0.999617588	0.0003824
	SW3	0.244500836	0.499998539	0.1222501				
LP1	SW4	0.298500836	11.11320193	3.3173001				
	SW7	0.244500836	1.457050483	0.3562501				
	SW9	0.244500836	0.499998539	0.1222501				
LP2	SW10	0.308250836	10.91967863	3.3660001				
	SW13	0.244500836	1.457050483	0.3562501				
	SW15	0.244500836	0.499998539	0.1222501				
LP3	SW16	0.298500836	11.11320193	3.3173001				
	SW19	0.244500836	1.397255186	0.3416301				

	SW21	*0.244500836*	*0.499998539*	*0.1222501*				
LP4	*SW22*	*0.311500836*	*10.85807701*	*3.3823001*				
LP5	*SW25*	*0.308250836*	*10.91967863*	*3.3660001*				
	SW28	*0.244500836*	*1.217787497*	*0.2977501*				
	SW30	*0.244500836*	*0.499998539*	*0.1222501*				
LP6	*SW31*	*0.311500836*	*10.85807701*	*3.3823001*				
LP7	*SW34*	*0.308250836*	*10.91967863*	*3.3660001*				
	Bus 4/Feeder:2 Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.147000836*	*2.18706281*	*0.3215001*	*0.768916727*	*3.9720021*	*0.999912224*	*8.778E-05*
	SW3	*0.147000836*	*2.18706281*	*0.3215001*				
LP8	*SW4*	*0.186000836*	*2.776869572*	*0.5165001*				
	SW6	*0.147000836*	*3.778890497*	*0.5555001*				
	SW8	*0.147000836*	*3.778890497*	*0.5555001*				
LP9	*SW9*	*0.195750836*	*4.08299693*	*0.7992501*				
	SW11	*0.147000836*	*4.972761263*	*0.7310001*				
	SW13	*0.147000836*	*4.972761263*	*0.7310001*				
LP10	*SW14*	*0.199000836*	*4.979878893*	*0.9910001*				
	Bus 4/Feeder:2 With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.147000836*	*2.18706281*	*0.3215001*	*0.306416727*	*1.5828605*	*0.999965021*	*3.498E-05*
	SW3	*0.147000836*	*0.499997569*	*0.0735001*				
LP8	*SW4*	*0.186000836*	*1.443542228*	*0.2685001*				
	SW6	*0.147000836*	*2.091825256*	*0.3075001*				
	SW8	*0.147000836*	*0.499997569*	*0.0735001*				
LP9	*SW9*	*0.195750836*	*1.620683046*	*0.3172501*				
	SW11	*0.147000836*	*1.693868335*	*0.2490001*				
	SW13	*0.147000836*	*0.499997569*	*0.0735001*				
LP10	*SW14*	*0.199000836*	*1.675872664*	*0.3335001*				
	Bus 4/Feeder:3 Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.234750836*	*1.494137645*	*0.3507501*	*3.918347333*	*13.188107*	*0.9995527*	*0.0004473*

	SW3	*0.234750836*	*1.494137645*	*0.3507501*				
LP11	*SW4*	*0.301750836*	*11.96616425*	*3.6108001*				
	SW7	*0.234750836*	*2.241738818*	*0.5262501*				
	SW9	*0.234750836*	*2.241738818*	*0.5262501*				
LP12	*SW10*	*0.298500836*	*12.6297806*	*3.7700001*				
	SW13	*0.234750836*	*3.238540382*	*0.7602501*				
	SW15	*0.234750836*	*3.238540382*	*0.7602501*				
LP13	*SW16*	*0.298500836*	*13.413698*	*4.0040001*				
LP14	*SW19*	*0.288750836*	*13.69762291*	*3.9552001*				
	SW22	*0.234750836*	*4.235341946*	*0.9942501*				
	SW24	*0.234750836*	*4.235341946*	*0.9942501*				
LP15	*SW25*	*0.298500836*	*14.1976154*	*4.2380001*				
	SW28	*0.234750836*	*4.983156111*	*1.1698001*				
	SW30	*0.234750836*	*4.983156111*	*1.1698001*				
LP16	*SW31*	*0.298500836*	*14.78555346*	*4.4135001*				
LP17	*SW34*	*0.288750836*	*15.11580063*	*4.3647001*				
	Bus 4/Feeder:3 With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.234750836*	*1.494137645*	*0.3507501*	*3.354177333*	*11.289262*	*0.999617103*	*0.0003829*
	SW3	*0.234750836*	*0.499977179*	*0.1173701*				
LP11	*SW4*	*0.301750836*	*11.19267841*	*3.3774001*				
	SW7	*0.234750836*	*1.24762095*	*0.2928801*				
	SW9	*0.234750836*	*0.499977179*	*0.1173701*				
LP12	*SW10*	*0.298500836*	*11.25993518*	*3.3611001*				
	SW13	*0.234750836*	*1.496778743*	*0.3513701*				
	SW15	*0.234750836*	*0.499977179*	*0.1173701*				
LP13	*SW16*	*0.298500836*	*11.25993518*	*3.3611001*				
LP14	*SW19*	*0.288750836*	*11.47148217*	*3.3124001*				
	SW22	*0.234750836*	*1.496778743*	*0.3513701*				
	SW24	*0.234750836*	*0.499977179*	*0.1173701*				
LP15	*SW25*	*0.298500836*	*11.25993518*	*3.3611001*				
	SW28	*0.234750836*	*1.24762095*	*0.2928801*				

	SW30	*0.234750836*	*0.499977179*	*0.1173701*				
LP16	*SW31*	*0.298500836*	*11.25993518*	*3.3611001*				
LP17	*SW34*	*0.288750836*	*11.47148217*	*3.3124001*				
	Bus 4/Feeder:4Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.251000836*	*1.488043096*	*0.3735001*	*3.953008522*	*12.689184*	*0.999548743*	*0.0004513*
	SW3	*0.251000836*	*1.488043096*	*0.3735001*				
LP18	*SW4*	*0.314750836*	*11.49258287*	*3.6173001*				
	SW7	*0.251000836*	*2.420310909*	*0.6075001*				
	SW9	*0.251000836*	*2.420310909*	*0.6075001*				
LP19	*SW10*	*0.305000836*	*12.46717916*	*3.8025001*				
LP20	*SW13*	*0.314750836*	*12.23571036*	*3.8512001*				
	SW16	*0.251000836*	*3.352578722*	*0.8415001*				
	SW18	*0.251000836*	*3.352578722*	*0.8415001*				
LP21	*SW19*	*0.314750836*	*12.97915557*	*4.0852001*				
LP22	*SW22*	*0.305000836*	*13.23439017*	*4.0365001*				
	SW25	*0.251000836*	*4.284846535*	*1.0755001*				
	SW27	*0.251000836*	*4.284846535*	*1.0755001*				
LP23	*SW28*	*0.314750836*	*13.72260078*	*4.3192001*				
	SW31	*0.251000836*	*4.984047395*	*1.2510001*				
	SW33	*0.251000836*	*4.984047395*	*1.2510001*				
LP24	*SW34*	*0.314750836*	*14.28018468*	*4.4947001*				
LP25	*SW37*	*0.305000836*	*14.57700945*	*4.4460001*				
	Bus 4/Feeder:4With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.251000836*	*1.488043096*	*0.3735001*	*3.353158522*	*10.763661*	*0.999617219*	*0.0003828*
	SW3	*0.251000836*	*0.499998576*	*0.1255001*				
LP18	*SW4*	*0.314750836*	*10.70465804*	*3.3693001*				
	SW7	*0.251000836*	*1.432266389*	*0.3595001*				
	SW9	*0.251000836*	*0.499998576*	*0.1255001*				
LP19	*SW10*	*0.305000836*	*10.88685562*	*3.3205001*				
LP20	*SW13*	*0.314750836*	*10.70465804*	*3.3693001*				

	SW16	*0.251000836*	*1.432266389*	*0.3595001*				
	SW18	*0.251000836*	*0.499998576*	*0.1255001*				
LP21	*SW19*	*0.314750836*	*10.70465804*	*3.3693001*				
LP22	*SW22*	*0.305000836*	*10.88685562*	*3.3205001*				
	SW25	*0.251000836*	*1.432266389*	*0.3595001*				
	SW27	*0.251000836*	*0.499998576*	*0.1255001*				
LP23	*SW28*	*0.314750836*	*10.70465804*	*3.3693001*				
	SW31	*0.251000836*	*1.199199436*	*0.3010001*				
	SW33	*0.251000836*	*0.499998576*	*0.1255001*				
LP24	*SW34*	*0.314750836*	*10.70465804*	*3.3693001*				
LP25	*SW37*	*0.305000836*	*10.88685562*	*3.3205001*				
	Bus 4/Feeder:5Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.143750836*	*2.225239661*	*0.3198801*	*0.74292006*	*3.9032406*	*0.999915192*	*8.481E-05*
	SW3	*0.143750836*	*2.225239661*	*0.3198801*				
LP26	*SW4*	*0.192500836*	*2.927935658*	*0.5636301*				
	SW6	*0.143750836*	*3.44610213*	*0.4953801*				
	SW8	*0.143750836*	*3.44610213*	*0.4953801*				
LP27	*SW9*	*0.195750836*	*3.858885498*	*0.7553801*				
	SW11	*0.143750836*	*4.972145434*	*0.7147501*				
	SW13	*0.143750836*	*4.972145434*	*0.7147501*				
LP28	*SW14*	*0.182750836*	*4.978089747*	*0.9097501*				
	Bus 4/Feeder:5With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.143750836*	*2.225239661*	*0.3198801*	*0.304793394*	*1.6013593*	*0.999965206*	*3.479E-05*
	SW3	*0.143750836*	*0.499997514*	*0.0718751*				
LP26	*SW4*	*0.192500836*	*1.639629561*	*0.3156301*				
	SW6	*0.143750836*	*1.720894766*	*0.2473801*				
	SW8	*0.143750836*	*0.499997514*	*0.0718751*				
LP27	*SW9*	*0.195750836*	*1.695420914*	*0.3318801*				
	SW11	*0.143750836*	*2.026075601*	*0.2912501*				
	SW13	*0.143750836*	*0.499997514*	*0.0718751*				

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
LP28	*SW14*	*0.182750836*	*1.460294612*	*0.2668701*				
	Bus 4/Feeder:6Without DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	*0.156750836*	*1.98882551*	*0.3117501*	*0.75700006*	*3.8040044*	*0.999913584*	*8.642E-05*
	SW3	*0.156750836*	*1.98882551*	*0.3117501*				
LP29	*SW4*	*0.195750836*	*2.588750434*	*0.5067501*				
	SW6	*0.156750836*	*3.48164052*	*0.5457501*				
	SW8	*0.156750836*	*3.48164052*	*0.5457501*				
LP30	*SW9*	*0.205500836*	*3.841833823*	*0.7895001*				
	SW11	*0.156750836*	*4.974455529*	*0.7797501*				
	SW13	*0.156750836*	*4.974455529*	*0.7797501*				
LP31	*SW14*	*0.195750836*	*4.979544827*	*0.9747501*				
	Bus 4/Feeder:6With DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	*0.156750836*	*1.98882551*	*0.3117501*	*0.289626727*	*1.4554046*	*0.999966938*	*3.306E-05*
	SW3	*0.156750836*	*0.49999772*	*0.0783751*				
LP29	*SW4*	*0.195750836*	*1.396571615*	*0.2733801*				
	SW6	*0.156750836*	*1.992844628*	*0.3123801*				
	SW8	*0.156750836*	*0.49999772*	*0.0783751*				
LP30	*SW9*	*0.205500836*	*1.567487838*	*0.3221201*				
	SW11	*0.156750836*	*1.992844628*	*0.3123801*				
	SW13	*0.156750836*	*0.49999772*	*0.0783751*				
LP31	*SW14*	*0.195750836*	*1.396571615*	*0.2733801*				
	Bus 4/Feeder:7Without DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	*0.238000836*	*1.480583292*	*0.3523801*	*3.986285332*	*13.258118*	*0.999544945*	*0.0004551*
	SW3	*0.238000836*	*1.480583292*	*0.3523801*				
LP32	*SW4*	*0.305000836*	*11.84390218*	*3.6124001*				
	SW7	*0.238000836*	*2.217975661*	*0.5278801*				
	SW9	*0.238000836*	*2.217975661*	*0.5278801*				
LP33	*SW10*	*0.305000836*	*12.41931044*	*3.7879001*				
	SW13	*0.238000836*	*3.139695114*	*0.7472501*				

	SW15	*0.238000836*	*3.139695114*	*0.7472501*				
LP34	*SW16*	*0.292000836*	*13.50098897*	*3.9423001*				
LP35	*SW19*	*0.305000836*	*13.13865273*	*4.0073001*				
	SW22	*0.238000836*	*4.061456584*	*0.9666301*				
	SW24	*0.238000836*	*4.061456584*	*0.9666301*				
LP36	*SW25*	*0.292000836*	*14.25201422*	*4.1616001*				
	SW28	*0.238000836*	*4.983176038*	*1.1860001*				
	SW30	*0.238000836*	*4.983176038*	*1.1860001*				
LP37	*SW31*	*0.305000836*	*14.57700945*	*4.4460001*				
LP38	*SW34*	*0.292000836*	*15.00338193*	*4.3810001*				
	Bus 4/Feeder:7With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.238000836*	*1.480583292*	*0.3523801*	*3.357333394*	*11.166266*	*0.999616743*	*0.0003833*
	SW3	*0.238000836*	*0.499998499*	*0.1190001*				
LP32	*SW4*	*0.305000836*	*11.07865837*	*3.3790001*				
	SW7	*0.238000836*	*1.237390868*	*0.2945001*				
	SW9	*0.238000836*	*0.499998499*	*0.1190001*				
LP33	*SW10*	*0.305000836*	*11.07865837*	*3.3790001*				
	SW13	*0.238000836*	*1.421759969*	*0.3383801*				
	SW15	*0.238000836*	*0.499998499*	*0.1190001*				
LP34	*SW16*	*0.292000836*	*11.3492828*	*3.3140001*				
LP35	*SW19*	*0.305000836*	*11.07865837*	*3.3790001*				
	SW22	*0.238000836*	*1.421759969*	*0.3383801*				
	SW24	*0.238000836*	*0.499998499*	*0.1190001*				
LP36	*SW25*	*0.292000836*	*11.3492828*	*3.3140001*				
	SW28	*0.238000836*	*1.421759969*	*0.3383801*				
	SW30	*0.238000836*	*0.499998499*	*0.1190001*				
LP37	*SW31*	*0.305000836*	*11.07865837*	*3.3790001*				
LP38	*SW34*	*0.292000836*	*11.3492828*	*3.3140001*				

Table 4.3. HLIII Load points indices for the RBTS at Bus 5

			Bus 5/Feeder:1 Without DG					
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.1753	1.4100882	0.2471885	3.616078701	15.581028	0.999587206	0.0004128
LP1	SW3	0.2423	14.47477698	3.5072385				
LP2	SW6	0.2423	14.47477698	3.5072385				
	SW9	0.1753	2.494686033	0.4373185				
LP3	SW11	0.2423	15.25934157	3.6973385				
LP4	SW14	0.2228	16.15726419	3.5998385				
	SW17	0.1753	3.57922682	0.6274385				
LP5	SW19	0.23255	16.50672312	3.8386385				
LP6	SW22	0.2228	17.01049579	3.7899385				
	SW25	0.1753	4.914081355	0.8614385				
LP7	SW27	0.2423	17.0096511	4.1214385				
			Bus 5/Feeder:1 With DG					
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.1753	1.4100882	0.2471885	3.473018614	14.964608	0.999603537	0.0003965
LP1	SW3	0.2423	14.47477698	3.5072385				
LP2	SW6	0.2423	14.47477698	3.5072385				
	SW9	0.1753	1.580538856	0.2770685				
LP3	SW11	0.2423	14.59776501	3.5370385				
LP4	SW14	0.2228	15.43778484	3.4395385				
	SW17	0.1753	1.580538856	0.2770685				
LP5	SW19	0.23255	15.0003804	3.4883385				
LP6	SW22	0.2228	15.43778484	3.4395385				
	SW25	0.1753	1.830795559	0.3209385				
LP7	SW27	0.2423	14.77894536	3.5809385				
			Bus 5/Feeder:2 Without DG					
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.2078	1.478914637	0.3073185	3.505759689	13.107784	0.999599799	0.0004002
LP8	SW3	0.2553	13.59121998	3.4698385				
	SW6	0.2078	1.200377582	0.2494385				

LP9	*SW8*	*0.26505*	*13.05692685*	*3.4607385*				
	SW11	*0.2078*	*1.411542163*	*0.2933185*				
LP10	*SW13*	*0.2748*	*12.93063487*	*3.5533385*				
	SW16	*0.2078*	*1.200377582*	*0.2494385*				
LP11	*SW18*	*0.26505*	*13.05692685*	*3.4607385*				
	SW21	*0.2078*	*1.622658621*	*0.3371885*				
LP12	*SW23*	*0.2553*	*13.7083371*	*3.4997385*				
LP13	*SW26*	*0.26505*	*13.38780782*	*3.5484385*				
	Bus 5/Feeder:2 With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.2078*	*1.478914637*	*0.3073185*	*3.505759689*	*13.107784*	*0.999599799*	*0.0004002*
LP8	*SW3*	*0.2553*	*13.59121998*	*3.4698385*				
	SW6	*0.2078*	*1.200377582*	*0.2494385*				
LP9	*SW8*	*0.26505*	*13.05692685*	*3.4607385*				
	SW11	*0.2078*	*1.411542163*	*0.2933185*				
LP10	*SW13*	*0.2748*	*12.93063487*	*3.5533385*				
	SW16	*0.2078*	*1.200377582*	*0.2494385*				
LP11	*SW18*	*0.26505*	*13.05692685*	*3.4607385*				
	SW21	*0.2078*	*1.622658621*	*0.3371885*				
LP12	*SW23*	*0.2553*	*13.7083371*	*3.4997385*				
LP13	*SW26*	*0.26505*	*13.38780782*	*3.5484385*				
	Bus 5/Feeder:3 Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*0.1753*	*1.910658651*	*0.3349385*	*3.707563736*	*15.940634*	*0.999576762*	*0.0004232*
LP14	*SW3*	*0.2423*	*14.83672498*	*3.5949385*				
	SW6	*0.1753*	*2.744942736*	*0.4811885*				
LP15	*SW8*	*0.23255*	*15.87804112*	*3.6924385*				
LP16	*SW11*	*0.2228*	*16.35430189*	*3.6437385*				
	SW14	*0.1753*	*3.829540568*	*0.6713185*				
LP17	*SW16*	*0.2423*	*16.22508651*	*3.9313385*				
	SW19	*0.1753*	*4.914081355*	*0.8614385*				
LP18	*SW21*	*0.2228*	*18.06076509*	*4.0239385*				

LP Nbr	Segment_Name	Seg_LP_FR	Seg_LP_REP	Seg_DTs	SAIDI	Sys_CAIDI	ASAI	ASUI
LP19	SW24	0.2423	17.0096511	4.1214385				
	Bus 5/Feeder:3 With DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.1753	1.910658651	0.3349385	3.452938462	14.845875	0.999605829	0.0003942
LP14	SW3	0.2423	14.83672498	3.5949385				
	SW6	0.1753	1.330225109	0.2331885				
LP15	SW8	0.23255	14.81160379	3.4444385				
LP16	SW11	0.2228	15.24119597	3.3957385				
	SW14	0.1753	1.580538856	0.2770685				
LP17	SW16	0.2423	14.59776501	3.5370385				
	SW19	0.1753	1.580538856	0.2770685				
LP18	SW21	0.2228	15.43778484	3.4395385				
LP19	SW24	0.2423	14.59776501	3.5370385				
	Bus 5/Feeder:4 Without DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.16555	1.728713147	0.2861885	3.76115573	16.918076	0.999570644	0.0004294
LP20	SW3	0.23255	15.24935911	3.5462385				
LP21	SW6	0.21305	16.18746051	3.4487385				
	SW9	0.16555	2.612132054	0.4324385				
LP22	SW11	0.2228	16.35430189	3.6437385				
LP23	SW14	0.23255	15.87804112	3.6924385				
	SW17	0.16555	3.495550961	0.5786885				
LP24	SW19	0.2228	17.01049579	3.7899385				
	SW22	0.16555	4.909021211	0.8126885				
LP25	SW24	0.21305	18.65871139	3.9752385				
LP26	SW27	0.23255	17.51338835	4.0727385				
	Bus 5/Feeder:4 With DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	0.16555	1.728713147	0.2861885	3.507670854	15.777875	0.999599581	0.0004004
LP20	SW3	0.23255	15.24935911	3.5462385				
LP21	SW6	0.21305	16.18746051	3.4487385				
	SW9	0.16555	1.379090677	0.2283085				

LP22	*SW11*	*0.2228*	*15.43778484*	*3.4395385*
LP23	*SW14*	*0.23255*	*15.0003804*	*3.4883385*
	SW17	*0.16555*	*1.379090677*	*0.2283085*
LP24	*SW19*	*0.2228*	*15.43778484*	*3.4395385*
	SW22	*0.16555*	*1.909142021*	*0.3160585*
LP25	*SW24*	*0.21305*	*16.32733378*	*3.4785385*
LP26	*SW27*	*0.23255*	*15.3775036*	*3.5760385*

Table 4.4. HLIII Load points indices for the RBTS at Bus 6

Bus 6/Feeder:1 Without DG								
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	1.32665	0.469937436	0.6234425	4.327144856	3.1219007	0.999506034	0.000494
LP1	SW3	1.38065	2.765684641	3.8184425				
	SW6	1.32665	0.60222553	0.7989425				
LP2	SW8	1.39365	2.912454705	4.0589425				
	SW11	1.32665	0.767589417	1.0183225				
LP3	SW13	1.3904	3.065335515	4.2620425				
	SW16	1.32665	0.932945766	1.2376925				
LP4	SW18	1.38065	3.210547568	4.4326425				
	SW21	1.32665	1.065271549	1.4132425				
LP5	SW23	1.3904	3.349354502	4.6569425				
	SW26	1.32665	1.241655674	1.6472425				
LP6	SW28	1.38065	3.507146996	4.8421425				
	Bus 6/Feeder:1 With DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	1.32665	0.469937436	0.6234425	3.822259516	2.7576416	0.999563669	0.0004363
LP1	SW3	1.38065	2.765684641	3.8184425				
	SW6	1.32665	0.426308748	0.5655625				
LP2	SW8	1.39365	2.744980806	3.8255425				
	SW11	1.32665	0.45938454	0.6094425				
LP3	SW13	1.3904	2.771247483	3.8531425				
	SW16	1.32665	0.45938454	0.6094425				
LP4	SW18	1.38065	2.75554449	3.8044425				
	SW21	1.32665	0.426316285	0.5655725				
LP5	SW23	1.3904	2.739745757	3.8093425				
	SW26	1.32665	0.470412317	0.6240725				
LP6	SW28	1.38065	2.766119219	3.8190425				
	Bus 6/Feeder:2 Without DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	1.3559	0.438227377	0.5941925	4.412144977	3.1119688	0.99949633	0.0005037

LP7	*SW3*	*1.41965*	*2.70344275*	*3.8379425*				
	SW6	*1.3559*	*0.600023969*	*0.8135725*				
LP8	*SW8*	*1.4229*	*2.862845246*	*4.0735425*				
	SW11	*1.3559*	*0.729458293*	*0.9890725*				
LP9	*SW13*	*1.4229*	*2.986184904*	*4.2490425*				
	SW16	*1.3559*	*0.858892617*	*1.1645725*				
LP10	*SW18*	*1.4099*	*3.092093411*	*4.3595425*				
	SW21	*1.3559*	*1.031449591*	*1.3985425*				
LP11	*SW23*	*1.41965*	*3.270061283*	*4.6423425*				
	SW26	*1.3559*	*1.193260934*	*1.6179425*				
LP12	*SW28*	*1.4099*	*3.413676502*	*4.8129425*				
	SW31	*1.3559*	*1.322695258*	*1.7934425*				
LP13	*SW33*	*1.41965*	*3.548228437*	*5.0372425*				
	Bus 6/Feeder:2 With DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*1.3559*	*0.438227377*	*0.5941925*	*3.837041262*	*2.7063373*	*0.999561982*	*0.000438*
LP7	*SW3*	*1.41965*	*2.70344275*	*3.8379425*				
	SW6	*1.3559*	*0.4602644*	*0.6240725*				
LP8	*SW8*	*1.4229*	*2.729666526*	*3.8840425*				
	SW11	*1.3559*	*0.427902131*	*0.5801925*				
LP9	*SW13*	*1.4229*	*2.698884321*	*3.8402425*				
	SW16	*1.3559*	*0.427902131*	*0.5801925*				
LP10	*SW18*	*1.4099*	*2.677595929*	*3.7751425*				
	SW21	*1.3559*	*0.471046906*	*0.6386925*				
LP11	*SW23*	*1.41965*	*2.734788504*	*3.8824425*				
	SW26	*1.3559*	*0.4602644*	*0.6240725*				
LP12	*SW28*	*1.4099*	*2.708732889*	*3.8190425*				
	SW31	*1.3559*	*0.427902131*	*0.5801925*				
LP13	*SW33*	*1.41965*	*2.693581164*	*3.8239425*				
	Bus 6/Feeder:3 Without DG							
LP Nbr	***Segment_Name***	***Seg_LP_FR***	***Seg_LP_REP***	***Seg_DTs***	***SAIDI***	***Sys_CAIDI***	***ASAI***	***ASUI***
	SW1	*1.2389*	*0.467812172*	*0.5795725*	*3.822102045*	*2.9569777*	*0.999563687*	*0.0004363*

LP14	SW3	1.2929	2.919438858	3.7745425				
	SW6	1.2389	0.656689402	0.8135725				
LP15	SW8	1.28765	0.821125694	1.0573225				
	SW10	1.2389	0.798347324	0.9890725				
LP16	SW12	1.2909	0.967598187	1.2490725				
	SW14	1.2389	0.975415691	1.2084425				
LP17	SW16	1.2929	3.405864723	4.4034425				
	Bus 6/Feeder:3 With DG							
LP Nbr	**Segment_Name**	**Seg_LP_FR**	**Seg_LP_REP**	**Seg_DTs**	**SAIDI**	**Sys_CAIDI**	**ASAI**	**ASUI**
	SW1	1.2389	0.467812172	0.5795725	3.498022045	2.7062525	0.999600682	0.0003993
LP14	SW3	1.2929	2.919438858	3.7745425				
	SW6	1.2389	0.468312616	0.5801925				
LP15	SW8	1.28765	0.639880791	0.8239425				
	SW10	1.2389	0.421093309	0.5216925				
LP16	SW12	1.2909	0.605540708	0.7816925				
	SW14	1.2389	0.456511825	0.5655725				
LP17	SW16	1.2929	2.908610488	3.7605425				

4.4. Summary

This chapter presents the concepts of the application to overall assessment of a power system, which deals with actual customer levels of service, and illustrates the calculation of reliability indices at customer load points. It is an important requirement in today's changing utilities environment. Indices for the HLIII functional zone are presented and depicted here. At the *HLIII* system level, the required data are the results from the *HLII* analysis, and the distribution system analysis outcomes from chapter *2*, i.e. the relative contribution to the overall indices from *HLII* and the distribution functional zones.

Conclusion

The basic objective of the research work in this thesis is to develop a reliability evaluation of a complete electric power system including generation, transmission and distribution facilities, this study is also identified as *HLIII* assessment. The prime objective of the research on one hand is to put a foot in the world of power system reliability assessment by performing a reliability assessment at *HLIII*, i.e., to consider the independent failures in the three functional zones of generation, transmission and distribution, in order to obtain practical estimates of the reliability indices for each system customer load point. On the other hand, the objective was to have a base in the world of technical software, and specially reliability evaluation software.

The hierarchical level three *(HLIII)* adequacy assessments was performed, in this thesis the study do not starts at the *(HLI)* evaluation but it begins at the *(HLII)* study, this case is known as the composite system generation and transmission systems adequacy assessment, after that a distribution system assessment is achieved with the assumption of having *(HLII)* is *100%* reliable, after that and at the end the *(HLIII)* assessment can be completed by combining results from *(HLII)* and those obtained from the distribution system evaluation. It was possible to perform an adequacy study of *(HLI)* and *(HLII)* separately and then after combining the results to get the *(HLII)* results and then later perform *(HLIII)* adequacy evaluation, both ways gives the same results.

The well known Roy Billinton test system *(R.B.T.S)* is described in details and used in the study to show the performance of the techniques used in the assessments. Reliability indices were calculated for the entire system load points at all buses and for every system feeder.

The thesis presents basic indices for *HLII*, *HLIII* adequacy evaluation by application to the *R.B.T.S*. The overall adequacy evaluation is performed at load points of buses *3,4,5* and *6*. The basic adequacy indices are different for each hierarchical level and respond to the recognition of different factors and objectives at each level. *HLIII* adequacy indices are important as they recognize failures in all parts of an electric power system. The *HLIII* system performance indices depend on many factors, including the reliability of major components, such as generators, transmission lines, distribution feeder elements like, main circuit breakers and fuses.

Reliability indices were established for the *(HLII),* those indices concern the probability and the frequency for both system states and the failure events outgoing from these states. The expected load curtailment, expected energy not supplied and the expected durations emerging from these states are investigated. Frequencies and unavailabilities indices of each bus were also explored.

Apropos distribution system evaluation study, it was done separately i.e., without the effect of the generation and transmission system. In this case, a reliability analysis algorithm is presented. Sets calculations coupled with circuit traces are used to calculate the reliability of a given load point and the entire system at each bus. A computer program has been developed to implement this algorithm. The placement of distributed generation and its effects on reliability has been efficiently investigated. Here reliability indices produced by the reliability analysis program for particular segments and the entire system provide concrete figures to assess reliability improvements. At this level investigated over the related indices where established, these indices are related to individual load points and segments and others related to the entire system reliability, on one hand these indices show the failure rate, down time -unavailability- and the Rel_*CAIDI* for every load point in the feeders of the distribution system, on the other hand indices for the whole system are calculated such as, *SAIDI* and *Sys_CAIDI*.

Conclusions from the investigations concerning the distribution system assessment assuming that *HLII* is *100%* reliable are:

- The created reliability analysis algorithm is fast enough on large systems to be used in interactive design studies.
- A new reliability index, Relative_*CAIDI*, has been proposed which makes it easier for a design engineer to find circuit locations in need of improvement
- Placing distributed generators further out on a circuit, instead of locating them in the substation, can help enhance a system’s reliability.

In chapter *3* a draw up data generator as evaluation tools for the electrical system reliability of the grid networks was performed, it is a first try in its kind of work in Algeria. It is the realization stage of the technique described in chapter *2* used for the distribution system reliability evaluation. The programming method uses "object oriented" technology it allow to achieve multifunctional software called data generator. The software gives the possibility of drawing any pattern network with all the necessary components.

Thus, with the collected information by the data generator, studying and analyzing reliability; stability (dynamic and static) and load flow calculation, short-circuit calculation is possible.

At the end, adequacy indices were established for the *(HLIII)*, the calculation is done by using the appropriate techniques illustrated in chapter *4* these indices include the same indices calculated in the assessment of the distribution system (with the assumption that *HLII* is *100%* reliable). A comparison between these two sets of indices is investigated; this shows the effect of passing from *HLII* to *HLIII* on the individual load point indices and the entire system indices.

Furthermore in this research, an effort for overall power system reliability improvement is considered. This improvement in reliability is achieved by the interconnection of distributed generations *(DGs),* also known as distributed resources *(DRs)* to the system at the end points in the system feeder at each bus of the Roy Billinton test system *(R.B.T.S)*. The investigations were done by comparing the results between those calculated without the *DGs* and those after the introduction of the *DGs* in the system. The calculation shows that there is a patent improvement of the overall power system reliability. This gives to the *DGs* technologies an additional function to their use in today power system.

The techniques developed in this research work and described in this thesis cover a wide range of applications. The primary focus, however, was to develop procedures which can be used to evaluate load point indices in order to provide to the customers an adequate electric power delivery in quality and in continuity of service, associated with system configuration reinforcement and modifications. It is believed that the techniques described in this thesis can prove useful to power system planners and managers when considering alternate facilities configurations and in making decisions regarding reliability in electric power system.

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