Sudan University of Science and Technology

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School of Electrical and Nuclear Engineering

Power System Security (A case study: Yemeni National Grid)

أمن منظومة القدرة (دراسة حالة الشبكة الوطنية اليمنية للكهرباء)

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الآيــة

قَالَ تَعَالَىٰ:

أَعُوذُ بِٱللَّهِ مِنَ ٱلشَّيۡطَٰنِ ٱلرَّجِيمِ ﴿ إِذۡ قَالَ مُوسَىٰ لِأَهۡلِهِۦٓ إِنِّيٓ ءَانَسۡتُ نَارٗا سَـَٔاتِيكُم
مِّنۡهَا بِخَبَرٍ أَوۡ ءَاتِيكُم بِشِهَابٖ قَبَسٖ لَّعَلَّكُمۡ تَصۡطَلُونَ ﴿٧﴾ ﴾ النمل: ٧

Dedication

To the merciful and beautiful soul how suffer for me to bring me up, and every moment she asks Allah to help me;

My mother.

To the strong powered man, who always guides me up and always treat me as a future man and always gives me advices, the man who see himself in mine;

My father.

To the awesome family flowers;

My brothers and sister.

To my big brother who continuously encourage me to keep my study up;

Adnan Hussein.

To the one who suffers with me, and always askes Allah to help me;

My wife.

To my close friend, my director and motivator in a lot of life issues;

Dr. Mohammed Azzuddin Adlan.

To all of my friends, and all of classmates in the master, who encourage me, and help me in facing a lot of issues during the master period.

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Abstract

Maintaining power system security is one of the challenging tasks for the power system engineers. The security assessment is an essential task as it gives the knowledge about the system state in the event of a contingency; where power system becomes more severe under contingency conditions. In general, the contingencies may be outage of transmission lines or generators. To identify the effect of outages on system security, the contingency analysis is one of the analytical tools. This dissertation discusses the security of the power system for the purpose of maintaining the continuity of the power flow from the station to the consumers within rated values whatever the circumstances of the generation stations. The main objective of this dissertation is to study the security assessment of the power system in general, and then the study is extended to investigate the system security assessment of Yemen National grid (YNG) as a case study, presenting contingency analysis to predict the line outage (n-1), and to study the states of keeping the system secure and reliable by using load-flow method. DigSILENT power-factory version15 program is used to carry out the simulation of Yemen national grid (YNG), to fulfill these contingency studies. The obtained results are analyzed and discussed using analytical tables and figures and system security is evaluated. According the results of the dissertation the system "Yemen National Grid" is not secure.

المستخلص

الحفاظ على التشغيل الآمن لنظام القدرة يشكل تحدٍ كبير لمهندسي ومشغلي نظم القدرة . تقييم امن نظام القدرة له اهمية كبيرة في إعطاء معلومات عن حالة النظام في حالة حدوث أي عطل طارئ قد يجعل عمل النظام اكثر خطورة ، وفي الغالب يكون العطل الطارئ عبارة عن خروج احد خطوط النقل او المولدات . لمعرفة تأثير الإنقطاع على امن النظام فإن تحليل الحالة الطارئة يعتبر واحداً من الطرق التحليلة المستخدمة للتنبؤ بمثل تلك الحالات . تناقش الاطروحة التشغيل الآمن لنظام القدرة لغرض الحفاظ على استمراية تدفق القدرة بين محطات التوليد والمستهلكين في ظروف تشغلية معتبرة . الهدف الرئيسي من هذه الأطروحة هو دراسة وتقييم امن منظومة القدرة ، ومن ثم التحقق من التشغيل الآمن للشبكة الوطنية اليمنية (YNG) كدراسة حالة بإستخدام تحليل الطوارئ للتنبؤ بحالة النظام في حالة خروج احد خطوط النقل(n-1) ، وقد استخدمت طريقة تدفق القدرة لإجراء الدراسة . تم استخدام برنامج المحاكاة الحاسوبي (DigSILENT) لتمثيل ومحاكاة الشبكة الوطنية اليمنية . كما تم مناقشة وتحليل النتائج التي تم الحصول عليها عن طريق الجداول والرسومات التوضيحية لتقييم وضع وامن الشبكة . ومن خلال النتائج اتضح ان المنظومة "شبكة كهرباء اليمن" ليست آمنة .

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LIST OF ABBREVIATION

YNG	Yemen national grid
NERC	North American Electric Reliability Council
DSA	Dynamic security assessment
EMS	Energy management systems
SCADA	Supervisory control and data acquisition
RTU	Remote terminal units
SE	State estimator
DC	Direct current
AC	Alternative current
ANN	Artificial Neural Networks
FDLF	Fast decoupling load flow
PI	Performance index
PI_p	Active power performance index
PI_v	Reactive performance index
OPI	Overall performance index
DPF	Deterministic power flow
NRLF	Newton-Raphson load flow

Chapter one

Introduction

1.1 Overview:

Up until now engineers and planners have been mainly concerned with minimizing the cost of operating a power system. An overriding factor in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken offline because of auxiliary equipment failure. By maintaining proper amounts of spinning reserve, the remaining units on the system can make up the deficit without too low a frequency drop or need to shed any load. Similarly, a transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generation, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit [1].

“Security of power systems” provides an overview of the main issues related to the security of power systems. power system security concern is the ability of the system to operate such that sudden perturbations, such as short circuits in lines, loss of critical system components, grid congestion etc, do not give rise to loss of load or cause stress of system components beyond their ratings [2].

In power system stations two main studies are the most essential studies “Adequacy study is the ability to supply energy to satisfy load demand”, “security study is the ability of the system to withstand sudden disturbances”, a power system is said to be secured when it is free from danger or risk.

Power system security is understood as the ability of the power system to survive plausible contingencies without interruption to customer service. Power system security and power system stability are related terms. Stability is an important factor of power system security, but security is a wider term than stability. Security not only includes stability, but also encompasses the integrity of a power system and assessment of the equilibrium state from the point of view of overloads, under- or overvoltage and under frequency [3].

1.2 Problem Statement:

Now a day, because of the restructuring and deregulation of the power system network, the operation, control and management of the system becomes one of the most challenging tasks [3]. In competitive electricity markets, customers expect a least-cost and high-quality supply of electric energy, which may require additional investments and more sophisticated operation techniques for enhancing power systems security [4].

Electric power system has one of the most complex designs that is built and operated by engineers. The modern power system is ever increasing in size and complexity due to the high load demands from power energy consumers. However, electric power networks operating at this state are constantly subjected to contingencies in form of internal and external disturbances which are capable of causing instability. The need to determine the security status of these power systems during such conditions thus, evolves [5].

Therefore, maintaining power system security is one of the challenging tasks in the power system engineering, because of this aspect of systems operation, modern operations computers are equipped with contingency analysis programs that model possible systems troubles before they arise.

1.3 Objectives:

Yemen National Grid (YNG) has numerous of problems such as overloading, stressed power system, and voltage instability the majority of these problems occur due to inequality of the generation and load-demand. This dissertation study the security of Yemen National Grid (YNG) using contingency analysis program". The specified objective of this dissertation is to assist the security of transmitted power in Yemen National Grid (YNG).

1.4 Methodology /Approach:

Starting with studying power flow analysis, this dissertation study the state of Yemen national grid (YNG) in the steady state condition with normal operation. Any bus voltage must be in the range of (±1.05-0.95)pu in the normal operation.

The next stage is to apply contingency analysis to investigate which component is in the most severe dangerous during any contingency. The "N-1" contingency analysis has been used for such check, this methodology leads to the definition of "sizing incidents", or credible contingencies.

Computer programs are usually used to study the state of the grid by creating approached simulations. In this dissertation DigSILENT power factory program is used to carry out the simulation of Yemen National Grid (YNG).

1.5 Dissertation layout:

This dissertation is organized as following: Chapter two is devoted to the literature review, includes basic concepts related to power system security analysis, power system security problems, and discusses the method of power system security prediction “contingency analysis”. Chapter three discuss the methods of power system security solutions, discusses contingency analysis methods, contingency analysis using sensitivity factor, contingency analysis using artificial neural network method, and power-flow methods. Chapter four discusses Yemen National Grid (YNG) as a case study, it includes simulation for the grid with its results and discussion of the results. Finally, conclusion and recommendations are given in chapter five.

Chapter Two

Literature Review

2.1 Power System Security Definition:

Electric power energy is one of the most widely used forms of energy in the universe, and hence, has one of the most complex designs that is built and operated by engineers. Modern power system is ever increasing in size and complexity due to the high load demands from power energy consumers. Economic and technological reasons have caused most utilities to be interconnected into vast power grids in order to maximize efficiency of generation and distribution of electric power. In response to further economic pressure, another possible means of increasing efficiency is to operate assets closer to their thermal and stability limits. However, electric power networks operating at this state are constantly subjected to contingencies in form of internal and external disturbances which are capable of causing instability. The need to determine the security status of these power systems during such conditions thus, evolves [5].

In general, the main aim of power system operation and control is to meet the demand continuously without any failures. While, in this operation, sometimes, outage of generator due to failure of the auxiliary equipment or removal of a transmission line for maintenance purpose or due to storm and other effects may happens. Due to which, the system frequency may drop and leads to load shedding or uncontrolled operation and sometimes leads to system collapse condition. This happens mainly due to the overloading of the transmission lines, voltage deviation at the load buses and lack of reactive power support at the load buses [6].

North American Electric Reliability Council [NERC] defines reliability as the degree to which the performance of electrical system could results in power being delivered to consumers within accepted standards and desired amounts. NERC's definition of reliability encompasses two concepts: adequacy and security. Adequacy is the ability of a power system to supply consumers' electric power and energy requirements at all times. Security is defined as the ability of a power system to withstand sudden disturbances. In plain language, adequacy implies that sufficient generation and transmission resources are available to meet projected needs plus reserves for contingencies. Security implies that the power system will remain intact even after outages or equipment failures [4].

Power System Security concerns the technical performance and quality of service when a disturbance causes a change in system conditions [5]. Security is a term used to reflect a power system's ability to meets its load without unduly stressing its apparatus or allowing variables to stray from prescribed range under the apparatus or allowing variables to stray from prescribed range under certain pre-specified credible contingencies [7].

Security assessment can be categorized into static security assessment and dynamic security assessment. A static security assessment is usually based on a load flow analysis and deals with steady-state limit violations [5]. The process of obtaining this steady-state condition is known as security monitoring, while the process of obtaining limit violations depicts static security assessment. So many techniques have been developed to assess the steady-state operation of a power system using the power flow measure. In addition to the steady-state operation, the power system must be able to survive dynamic events [5].

Power system steady-state security analysis is one of the most important issues in power system. Contingency evaluation is one aspect of power system security assessment. Some cases in the contingency set may lead to transmission line overloads or bus voltage limit violations during power system operations. Such critical contingencies should be quickly identified for further detailed evaluation. The process of identifying these critical contingencies is referred to as contingency selection which uses the complete AC load flow program considering outage of each line or generator [8].

Dynamic security assessment (DSA) is more computationally intensive as it requires the electro-mechanical transient stability analysis of the system which concerns the transient behavior of the power system when moving from the pre to post-contingency operating point [5].

Dynamic Security Assessment (DSA) determines the capability of the system to withstand all credible contingencies, taking into considerations the detailed dynamic characteristics of the system. The system is said to be dynamically secure, if all of its synchronous machines maintain synchronism for a long duration, after it has been found to be transiently secure. It is a long term stability phenomenon with a time frame of study of the order of few seconds to minutes [9].

2.2 Outage Categories in Power Systems:

All equipment in a power system is designed such that it can be disconnected from the network. The reasons for these disconnections are generally divided into two categories: scheduled outages and forced outages [1].

2.2.1 **Scheduled outages:**

Are typically done to perform maintenance or replacement of the equipment, and, as its name implies, the time of disconnect is scheduled by operators to minimize the impact on the reliability of the system.

2.2.2 **Forced outages:**

Are those that happen at random and may be due to internal component failures or outside influences such as lightning, wind storms, ice buildup, etc. [1].

Because the specific times at which forced outages occur are unpredictable, the system must be operated at all times in such a way that the system will not be left in a dangerous condition should any credible outage event occur. Since power system equipment is designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If a forced outage occurs on a system that leaves it operating with limits violated on other components, the event may be followed by a series of further actions that switch other equipment out of service. If this process of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout [1].

2.3 Factors Affecting Power System Security:

As a consequence of many widespread blackouts in interconnected power systems, the priorities for operation of modern power systems have evolved to the following:

(1) Operate the system in such a way that power is delivered reliably.

(2) Within the constraints placed on the system operation by reliability considerations, the system will be operated most economically [1].

It is impossible to build a power system with so much redundancy (i.e., extra transmission lines, reserve generation, etc.) that failures never cause load to be dropped on a system. Rather, systems are designed so that the probability of dropping load is acceptably small. Thus, most power systems are designed to have sufficient redundancy to withstand all major failure events, but this does not guarantee that the system will be 100% reliable [1].

Within the design and economic limitations, it is the job of the operators to try to maximize the reliability of the system they have at any given time. Usually, a power system is never operated with all equipment "in" (i.e., connected) since failures occur or maintenance may require taking equipment out of service. Thus, the operators play a considerable role in seeing that the system is reliable [1].

One the possible consequences and remedial actions required by two major types of failure events is transmission-line outages, this failure can cause changes in the flows and voltages on the transmission equipment remaining connected to the system. Therefore, the analysis of transmission failures requires methods to predict these flows and voltages so as to be sure they are within their respective limits [1].

2.4 Transmission Outage:

2.4.1 Transmission line outages:

When a transmission line or transformer fails and is disconnected, the flow on that line goes to zero and all flows nearby will be affected. The result can be a line flow limit or bus voltage limit violation. There is no way to know which line or transformer outage is going to cause the worst violations. The operators therefore usually want to check as many of them as possible, as often as possible. Thus, the operators may seek to model and calculate the outage effects from an outage of every line and transformer in the system [1].

2.4.2 **Double outages:**

An even more difficult analysis is to check all pairs of possible simultaneous outages, which is denoted (n − 2). Thus, all pairs of generators, and all pairs of transmission lines as well as pairs of single generator outages plus a possible single transmission-line outage at the same time would have to be analyzed. This (n − 2) analysis is much more difficult because of the extremely large number of cases to model. The usual practice is to only study a few of the (n − 2) cases that are known by experience to be the most serious cases [1].

2.4.3 **Reactive losses:**

The reactive losses in the transmission system have a big effect on the voltages at the buses. There are two components to the reactive losses: the MVAR consumed by the line and transformer inductive reactance calculated as

$$\text{Inductive Losses} = \sum_{\text{all linces } \ell} I_\ell^2 \, x_\ell \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where,

Line current = I_ℓ

Line inductive reactance = x_ℓ

Note that the reactive power consumed by the transmission lines is proportional to the square of the line current. As lines become heavily loaded, this term goes up and more reactive power must be supplied from some other resource. The next term is the reactive power injected back into the power system by the capacitive charging of the transmission line, which we model as a capacitance at each end of the line. This term, because it is feeding reactive power into the network, is a negative loss. Its calculation is

$$\text{Negative losses} = -\sum_{\text{all linces } \ell} (V^2_{\substack{\text{from end of} \\ \text{line } \ell}} B_{\text{cap}_\ell} + V^2_{\substack{\text{to end of} \\ \text{line } \ell}} B_{\text{cap}_\ell} \quad \ldots\ldots\ldots\ldots\ldots \text{(2.2)}$$

Where,

B_{cap_ℓ}=capacitance at each end of the line

Last of all, we need to account for any fixed capacitors injecting reactive power into buses:

$$\text{Injecting reactive power into buses} = -\sum_{\text{all linces i}} V_i^2 B_{\substack{\text{fixed cap} \\ \text{at line i}}} \quad \ldots\ldots\ldots \text{(2.3)}$$

$B_{\substack{\text{fixed cap} \\ \text{at line i}}}$= fixed capacitors injecting at line ℓ

Then the reactive losses are calculated using the sum of these three terms:

$$\text{Reactive power losses} = \sum_{\text{all linces } \ell} I_\ell^2 x_\ell - \sum_{\text{all linces } \ell} (V^2_{\substack{\text{from end of} \\ \text{line } \ell}} B_{\text{cap}_\ell} + V^2_{\substack{\text{to end of} \\ \text{line } \ell}} B_{\text{cap}_\ell} - \sum_{\text{all linces i}} V_i^2 B_{\substack{\text{fixed cap} \\ \text{at line i}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.4)}$$

In reviewing the power flow cases in this section, the reference to this term as well as the real power losses that are defined as [1].

Real power losses = $\sum_{\text{all linces } \ell} I_\ell^2 \, r_\ell$ ……………………………….. (2.4)

r_ℓ= line Resistance

2.5 The Major Functions of Power System Security:

The on-line security analysis is performed by energy management systems (EMS) at power system control centers. On-line security analysis encompasses two main parts: system monitoring and contingency analysis. System monitoring is exclusively a real-time function, but contingency analysis, which is discussed in this in chapter 3, is also used in off-line applications considered in other time scales [1].

2.5.1 Contingency Analysis:

Contingencies are defined as potentially harmful disturbances that occur during the steady state operation of a power system. Load flow constitutes the most important study in a power system for planning, operation and expansion. The purpose of load flow study is to compute operating conditions of the power system under steady state. These operating conditions are normally voltage magnitudes and phase angles at different buses, line flows (MW and MVAR), real and reactive power supplied by the generators and power loss [10].

Contingency simulation is an essential procedure for power system security assessment, reliability evaluation, and real time operation. It is important that simulation methods solve the post contingency situation realistically. Also, because of the large number of system contingencies, solution methods must be efficient with acceptable accuracy [11].

The most straightforward simulation method is to run AC power flow using the iterative algorithm for each contingency. Although it provides accurate power flow solutions, this procedure, which involves a huge number of AC load flow calculations, is extremely costly from the computational point of view. To reduce the computational effort required for contingency simulations, some techniques have been developed in past several decades. These techniques include mainly subnetwork solutions, contingency ranking/screening methods, compensation methods, sparsity techniques, approximate load flow algorithms, and so on [11].

When referring to contingency analysis, it is essentially referred to the analysis of abnormal system conditions. In general, contingency analysis can be defined as: "the evaluation of the violations in system operating states (if any) that certain contingencies can pose to the electrical power system"; or put in other words, contingency analysis is the execution and evaluation (loading and voltage-wise) of post-fault load flows; each of which reflect the "outage" of a single or group of elements (such as transformers, bus bars , transmission lines, etc.) [12].

The main security function contingency analysis is the study of power system by which change in power flow in lines and bus voltage on the system due to any unscheduled outage of a line component or generator or any disturbances such as change in load demand is assessed [12].

By avoiding system troubles before their occurrence is contingency analysis. This happens by studying the outage events and alerting the operators to any potential over loads or serious voltage violations [12].

2.5.2 Contingency Analysis with Optimal Power Flow:

A contingency analysis is combined with an optimal power flow that seeks to make changes to the optimal dispatch of generation, as well as other adjustments, so that when a security analysis is run, no contingencies result in violations. To show how this can be done, the power system shall be divided into four operating objectives [1].

(1) Normal state dispatch: This is the state that the power system is in prior to any contingency. It is optimal with respect to economic operation, but it may not be secure. Suppose the trivial power system consisting of two generators, a load, and a double circuit line is to be operated with both generators supplying the load as shown in figure 2.1 (ignore losses):

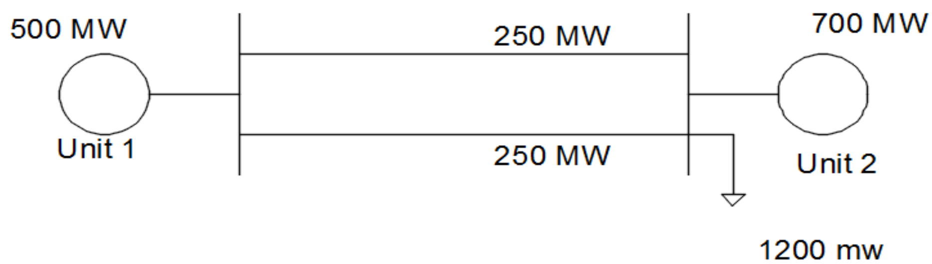

Figure 2.1: Normal dispatch of the system

Assume that the system as shown is in economic dispatch; that is, the 500 MW from unit 1 and the 700 MW from unit 2 are the optimum dispatch. Further, each circuit of the double circuit line can carry a maximum of 400 MW, so that, there is no loading problem in the base-operating condition.

(2) Post contingency: This is the objective after a contingency has occurred. Assume that this condition has a security violation (line or transformer beyond its flow limit or a bus voltage outside the limit).

Now, one of the two circuits making up the transmission line suffered a forced outage and opened. This results in the flows shown in the figure 2.2:

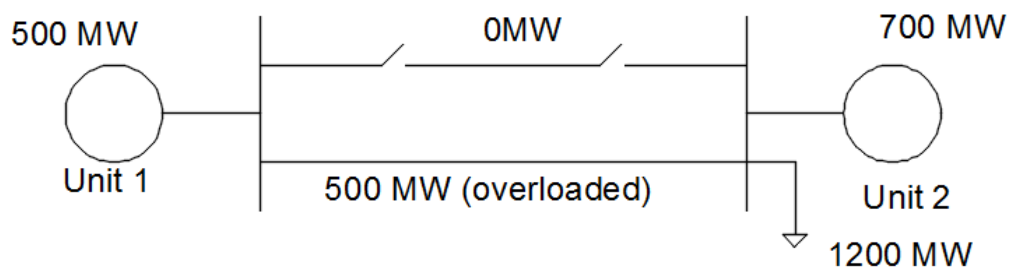

Figure 2.2: Post contingency state

There is an overload on the remaining circuit.

(3) Secure dispatch: This is the objective with no contingency outages is to correct the operating parameters to account for security violations.

Assume for this example this condition is not significant to arise and correct the condition by lowering the generation on unit 1 to 400 MW. The secure dispatch is in the figure 2.3.

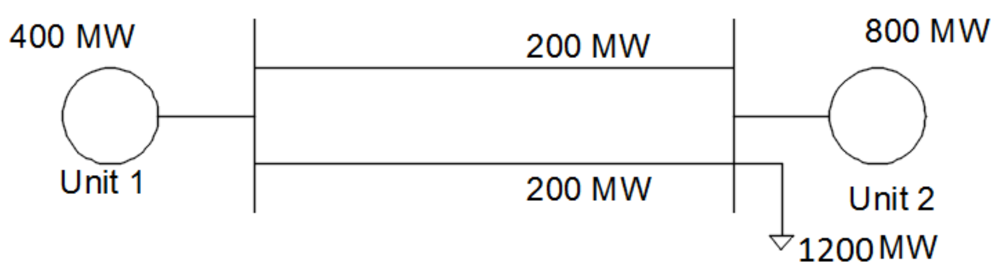

Figure 2.3: Secure dispatch

(4) Secure post-contingency: The objective is to re-mediate the contingency as applied to the base-operating condition with corrections. Now, if the same contingency analysis is done, the post contingency condition is shown in figure 2.4 [1].

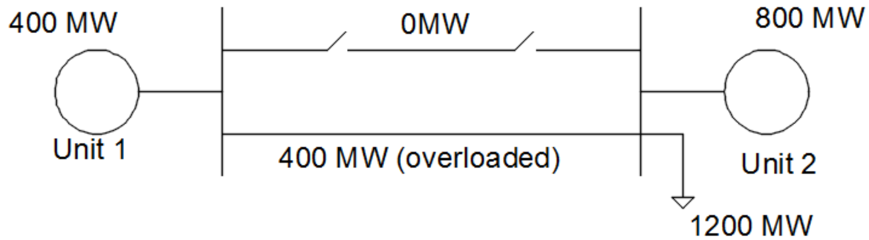

Figure2.4: Secure post-contingency

2.5.3 System Monitoring:

A power system is monitored through the supervisory control and data acquisition (SCADA) system installed at control centers. SCADA collects real-time data from remote terminal units (RTUs) installed in substations and power plants and distributed throughout the power system. SCADA scans RTUs at a frequency of about 2–5 s. The data acquired typically include watts, VARs, volts, amps, kilowatt hours, frequency, circuit breaker status, and tap changing and phase shifting transformer settings. These data are transmitted to the system control center and stored in the SCADA/EMS real-time database [4]

The system operator then monitors and controls the system in real time with the help of a state estimator (SE) program. The SE periodically computes an estimate of the operating state of the subnetwork of interest, which is almost always a part of a larger network. For the purposes of contingency analysis, the complete model computed by SE consists of the monitored subnetwork and an external equivalent that approximates the effects of the surrounding global network [4].

Chapter Three
Contingency Analysis Technique

3.1 Introduction:

The first method has been in use for many years and goes under various names such as "D factor methods," "linear sensitivity methods," "DC power flow methods," etc. This approach is useful if one only desires an approximate analysis of the effect of each outage. These methods are presented under the name linear sensitivity factors and uses the same derivation in [1], under the DC power flow methods. It has all the limitations attributed to the DC power flow; that is, only branch MW flows are calculated and these are only within about [$\pm$5%] accuracy. There is no knowledge of MVAR flows or bus voltage magnitudes [1].

If it is necessary to know a power system's MVA flows and bus voltage magnitudes after a contingency outage, then some form of complete AC power flow must be used. This presents a great deal of difficulty when thousands of cases must be checked. It is simply impossible, even on the fastest processors, to execute thousands of complete AC power flows quickly enough. Fortunately, this need not be done as most of the cases result in power flow results that do not have flow or voltage limit violations. There is needy of a technique to eliminate all or most of the non-violation cases and only run complete power flows on the "critical" cases. These techniques go under the names of "contingency selection" or "contingency screening" [1].

3.2 Contingency Analysis using Sensitivity Factors:

The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. One of the easiest ways to provide a quick calculation of possible overloads is to use sensitivity factors [1]. These factors show the approximate change in line flows for changes in generation on the network configuration and are derived from the DC load flow. These factors can be derived in a variety of ways and basically come down to two types:

(1) Generation Shift Factors.

(2) Line Outage Distribution Factors.

The generation shift factors are designated $\alpha_{\ell i}$ and have the following definition:

$$\alpha_{\ell i} = \frac{\Delta f_\ell}{\Delta P_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

where

ℓ = line index , i =bus index

Δf_ℓ = change in megawatt power flow on line ℓ when a change in generation ΔP_i occurs at bus i

ΔP_i = change in generation at bus i .

It is assumed that the change in generation ΔP_i is exactly compensated by an opposite change in generation at the reference bus, and that all other generators remain fixed. The $\alpha_{\ell i}$ factor then represents the sensitivity of the flow on line ℓ due to a change in generation at bus i. If the generator was generating P_i^0 MW and it was lost, it is represented by ΔP_i, as the new [1].

$$\Delta P_i = -P_i^0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

power flow on each line in the network could be calculated using a pre calculated set of “α” factors as follows:

$$f_\ell = f_\ell^0 + \alpha_{\ell i}\Delta P_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

for $\ell = 1 \ldots L$

where,

f_ℓ = flow on line ℓ after the generator on bus i fails

f_ℓ^0 = flow before the failure

The outage flow f_ℓ on each line can be compared to its limit and those exceeding their limit are flagged for alarming. This would tell the operations personal that the loss of the generator on bus i would result in an overload on line ℓ. The generation shift sensitivity factors are linear estimates of the change in flow with a change in power at a bus. Therefore, the effects of simultaneous changes on several generating buses can be calculated using superposition [1].

The line outage distribution factors are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{\ell,k} = \frac{\Delta f_\ell}{f_k^0} \quad \ldots\ldots\ldots\ldots\ldots\ldots;\ldots\ldots\ldots\ldots \text{(3.4)}$$

Where

$d_{\ell,k}$ =line outage distribution factor when monitoring line ℓ after an outage on line k

Δf_ℓ =change in MW flow on line ℓ

f_k^0 =original flow on line k before it was outaged i.e., opened

If one knows the power on line ℓ and line k, the flow on line ℓ with line k out can be determined using "d" factors.

$$f_{\ell} = f_{\ell}^{0} + d_{\ell,k} f_{k}^{0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

Where

f_{ℓ}^{0} and f_{k}^{0} = pre outage flows on lines ℓ and k, respectively

f_{ℓ}= flow on line ℓ with line k out.

By pre calculating the line outage distribution factors, a very fast procedure can be set up to test all lines in the network for overload for the outage of a particular line. Furthermore, this procedure can be repeated for the outage of each line in turn, with overloads reported to the operations personnel in the form of alarm messages. The generator and line outage procedures can be used to program a digital computer to execute a contingency analysis study of the power system. It is to be noted that a line flow can be positive or negative so that we must check f_{ℓ} against $-f_{\ell}^{max}$ as well as f_{ℓ}^{max}. It is assumed that the generator output for each of the generators in the system is available and that the line flow for each transmission line in the network is also available and the sensitivity factors have been calculated and stored [1].

3.3 Contingency Analysis Using Artificial Neural Network:

The contingency analysis process by conventional load flow solution using Fast decoupling load flow(FDLF) can give the solution to the contingency selected only for one loading and generating condition at one go. But practically a power system can have a varying level of operating conditions and to predict the solution of contingency analysis for all the possible and future operating points is an impossible task. In such cases, the use of Artificial Neural Networks (ANN) can be useful. Since ANN has the ability to predict the output for unseen input set once it gets trained with sufficient number of training patterns. It has been used for dynamic nature problems in power system like contingency analysis, load forecasting, component fault detection etc. The ability of Neural Networks to predict the outcome for a new pattern in a fast and accurate manner makes them suitable for online analysis also [13].

3.4 Contingency Selection:

Since contingency analysis process involves the prediction of the effect of individual contingency cases, the above process becomes very tedious and time consuming when the power system network is large. In order to alleviate the above problem contingency screening or contingency selection process is used. Practically it is found that all the possible outages do not cause the overloads or under voltage in the other power system equipment's. The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection. The contingencies are selected by calculating a kind of severity indices known as Performance Indices(PI) [1].

3.5 Contingency Ranking Approach:

The use of AC power flow solution in contingency analysis is that it gives active, reactive power flows and magnitudes of bus voltage. In power system contingency ranking approach, line outage case has been considered and the ranking is given based on the severity measured using the performance index. These indices are computed using the load flow (Newton Raphson Method) for each contingency. Based on the performance index obtained the contingencies are ranked starting with the highest value of PI [8].

3.5.1 Performance Indices:

There are two kind of performance indices are in use, active power performance index(PI_p) and reactive performance index(PI_v) .

(PI_p) reflects the violation of line active power flow in is given by

$$PI_p = \sum_{i-1}^{n} \left(\frac{P_i}{P_{imax}}\right)^{2m} \quad \text{.............................……...… (3.6)}$$

Where

P_i = active power flow in line i

P_{imax}= maximum active power flow in line i

m = the specified exponent

n = total of the transmission lines in the system

If m is a large number, the PI will be a small number if all flows are within limit, and it will be large if one or more lines are overloaded. Here the value of n has been kept unity. The value of maximum power flow in each line is calculated using the formula:

$$P_{imax} = \frac{V_i * V_j}{X} \quad \text{………………………………………………..... (3.7)}$$

Where:

V_i = Voltage at bus i obtained from solution

V_j = Voltage at bus j obtained from solution

X = Reactance of the line connecting bus $'i'$ and bus $'j'$

Another performance index parameter which is used is reactive power performance index corresponding to bus voltage magnitude violations. It mathematically given the last equation above. Reactive performance index(PI_v). Corresponding to the bus voltage magnitude violation (PI_v) is used ,and it is given by.

$$PI_v = \sum_{i=1}^{N_{pq}} \left(\frac{2(V_i - V_{inom})}{V_{imax} - V_{imin}}\right)^2 \quad \text{……………..………... (3.8)}$$

Where

V_i = voltage in bus i

V_{imax} = maximum voltage limit

V_{imin} = minimum voltage limits

V_{inom} = average of V_{imax} and V_{imin}

N_{pq} = total number of load buses in the system [1].

For calculation of PI_v it is required to know the maximum and minimum voltage limits, generally a margin of + 5% is kept for assigning the limits i.e. 1.05 P.U. for maximum and 0.95 P.U. for minimum. It is to be noted that the above performance indices are useful for performing the contingency selection for line contingencies only. To obtain the value of PI for each contingency the lines in the bus system are being numbered as per convenience, then a particular transmission line at a time is simulated for outage condition and the individual power flows and the bus voltages are being calculated with the help of fast decoupled load flow solution [8].

3.6 Contingency Analysis using Power Flow:

The conventional deterministic power flow (DPF) is the most widely used tool in power system analysis, operations, planning and control [14].

Power-flow studies are of great importance in planning and designing the future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from a power-flow study is the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line. However, much additional information of value is provided by the printout of the solution from computer programs used by the electric utility companies [15].

Power flow studies, commonly referred to as load flow, are essential of power system analysis and design. Load flow studies are necessary for planning, economic operation, scheduling and exchange of power between utilities. Load flow study is also required for many other analyses such as transient stability, dynamic stability, contingency and state estimation [16].

3.6.1 Bus classifications:

Four quantities are associated with each bus. These are voltage magnitude $|V|$, phase angle δ, real power P(MW) and reactive power Q(Mvar). In a load flow study, two out of four quantities are specified and the remaining two quantities are to be obtained through the solutions of equations. The system buses are generally classified into three categories [16].

(1) Slack bus: Also known as swing bus and taken as reference where the magnitude and phase angle of the voltage are specified. This bus provides the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained.

(2) Load buses: Also known as PQ bus. At these buses the real and reactive powers are specified. The magnitude and phase angle of the bus voltage are unknown until the final solution is obtained.

(3) Voltage controlled buses: Also known as generator buses or regulated buses or $P|V|$ buses. At these buses, the real power and voltage magnitude are specified. The phase angles of the voltages and the reactive power are unknown until the final solution is obtained. The limits on the value of reactive power are also specified [16].

3.6.2 Power-flow analysis:

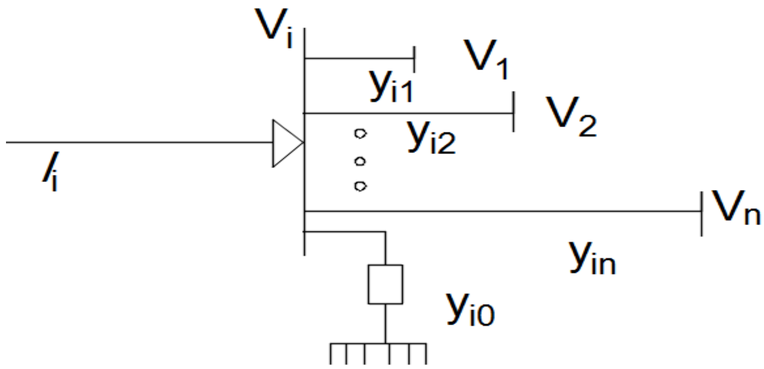

Figure3.1: show I − th bus of power system

Net injected current Ii into the bus i can be written as

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i1}(V_i - V_2) + \cdots + y_{in}(V_i - V_n) \ldots. (3.8)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_{i1} - y_{i2}V_2 - \cdots - y_{in}V_n \quad \ldots\ldots (3.9)$$

Let us define

$$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in} \quad \ldots\ldots (3.10)$$

$$Y_{i1} = -y_{i1}$$

$$Y_{i2} = -y_{i2}$$

$$Y_{in} = -y_{in}$$

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n \quad \ldots\ldots (3.11)$$

Or

$$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \quad \ldots\ldots (3.12)$$

The real and reactive power injected at bus I is

$$P_i - jQ_i = V_i^* I_i \quad \ldots\ldots (3.13)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad \text{...} (3.14)$$

From the last equation we get

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \quad \text{...} (3.15)$$

$$Y_{ii}V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \quad \text{......................................} (3.16)$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \quad \text{......................................} (3.17)$$

Where,

$$Y_{ii} = |Y_{ii}|\llcorner\theta_{ii},\ Y_{ik} = |Y_{ik}|\llcorner\theta_{ik} \quad \text{......................................} (3.18)$$

$$V_i = |V_i|\llcorner\delta_i$$

$$V_k = |V_k|\llcorner\delta_k,\ \ V_i^* = |V_i|\llcorner-\delta_i \quad \text{......................................} (3.19)$$

I_i = injected current

V = bus voltage , $V_i, V_1, V_2, \dots\dots, V_n$

y = impedance of the line connecting between two buses [14].

3.6.3 Newton-Raphson Method:

The most widely used method for solving power flow problems nonlinearly is Newton-Raphson method [17].

Newton-Raphson (NR) method is more efficient and practical for large power systems. Main advantage of this method is that the number of iterations required to obtain a solution is independent of the size of the problem and computationally it is very fast. Here loads flow problem is formulated in polar form [16].

By solving the eqn. (3.17), the eqns. (3.20) and (3.21) can be produced, and they are given as

$$P_i = \sum_{k=1}^{n}|V_i||V_k||Y_{ik}|\cos(\theta_{ik} - \delta_i + \delta_k) \quad \text{......................................} (3.20)$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}||V_i||V_k| \sin(\theta_{ik} - \delta_i + \delta_k) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.21)}$$

The last two eqns. (3.20) and (3.21) constitute a set of nonlinear algebraic equations m terms of the independent variables, voltage magnitude in per unit and phase angles in radians.it can be easily observed that two equations for each load bus given by eqn. (3.20) and (3.21) and one equation for each voltage controlled bus, given by eqn. (3.20). Expanding eqns. (3.20) and (3.21) in Taylor-series and neglecting higher-order terms. We obtain [16].

$$\begin{bmatrix} \Delta P_2^p \\ . \\ \vdots \\ \frac{\Delta P_n^p}{\Delta Q_2^p} \\ \vdots \\ . \\ \Delta Q_n^p \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} \left(\frac{\partial P_2}{\partial \delta_2}\right)^p & \cdots & \left(\frac{\partial P_2}{\partial \delta_2}\right)^p \\ \vdots & \ddots & \vdots \\ \left(\frac{\partial P_n}{\partial \delta_2}\right)^p & \cdots & \left(\frac{\partial P_2}{\partial \delta_n}\right)^p \end{pmatrix} & \cdots & \begin{pmatrix} \left(\frac{\partial P_2}{\partial |V_2|}\right)^p & \cdots & \left(\frac{\partial P_2}{\partial |V_2|}\right)^p \\ \vdots & \ddots & \vdots \\ \left(\frac{\partial P_n}{\partial |V_2|}\right)^p & \cdots & \left(\frac{\partial P_n}{\partial |V_n|}\right)^p \end{pmatrix} \\ \vdots & \ddots & \vdots \\ \begin{pmatrix} \left(\frac{\partial Q_2}{\partial \delta_2}\right)^p & \cdots & \left(\frac{\partial Q_n}{\partial \delta_2}\right)^p \\ \vdots & \ddots & \vdots \\ \left(\frac{\partial Q_2}{\partial \delta_2}\right)^p & \cdots & \left(\frac{\partial Q_2}{\partial \delta_n}\right)^p \end{pmatrix} & \cdots & \begin{pmatrix} \left(\frac{\partial Q_2}{\partial |V_2|}\right)^p & \cdots & \left(\frac{\partial Q_2}{\partial |V_2|}\right)^p \\ \vdots & \ddots & \vdots \\ \left(\frac{\partial Q_n}{\partial |V_2|}\right)^p & \cdots & \left(\frac{\partial Q_n}{\partial |V_n|}\right)^p \end{pmatrix} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^p \\ . \\ \vdots \\ \frac{\Delta \delta_n^p}{\Delta |V_2|_2^p} \\ \vdots \\ . \\ \Delta |V_n|_n^p \end{bmatrix}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.22)}$$

In the eqn. (3.22), bus-1 is assumed to be the slack bus, and it can be written in short form as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{vmatrix} J_1 & J_2 \\ J_3 & J_4 \end{vmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.23)}$$

Where

ΔP = change in bus real power, ΔQ= change in bus reactive power

$\Delta \delta$ = change in phase angle , $\Delta |V|$ = change in voltage magnitude

J= Jacobean matrix

3.6.4 Newton-Raphson in DigSILENT Power Factory:

In Power Factory the nodal equations used to represent the analyzed networks are implemented using two different formulations:

(1) Newton-Raphson (Current Equations).

(2) Newton-Raphson (Power Equations, classical).

In both formulations, the resulting non-linear equation systems must be solved by an iterative method. Power Factory uses the Newton-Raphson method as its non-linear equation solver. The selection of the method used to formulate the nodal equations is user-defined, and should be selected based on the type of network to be calculated. For large transmission systems, especially when heavily loaded, the standard Newton-Raphson algorithm using the “Power Equations" formulation usually converges best. Distribution systems, especially unbalanced distribution systems, usually converge better using the “Current Equations" formulation [12].

In addition to the Newton-Raphson iterations, which solve the network nodal equations, Power Factory applies an outer loop when the control characteristic of automatic transformer tap changers and/or switchable shunts is considered. Once the Newton-Raphson iterations converge to a solution within the defined tolerance (without considering the set-point values of load flow quantities defined in the control characteristic of the tap changers/switchable shunts, the outer loop is applied in order to reach these target values. The actions taken by the outer iterative loop are [12]:

(1) Increasing/decreasing discrete taps;

(2) Increasing/decreasing switchable shunts; and

(3) Limiting/releasing synchronous machines to/from max/min reactive power limits.

Once the above-listed actions are taken, a new Newton-Raphson load flow iteration takes place in order to determine the new network operating point [12].

3.7 Contingency Simulation:

Contingency simulation is an essential procedure for power system security assessment, reliability evaluation, and real time operation. It is important that simulation methods solve the post contingency situation realistically. Also, because of the large number of system contingencies, solution methods must be efficient with acceptable accuracy. The most straightforward simulation method is to run AC power flow using the iterative algorithm for each contingency [11].

3.8 Contingency Analysis Algorithm using Newton Raphson Method:

Step 1: Read the given system's line data and bus data.

Step 2: Without considering the line contingency perform the load flow analysis for base case.

Step 3: Simulating a line outage or line contingency, i.e. removing a line and proceeding to the next step.

Step 4: Load flow analysis is done for this particular outage, then calculation of the active power flow is done in the remaining lines and value Pmax is found out.

Step 5: The active power performance index (PI_p) is found, which indicates the active power limit violation of the system model taken.

Step 6: subsequently for the particular line contingency; voltages of all the load buses are calculated.

Step 7: Then voltage performance index (PI_v) is being calculated which indicates the voltage limit violation at all the load buses due to the line contingencies.

Step 8: Computation of overall performance index is done by adding PI_p and PI_v for each line outage of the system.

Step 9: Steps 3 to 8 for all line outages is repeated to obtain the PI_p and PI_v. for all line outages.

Step10: Then contingencies are ranked based on the overall performance index (OPI) which is calculated according to the values of the performance indices obtained.

Step11: Do the power flow analysis for the most severe contingency case and obtain the results [8]**.**

3.9 Contingency Analysis in DigSILENT Power Factory:

3.9.1 Technical Background:

The contingency analysis module available in Power Factory offers two distinct contingency analysis methods.

(1) Single Time Phase Contingency Analysis:

The non-probabilistic (deterministic) assessment of failure effects under given contingencies, within a single time period. The single time phase contingency analysis function first performs a pre-fault (base) load flow calculation. Following this, for each contingency (stored inside the command itself) it performs a corresponding post-contingency load flow (for a **single time phase**), which take one or more primary components out of service. The command calculates the initial consequences of the contingencies, but does not regard the operational measures taken to mitigate voltage band problems or supply interruptions [12].

Figures 3.2 and 3.3 illustrate the general sequence of both methods. Here the results of both pre- and post-fault load flows are compared to the specified loading and voltage limits; based on this comparison contingency reports are generated. In Figure3.2 the term Single Time Phase is used because only one post-fault load flow is analyzed per contingency case [11].

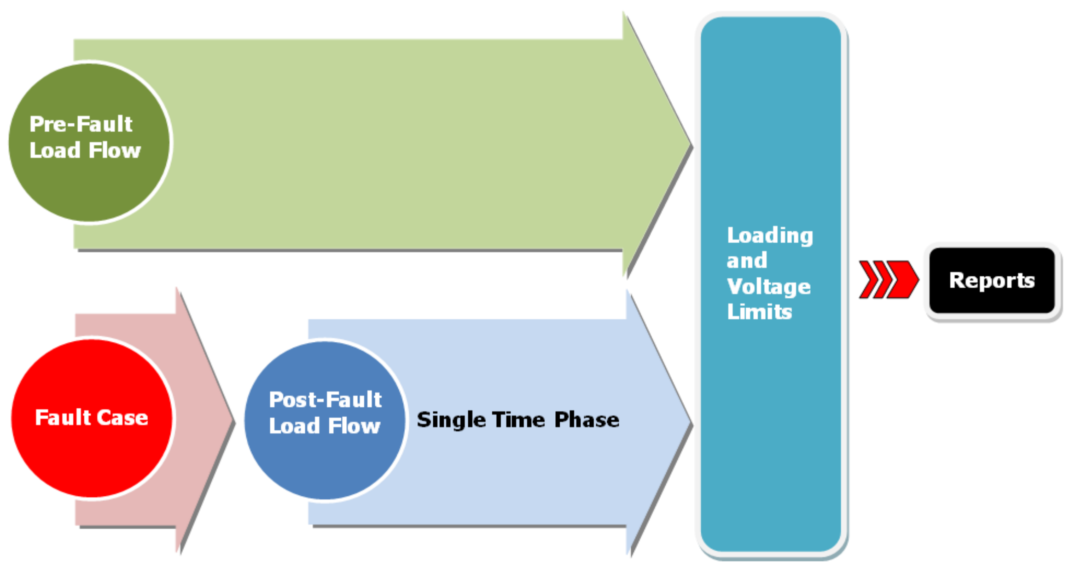

Figure3.2: Single Time Phase Contingency Analysis Method

(2) Multiple Time Phase Contingency Analysis:

The non-probabilistic (deterministic) assessment of failure effects under given contingencies, performed over different time periods, each of which defines a time elapsed after the contingency occurred. It allows the definition of user defined post-fault actions.

Power-Factory provides tools for the analysis of contingencies over multiple time phases, allowing the definition of post-fault actions that can lead to the mitigation of voltage band problems or supply interruptions which are caused by faults in the networks under analysis. As in the single time phase contingency analysis, the multiple time phases contingency analysis function first performs a pre-fault (base) load flow calculation. The major difference here is that for each contingency (stored inside the command), it loops over the list of defined **time phases** (also stored inside the command itself), calculating the corresponding post-contingency load flows. For each load flow calculation, the events (faults and post-fault actions) whose time of occurrence are earlier than, or equal to, the corresponding Post Contingency Time, are considered [12].

Figure (3.2) illustrates the multiple time phases contingency analysis method. Here, more than one post-fault load flow can be analyzed for the same contingency; hence the term Multiple Time Phase. Furthermore, if required, each time phase can have its own post-fault actions defined. The defined post-fault actions can be either a single event or a combination of the following events [12],

- Load shedding
- Generator re-dispatching
- Switching action (opening or closing)
- Tap changing

In **Power-Factory**, the term Fault Case (used in both Figures) is used to define a contingency.

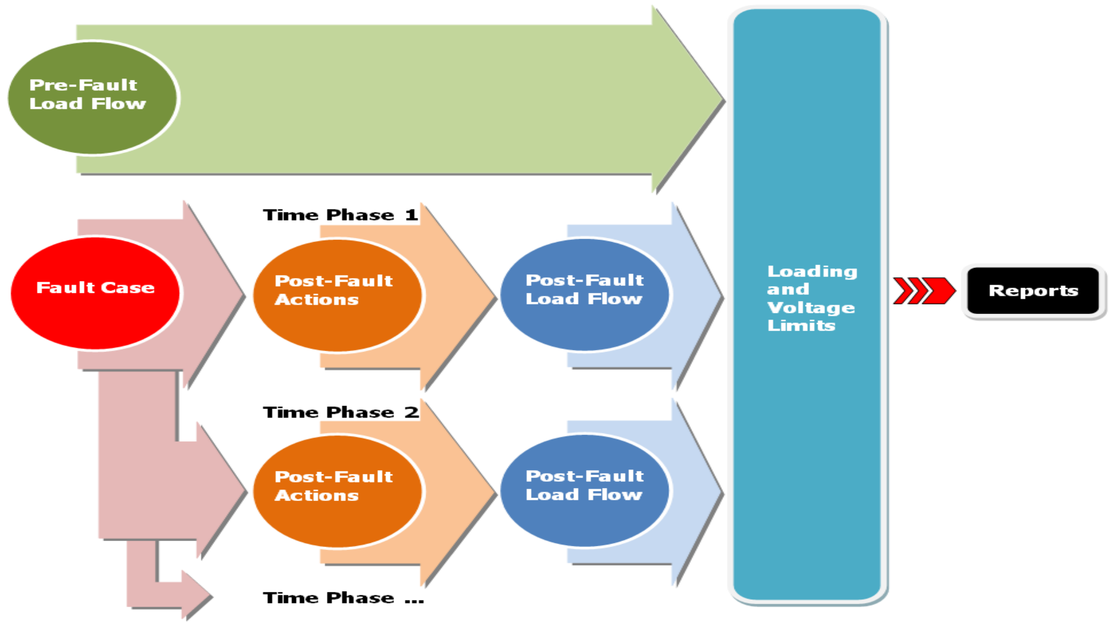

Figure3.3: Multiple Time Phase Contingency Analysis Method

3.9.2 Results of Contingency Analysis in DigSILENT Power Factory:

In **DigSILENT** Power Factory the Contingency Analysis function has a special set of predefined report formats that can be launched by clicking on the Report Contingency Analysis Results button. Once the reporting of results has been launched, the dialogue window illustrated in Figure3.4 will be displayed [12].

The following types of report can be selected:

(1) Maximum Loadings: Only the maximum loaded component (according to the specified loading limit) for each contingency is displayed in a single list.

(2) Loading Violations: All overloaded components (according to the specified loading limit) for each contingency are displayed in a single list.

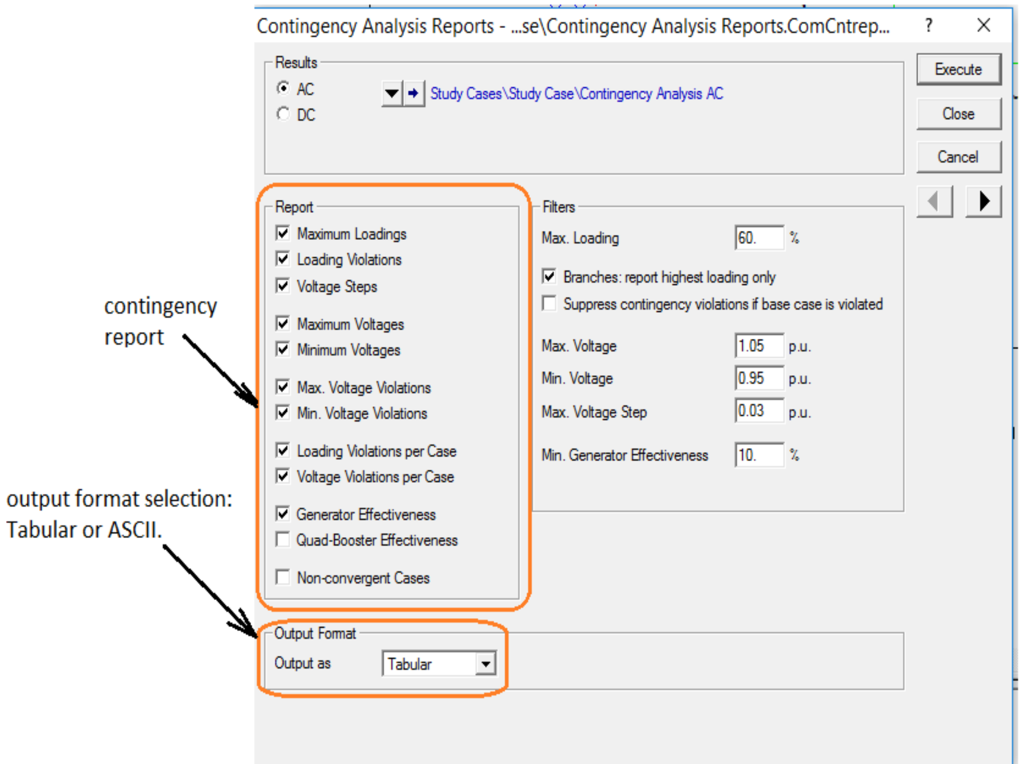

Figure3.4: Contingency Analysis Reports Dialogue

(3) Voltage Steps: All voltage deviations of terminals (between the base case and the contingency case) for each contingency are displayed in a single list. Reports the highest voltage deviation of terminals (between the base case and the contingency case) considering all contingencies. Any such terminal is reported only once. Only terminals with the highest voltage deviation greater than the specified maximum voltage step are reported.

(4) Maximum Voltages: Reports the greatest voltage violation of a terminal (greater than or equal to the specified voltage limit) considering all contingencies. Any such terminal is reported only once (i.e. it is reported for the contingency causing this violation).

(5) Minimum Voltages: Reports the greatest voltage violation of a terminal (less than or equal to the specified voltage limit) considering all contingencies. Any such terminal is reported only once (i.e. it is reported for the contingency causing this violation).

(6) Maximum Voltage Violations: Reports all voltage violations of a terminal (greater than or equal to the specified upper voltage limit) considering all contingencies.

(7) Minimum Voltage Violations: Reports all voltage violations of a terminal (less than or equal to the specified lower voltage limit) considering all contingencies.

(8) Loading Violations per Case: All overloaded components (according to the specified loading limit) for each contingency are displayed in separate lists (i.e. one list per contingency case).

(9) Voltage Violations per Case: All buses with exceeding voltage (maximum or minimum) are displayed in separate lists[12].

Chapter Four

Simulation and Results

4.1 Overview of Yemen National Grid YNG:

Previously Yemen National Grid (YNG) was separated into two grids before the 1990, but during the period of 1990-1994 southern and northern Yemen grids were linked together as one grid.

Electricity in Yemen is divided into two types, they are classified as follow:

- Governmental generation (950MW)
- Rented generation (350MW)

The whole generation of Yemen National Grid (YNG) recently seeks 1300MW. In Yemen National Grid (YNG) generation consists of several types of generations, Mareb Gas station(400MW) is located in the east of Yemen it is considered the reference of the network, Raskateeb steam power station(165MW) ,it is located in Hodeida the northern west of Yemen ,Mukha steam power station(160MW) which is located in Taiz the west of Yemen ,Haswa1 steam power station(125MW) ,Haswa2 power station (60MW) ,these two stations are located in Lahaj in swath of Yemen, Sana'a diesel power stations ,they are located in three places, Asser power stations(11MW) , Hizyaz power station(133MW) and Dhaban power station(45MW).

Mansoura1 diesel power station (65MW) Mansoura2 diesel power station (70MW) these two power stations are located in Aden in the south of Yemen, Khormaksar diesel power station(45MW) also is located in Aden in the north of Yemen, Taiz Diesel power station(26MW) is located in the west of Yemen, Hali diesel power station (26MW) is located in Hodeida in the northern west of Yemen, and Ja'ar deisel power station(5MW) is located in Lahaj in the south of Yemen.

Yemen National Grid (YNG) on the transmission and sub-transmission Levels is interconnected by 400KV,132 KV and 33 KV networks linking the points of consumption to those of generation. 400KV the highest level of voltage, it is interconnected between the slack bus (Mareb power generation station) and the Bani-Alharith power substation (two of three winding transformers). The most significant transmission line is the 132 KV double circuit line extending over a distance of about 600 KM.

4.2 Software Tool:

DIgSILENT Power Factory Version 15 is used to create a simulation of the large power systems, this software can help lanners to proceed several of power system analysis calculations, this dissertation focuses on power flow and contingency analysis procedures.

DIgSILENT Power Factory is very flexible power system analysis software, and it has a very wide range of modelling features in terms of transmission lines. Power Factory provides models from DC to AC lines over all possible phase technologies (3ph, 2ph and single phase, with/without neutral conductor and ground wires) for both single circuit and mutually coupled parallel circuits [18].

4.3 Simulation of Yemen National Grid(YNG):

Yemen National Grid (YNG) is considered as a case study, single line diagram is simulated, the voltage levels diagram is shown in appendix

D(figure_D1), where four voltage levels 400, 132, 33 and 11KV are considered, data and parameters of the grid are shown in the appendices

4.4 The System Results:

The system is simulating using the operational data given in appendix (A, B, and C). This dissertation started with study the power flow analysis in Yemen national grid (YNG) in its normal operations. To study the security of Yemen national grid (YNG), the contingency analysis is applied on the system. The rated values must be loading 60%, and voltage violation of a terminal is in the range [$\pm$ 5%].

4.4.1 Case (1): Results of Power Flow in Normal Operation:

(1) Bus voltages in the normal operation

Table 4.1: Bus voltages in the normal operation:

number	Bus name	rated voltage	voltage Deviation	
		Kv	pu	Kv
1	MarebBB1	33	1.037	34.221
2	Sana'aBB2	33	0.959	31.647
3	HizyazBB1	132	0.995	131.34
4	HizyazBB2	33	0.971	32.043
5	DhamarBB	132	0.96	126.72
6	RaskateebBB1	132	0.985	130.02
7	BajilBB1	132	0.983	129.756
8	RaskateebBB2	33	0.976	32.208
9	BajilBB2	33	0.962	31.746
10	HodiedaBB	132	0.971	128.172
11	HodiedaBB2	33	0.957	31.581
12	BaniAlharithBB1	400	1.039	415.6
13	HaliBB2	11	1	11
14	JarahiBB	33	0.964	31.812
15	MakhaBB1	132	1.023	135.036
16	MakhaBB2	33	1.013	33.429
17	TaizBB1	132	0.965	127.38

Table 4.1: Bus voltages in the normal operation:

18	BarhBB	33	0.973	32.109
19	TaizBB2	33	0.952	31.35
20	TaizBB3	11	1	11
21	RahidaBB1	132	0.964	127.248
22	BaniAlharith3	33	1.039	34.287
23	N.DoukiamBB	132	0.969	127.908
24	HablianBB1	132	0.963	127.116
25	HaswaBB1	132	0.98	129.36
26	HaswaBB2	33	0.998	32.934
27	HaswaBB3	11	0.969	10.659
28	Ja'arBB2	11	1	11
29	BaniAlharithBB2	132	1.022	134.904
30	Ja'arBB1	33	0.968	31.944
31	MansoraBB	33	0.991	32.703
32	ShinazBB	33	0.98	32.34
33	Block80BB	33	0.987	32.571
34	KhormaksarBB1	33	0.983	32.439
35	DahbanBB1	33	0.976	32.208
36	DahbanBB2	132	0.999	131.868
37	AmranBB1	132	0.993	131.076
38	AmranBB2	33	0.977	32.241
39	Sana'aBB1	132	0.993	131.076
40	MarebBB	400	1.049	419.6
41	Barh node	132	0.99	130.68
42	Ibb Damar Taiz node	132	0.953	125.796
43	Asser node	11	0.959	10.549

Table 4.1 shows the voltage of all buses of the grid in the normal case is observed between the maximum value in MarebBB 1.49 pu, and the minimum critical value in TaizBB2 0.952 pu .

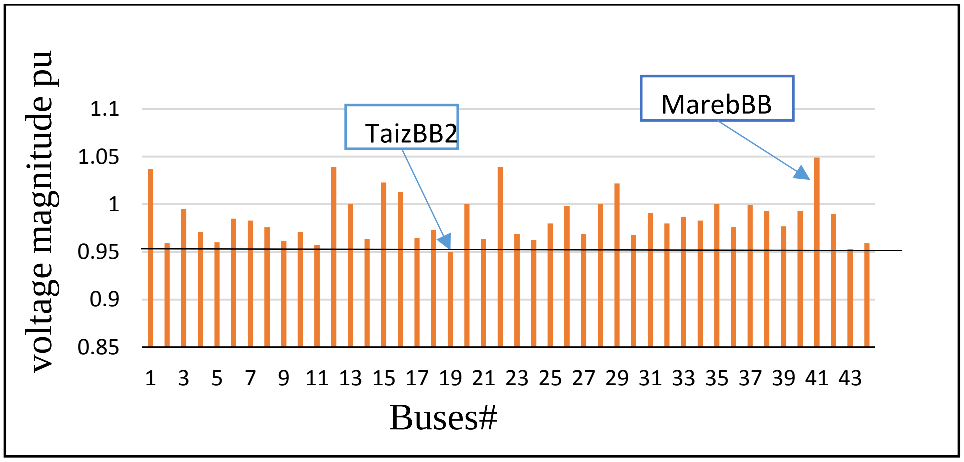

Figure 4.1: Voltage profile of the system in the normal operation

The figure 4.1 shows maximum and minimum voltages in pu in compared with the other grid buses.

(2) Transmission lines loading

Table 4.2: Transmission lines loading in the normal operation

number	line	loading%
1	BaniAlharith-Dahban	49.33
2	Bajil-Jarahi	4.98
3	BaniAlharith-Hizyaz	27.59
4	Barh-Taiz	20.12
5	Block80-Khormaksar	8.27
6	Dahban-Amran	8.68
7	Dahban-Sana'a	17.56
8	Dhamar-Bajil	9.64
9	Dhamar-Ibb	2.68
10	Haswa-Ja'ar	2.72
11	HaswaBB1-HaswaBB2	56.82
12	HaswaBB2-Mansorah	22.66
13	Hiziaz-Sana'a	6.81
14	Hizyaz-Dhamar	12.52

Table 4.2: Transmission lines loading in the normal operation

15	Mansorah-Bolck80	47.7
16	Mansorah-Khormaksar	16.4
17	Mansorah-SHinaz	21.16
18	Mareb-BaniAhharith	25.2
19	Mokha-Jarahi	7.8
20	Mokha-barh	22.89
21	N.Doukiam-Habilain	5.79
22	N.Doukiam-Haswa	11.96
23	Rahida-N.Doukiam	6.81
24	Raskateeb-Bajil	11.5
25	Raskateeb-Hodieda	21.31
26	SHinaz-Khormaksar	19.46
27	Sana'a-Amran	0.84
28	Taiz-Ibb	10.54
29	Tiaz-Rahida	2.6

Table 4.2 shows the loading in transmission lines. It can be observed that the loading has the range 0.84% Sana'a-Amran, 56.82% HaswaBB1-HaswaBB2.

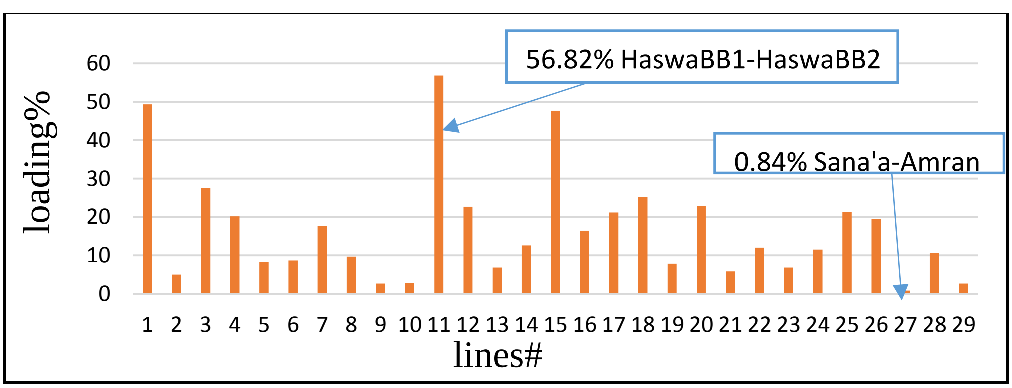

Figure4.2 : Lines loading in the normal operation

Maximum and minimum transmission line loading are illustrated in figure 4.2.

(3) Transformers loading

Table4.3 :System transformers loading in the normal operation

number	name of Trans	loading%
1	AmranPT	47.83
2	BajilPT	57.65
3	BarhPT	29.64
4	DahbanGT1	48.7
5	DahbanGT2	69.29
6	DahbanPT	57.02
7	HaliGT	45.99
8	HaswaGT1	60.31
9	HaswaGT2	66.07
10	HizyazGT1	67.01
11	HizyazGT2	75.45
12	HizyazPT	36.45
13	HodiedaPT	54.14
14	Ja'ar PT	19.75
15	Ja'ar GT	74.91
16	JarahiPT	65.21
17	KhormaksarGT	24.61
18	MakhaGT	77.31
19	MakhaPT	23.86
20	MansoraGT1	78.35
21	MansoraGT2	76.11
22	MarebGT	69.25
23	MarebPT	26.96
24	RaskateebGT	78.11
25	RaskateebPT	19.33
26	Sana'aGT	17.39
27	Sana'aPT	66.78
28	TaizGT	71.58
29	TaizPT	61.6
30	BaniAlharithPT	29.1
31	HaswaPT	51.55

Table4.3 shows the loading of transformers considering its range 60% in normal operation, the power flow result illustrates the loading.

It is observed that 15 transformers were loaded, these transformers are “DahbanGT2, HaswaGT1, HaswaGT2, HizyazGT1, HizyazGT2, JarahiGT, JarahiPT, MakhaGT, MansoraGT1, MansoraGT2, MarebGT, RaskateebGT, Sana'aPT, TaizGT, and TaizPT”.

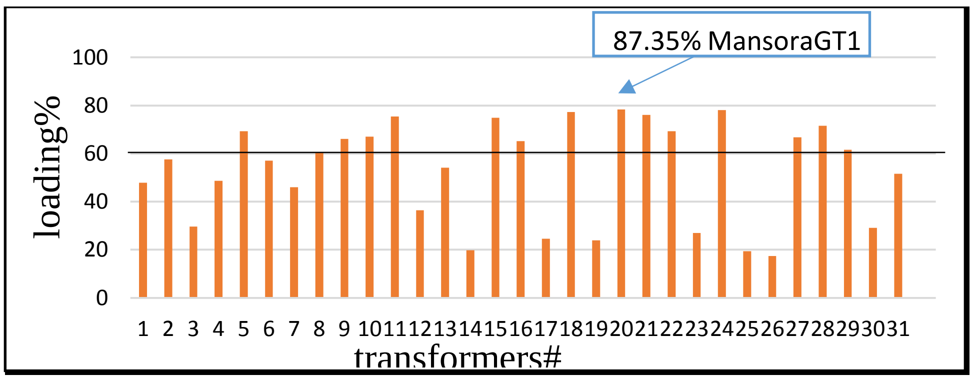

Figure4.3: System transformers loading in the normal operation

4.4.2 Case (2): Transmission line outage.

In **DIgSILENT PowerFactory** Version 15 software, the whole contingency cases can be calculated together, in other words this software can calculate all lines outages and it can give the whole result together in one report, and the following types of reports can be selected as a result of contingency analysis:

(1) Loading violations:

The loading on the transmission lines and transformers are performed with the loading limit is 60%, the result of contingency is shown in the table4.4:

Table 4.4: Loading violations corresponding to contingencies:

No	Cong, name	Loaded component	loading% base case	loading%cong.
1	BaniAlharith-Dahban	DahbanGT2	69.28969	115.1662
2	Base Case	DahbanGT2	69.28969	69.28969
3	Mokha-barh	TaizGT	71.58394	99.18018
4	Barh-Taiz	TaizGT	71.58394	99.18018
5	N.Doukiam-Haswa	TaizGT	71.58394	84.75474
6	Base Case	TaizGT	71.58394	71.58394
7	BaniAlharith-Dahban	DahbanGT1	48.69689	84.24209
8	BaniAlharith-Dahban	HizyazGT2	75.45404	82.44659
9	Base Case	HizyazGT2	75.45404	75.45404
10	HaswaBB1-HaswaBB2	MarebGT	69.25197	82.39088
11	N.Doukiam-Haswa	MarebGT	69.25197	80.20295
12	Base Case	MarebGT	69.25197	69.25197
13	HaswaBB1-HaswaBB2	Ja'arGT	74.91129	82.14613
14	Barh-Taiz	Ja'arGT	74.91129	81.5162
15	Mokha-Barh	Ja'arGT	74.91129	81.5162
16	Base Case	Ja'arGT	74.91129	74.91129
17	Barh-Taiz	RaskateebGT	78.10547	81.92864
18	Mokha-barh	RaskateebGT	78.10547	81.92864
19	Base Case	RaskateebGT	78.10547	78.10547
20	N.Doukiam-Haswa	MakhaGT	77.30897	80.19307
21	Base Case	MakhaGT	77.30897	77.30897

Table 4.4: Loading violations corresponding to contingencies

22	Base Case	MansoraGT1	78.34711	78.34711
23	Base Case	MansoraGT2	76.11135	76.11135
24	Base Case	HizyazGT1	67.00899	67.00899
25	Base Case	Sana'aPT	66.78045	66.78045
26	Base Case	HaswaGT2	66.06508	66.06508
27	Base Case	JarahiPT	65.21076	65.21076
28	Base Case	TaizPT	61.59725	61.59725
29	Base Case	HaswaGT1	60.31372	60.31372

In table 4.4 All overloaded component (according to the specified loading limit 60%) for each contingency are showen.

DahbanGT2

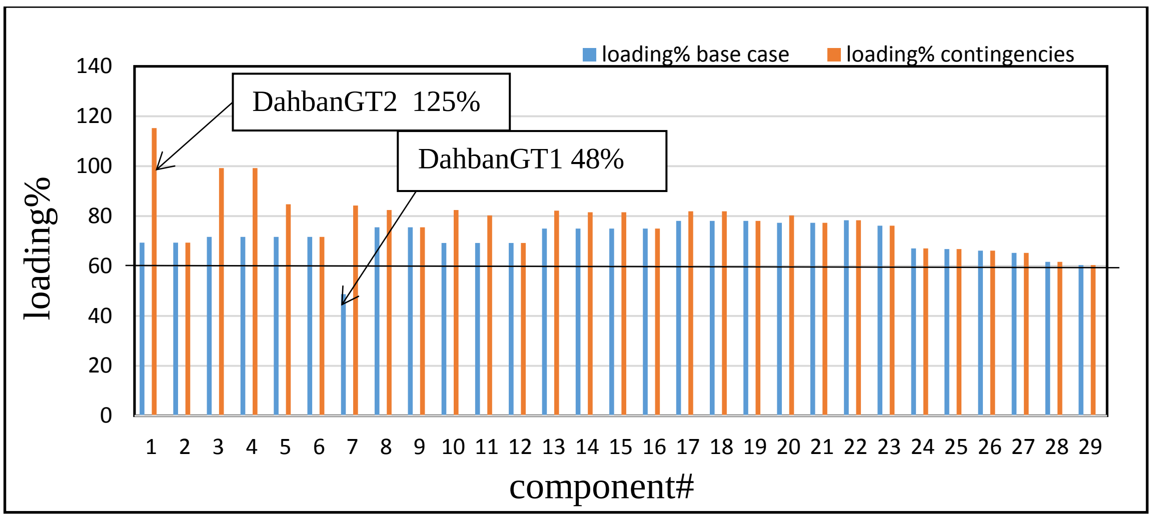

Figure4.4: Transformers loading corresponding to the contingencies.

figure 4.4 shows the components loading corresponding to base case and contingency case.

(2) Maximum loading:

Table 4.5: Maximum loading corresponding to contingencies

nomber	contingency name	Loaded component	loading% base case	loading% contingincies
1	BaniAlharith-Dahban	DahbanGT2	69.29	115.17
2	Barh-Taiz	TaizGT	71.58	99.18
3	BaniAlharith-Dahban	DahbanGT1	48.70	84.24
4	BaniAlharith-Dahban	HizyazGT2	75.45	82.45
5	HaswaBB1-HaswaBB2	MarebGT	69.25	82.39
6	HaswaBB1-HaswaBB2	Ja'arGT	74.91	82.15
7	Barh-Taiz	RaskateebGT	78.11	81.93
8	N.Doukiam-Haswa	MakhaGT	77.31	80.19
9	BaniAlharith-Dahban	BaniAlharith-Hizyaz	27.59	78.92
10	Barh-Taiz	MansoraGT1	78.35	78.89
11	BaniAlharith-Dahban	HizyazGT1	67.01	76.72
12	Barh-Taiz	MansoraGT2	76.11	76.66
13	BaniAlharith-Hizyaz	BaniAlharith-Dahban	49.33	76.00
14	BaniAlharith-Dahban	Sana'aPT	66.78	73.20
15	HaswaBB1-HaswaBB2	HaswaGT1	60.31	70.08
16	Barh-Taiz	HaswaGT2	66.07	68.11
17	Barh-Taiz	JarahiPT	65.21	66.39
18	Dhamar-Ibb	TaizPT	61.60	62.63
19	Barh-Taiz	HaswaBB1-HaswaBB2	56.82	60.39658

Table 4.5 shows the loading in the normal operation, and the result of loading corresponding to all contingencies. Only the maximum loaded component (according to the specified loading limit 60%) for each contingency is shown in table 4.5.

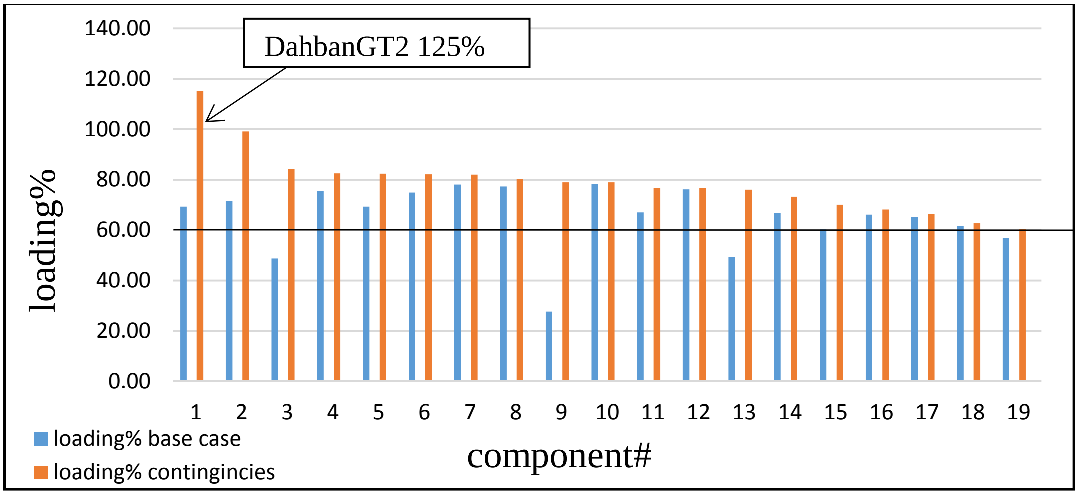

Figure4.5: Maximum loading corresponding to contingencies

Figure4.5 shows the maximum loading of loaded component in base case and corresponding to contingencies.

(3) Maximum Voltages:

Table 4.6: Maximum Voltages corresponding to all contingencies

number	Contingency Name	Loaded Component	Voltage Base [p.u.]	Voltage contingencies. [p.u.]	Voltage Step [p.u.]
1	Hizyaz-Dhamar	MarebBB	1.0483	1.055	0.0055
2	Hizyaz-Dhamar	BaniAlharithBB1	1.0388	1.05107	0.0107

Table4.6 shows the maximum voltages corresponding to the contingencies which are greater than or equal to the specified voltage limit 1.05pu.

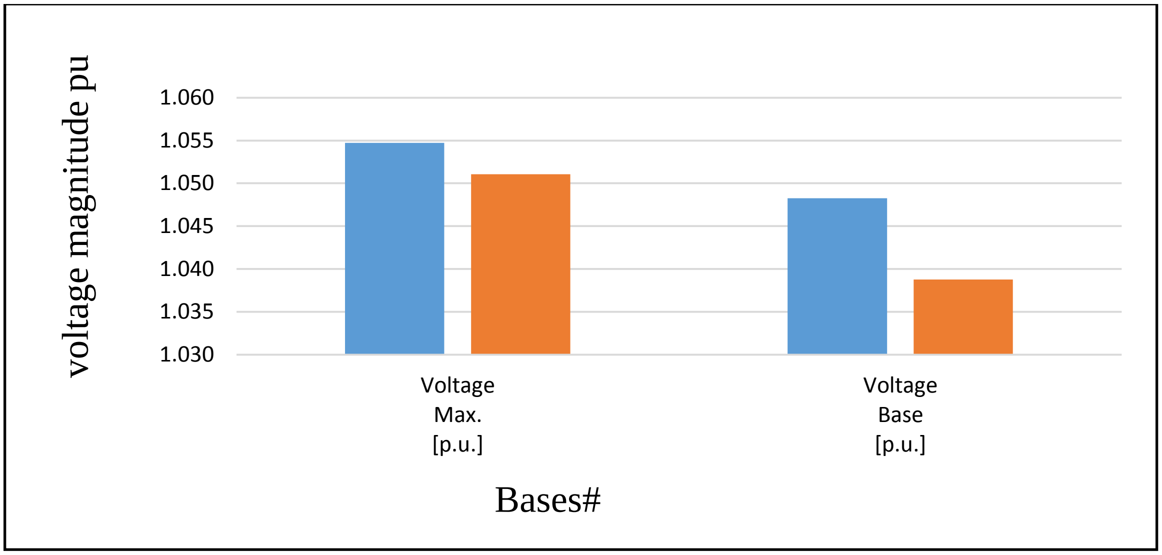

Figure4.6: Maximum voltage corresponding to all contingencies

Figure 4.6 shows the maximum voltage corresponding to Hizyaz-Dhamar line outage, these two buses are MarebBB, and BaniAlharithBB1.

(4) Maximum Voltage violations:

The following table show the maximum loading voltages corresponding to the contingencies shown in the grid.

Table 4.7: Maximum Voltage violations corresponding to the contingencies

number	Contingency Name	Loaded Component	Voltage Base [p.u.]	Voltage Max. [p.u.]	Voltage Step [p.u.]
1	Hizyaz-Dhamar	MarebBB	1.0492	1.0547	0.0055
2	BaniAlharith-Hizyaz	MarebBB	1.0492	1.0513	0.0021
3	Raskateeb-Hodieda	MarebBB	1.0492	1.0501	0.0009
4	Dhamar-Ibb	MarebBB	1.0492	1.0501	0.0009
5	Taiz-Ibb	MarebBB	1.0492	1.0501	0.0009
6	'Hizyaz-Dhama	'BaniAlharithBB1	1.0387	1.05107	0.0122

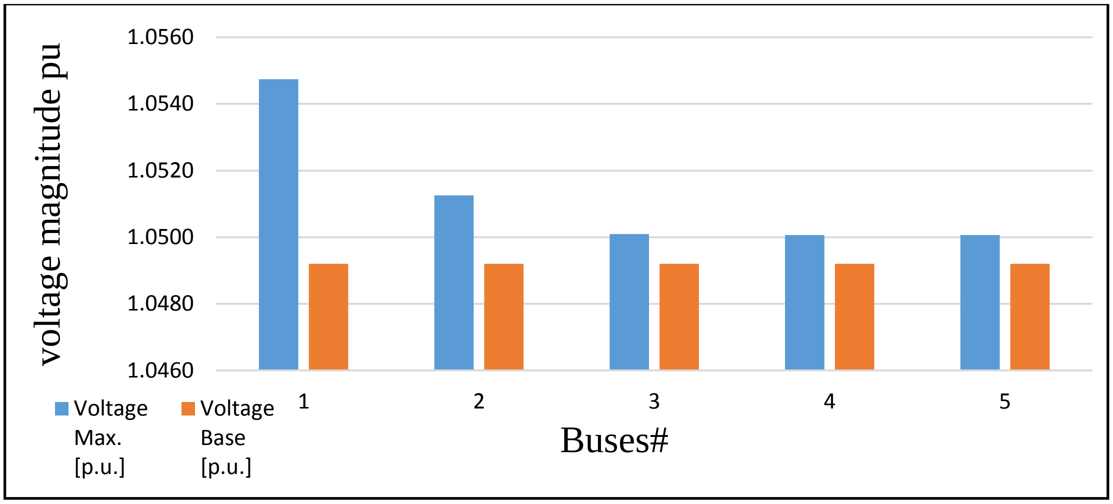

Figure4.7: Maximum voltage violations corresponding to all contingencies

Table 4.7 shows maximum voltage violation at base case and contingency case. Hizyaz-Dhamar is the most severe contingency which result in a violation of 1.0547pu at bus MarebBB.

(5) Minimum Voltages:

Table 4.8 illustrates the minimum voltages in the system with considering to all contingencies.

Table 4.8: Minimum voltages with considering all contingencies:

No	**contingency name**	**bus nmae**	**voltage base case pu**	**voltage contingency pu**	**voltage step**
1	Barh-Taiz	HodiedaBB2	0.9572803	0.9478201	-0.009
2	Barh-Taiz	JarahiBB	0.9644606	0.9473783	-0.017
3	BaniAlharith-Dahban	Dahban node1	1	0.9469769	-0.053
4	Barh-Taiz	HaswaBB3	0.9685906	0.9394904	-0.029
5	Mansorah-Bolck80	Block80BB	0.9870214	0.938061	-0.049
6	Barh-Taiz	BajilBB2	0.9620692	0.9354966	-0.027
7	N.Doukiam-Haswa	N.DoukiamBB	0.9693514	0.9255272	-0.044
8	N.Doukiam-Haswa	HablianBB1	0.9628929	0.918675	-0.044
9	Barh-Taiz	DhamarBB	0.9600667	0.9168123	-0.043

Table 4.8: Minimum voltages with considering all contingencies.

10	Barh-Taiz	RahidaBB1	0.9641083	0.9133645	-0.051
11	BaniAlharith-Dahban	Sana'aBB1	0.9931685	0.9129168	-0.08
12	BaniAlharith-Dahban	DahbanBB2	0.9990171	0.9065774	-0.092
13	BaniAlharith-Dahban	AmranBB1	0.9925824	0.9048951	-0.088
14	Barh-Taiz	TaizBB1	0.9645135	0.9015117	-0.063
15	BaniAlharith-Dahban	DahbanBB1	0.976418	0.8999253	-0.076
16	Barh-Taiz	TaizBB2	0.950089	0.8955718	-0.055
17	Barh-Taiz	Ibb Damar Taiz node	0.9531555	0.8953272	-0.058
18	BaniAlharith-Dahban	AmranBB2	0.9771448	0.887674	-0.089
19	BaniAlharith-Dahban	Sana'aBB2	0.9586567	0.874728	-0.084
20	BaniAlharith-Dahban	Asser node	0.9585795	0.8746263	-0.084

Table 4.8 shows the voltage less than or equal to the specified voltage limit 0.95pu) considering all contingencies. the base case voltage and contingency voltage are shown .

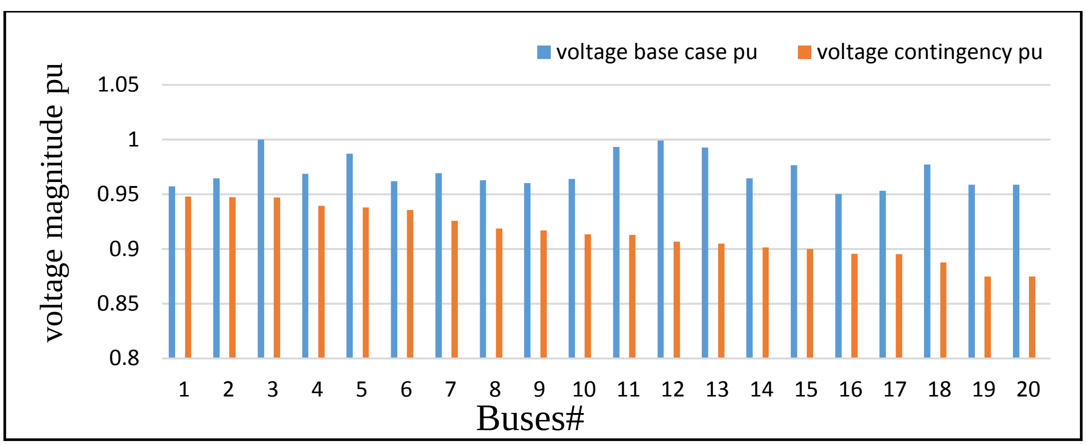

Figure4.8: Minimum voltages with considering all contingencies.

figure 4.8 shows base case voltage and contingency voltage for 20-bus, which become under minimum limit corresponding to all lines outages.

(6) Minimum Voltage Violations:

Table 4.9: Result of all minimum bus voltages violations for all contingencies:

number	contingency mane	bus name	voltage base case	voltage contingency	voltage step
1	HaswaBB1-HaswaBB2	DhamarBB	0.960067	0.949926	-0.01014
2	Sana'a-Amran	TaizBB2	0.950089	0.949867	-0.00022
3	Dahban-Amran	TaizBB2	0.950089	0.949661	-0.00043
4	Tiaz-Rahida	TaizBB2	0.950089	0.949173	-0.00092
5	Bajil-Jarahi	Ibb Damar Taiz node	0.953156	0.948876	-0.00428
6	Mokha-Jarahi	Ibb Damar Taiz node	0.953156	0.948876	-0.00428
7	Dahban-Sana'a	TaizBB2	0.950089	0.948851	-0.00124
8	Raskateeb-Hodieda	Ibb Damar Taiz node	0.953156	0.948837	-0.00432
9	Raskateeb-Bajil	Ibb Damar Taiz node	0.953156	0.948704	-0.00445
10	Bajil-Jarahi	BajilBB2	0.962069	0.948245	-0.01382
11	Mokha-Jarahi	BajilBB2	0.962069	0.948245	-0.01382
12	Raskateeb-Bajil	TaizBB2	0.950089	0.948101	-0.00199
13	HaswaBB1-HaswaBB2	HablianBB1	0.962893	0.948082	-0.01481
14	Rahida-N.Doukiam	RahidaBB1	0.964108	0.948012	-0.0161
15	Barh-Taiz	HodiedaBB2	0.95728	0.94782	-0.00946
16	Mokha-barh	HodiedaBB2	0.95728	0.94782	-0.00946
17	Bajil-Jarahi	TaizBB2	0.950089	0.947721	-0.00237
18	Mokha-Jarahi	TaizBB2	0.950089	0.947721	-0.00237
19	Barh-Taiz	JarahiBB	0.964461	0.947378	-0.01708
20	Mokha-barh	JarahiBB	0.964461	0.947378	-0.01708
21	Raskateeb-Hodieda	TaizBB2	0.950089	0.947229	-0.00286
22	BaniAlharith-Dahban	Dahban node1	1	0.946977	-0.05302
23	BaniAlharith-Hizyaz	Sana'aBB2	0.958657	0.946504	-0.01215
24	BaniAlharith-Hizyaz	Asser node	0.95858	0.946424	-0.01216
25	N.Doukiam-Haswa	DhamarBB	0.960067	0.9463	-0.01377

Table 4.9: Result of all minimum bus voltages violations for all contingencies:

26	Mokha-barh	Sana'aBB2	0.958657	0.945991	-0.01267
27	Barh-Taiz	Sana'aBB2	0.958657	0.945991	-0.01267
28	Mokha-barh	Asser node	0.95858	0.945911	-0.01267
29	Barh-Taiz	Asser node	0.95858	0.945911	-0.01267
30	BaniAlharith-Hizyaz	TaizBB2	0.950089	0.945529	-0.00456
31	BaniAlharith-Hizyaz	DhamarBB	0.960067	0.944821	-0.01525
32	Dahban-Sana'a	Sana'aBB2	0.958657	0.944399	-0.01426
33	Dahban-Sana'a	Asser node	0.95858	0.944319	-0.01426
34	Rahida-N.Doukiam	Ibb Damar Taiz node	0.953156	0.943842	-0.00931
35	BaniAlharith-Hizyaz	Ibb Damar Taiz node	0.953156	0.943482	-0.00967
36	N.Doukiam-Haswa	TaizBB1	0.964514	0.942582	-0.02193
37	HaswaBB1-HaswaBB2	Ibb Damar Taiz node	0.953156	0.942568	-0.01059
38	BaniAlharith-Dahban	TaizBB2	0.950089	0.942564	-0.00753
39	HaswaBB1-HaswaBB2	TaizBB2	0.950089	0.94222	-0.00787
40	Rahida-N.Doukiam	TaizBB2	0.950089	0.941512	-0.00858
41	Dhamar-Bajil	TaizBB2	0.950089	0.939718	-0.01037
42	Barh-Taiz	HaswaBB3	0.968591	0.93949	-0.0291
43	Mokha-barh	HaswaBB3	0.968591	0.93949	-0.0291
44	Mansorah-Bolck80	Block80BB	0.987021	0.938061	-0.04896
45	BaniAlharith-Dahban	Ibb Damar Taiz node	0.953156	0.937196	-0.01596
46	Dhamar-Bajil	DhamarBB	0.960067	0.936953	-0.02311
47	Barh-Taiz	N.DoukiamBB	0.969351	0.935564	-0.03379
48	Mokha-barh	N.DoukiamBB	0.969351	0.935564	-0.03379
49	Barh-Taiz	BajilBB2	0.962069	0.935497	-0.02657
50	Mokha-barh	BajilBB2	0.962069	0.935497	-0.02657
51	Dhamar-Bajil	Ibb Damar Taiz node	0.953156	0.934962	-0.01819
52	BaniAlharith-Dahban	DhamarBB	0.960067	0.934918	-0.02515
53	N.Doukiam-Haswa	Ibb Damar Taiz node	0.953156	0.933972	-0.01918

Table 4.9: Result of all minimum bus voltages violations for all contingencies:

54	N.Doukiam-Haswa	TaizBB2	0.950089	0.932906	-0.01718
55	N.Doukiam-Haswa	RahidaBB1	0.964108	0.932571	-0.03154
56	Barh-Taiz	HablianBB1	0.962893	0.928805	-0.03409
57	Mokha-barh	HablianBB1	0.962893	0.928805	-0.03409
58	N.Doukiam-Haswa	N.DoukiamBB	0.969351	0.925527	-0.04382
59	N.Doukiam-Haswa	HablianBB1	0.962893	0.918675	-0.04422
60	Barh-Taiz	DhamarBB	0.960067	0.916812	-0.04325
61	Mokha-barh	DhamarBB	0.960067	0.916812	-0.04325
62	Barh-Taiz	RahidaBB1	0.964108	0.913365	-0.05074
63	Mokha-barh	RahidaBB1	0.964108	0.913365	-0.05074
64	BaniAlharith-Dahban	Sana'aBB1	0.993169	0.912917	-0.08025
65	BaniAlharith-Dahban	DahbanBB2	0.999017	0.906577	-0.09244
66	BaniAlharith-Dahban	AmranBB1	0.992582	0.904895	-0.08769
67	Barh-Taiz	TaizBB1	0.964514	0.901512	-0.063
68	Mokha-barh	TaizBB1	0.964514	0.901512	-0.063
69	BaniAlharith-Dahban	DahbanBB1	0.976418	0.899925	-0.07649
70	Barh-Taiz	TaizBB2	0.950089	0.895572	-0.05452
71	Mokha-barh	TaizBB2	0.950089	0.895572	-0.05452
72	Barh-Taiz	Ibb Damar Taiz node	0.953156	0.895327	-0.05783
73	Mokha-barh	Ibb Damar Taiz node	0.953156	0.895327	-0.05783
74	BaniAlharith-Dahban	AmranBB2	0.977145	0.887674	-0.08947
75	BaniAlharith-Dahban	Sana'aBB2	0.958657	0.874728	-0.08393
76	BaniAlharith-Dahban	Asser node	0.95858	0.874626	-0.08395

Table4.9 represent 76 cases of drop in buses voltages executed corresponding to all contingencies, where all voltage violations of a

terminal (less than or equal to the specified limit 0.95pu) considering all contingencies.

In this report all voltage less than the limit 0.59pu due to all contingencies are considered.

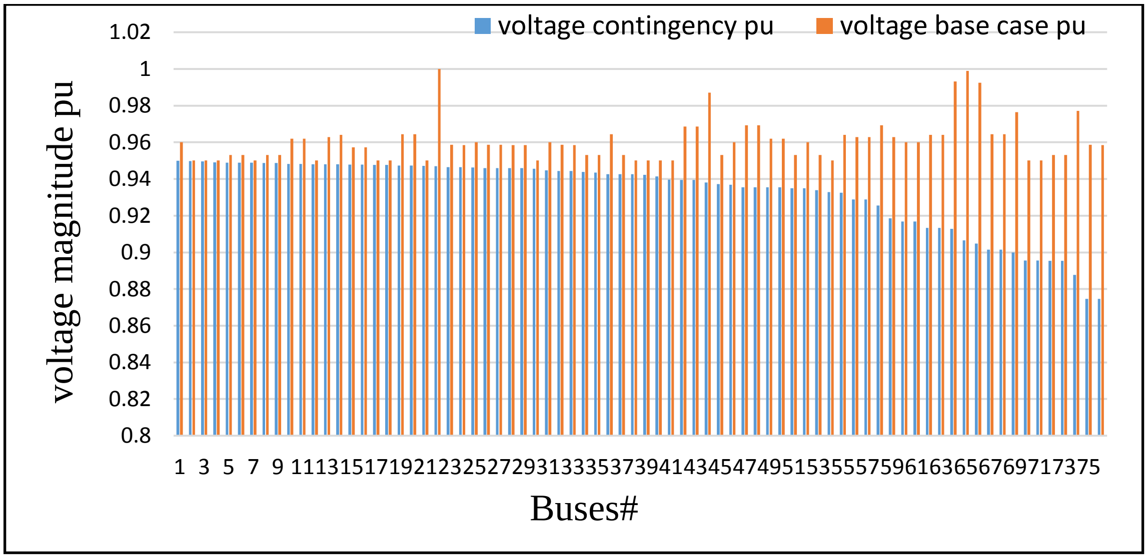

Figure 4.9: Minimum voltage violations corresponding to all contingencies

Figure 4.9 shows the bus voltage in base case and contingency case, where this report focuses on all minimum voltage violations.

According to the results obtained above the system is not secure due to the over-loading occurred in more in 15-transformers in normal operation, and also seven buses (Sana'aBB2, DhamarBB, HodiedaBB2, TaizBB2, Ibb Damar Taiz node, and Asser node) are in the critical minimum state limit of voltage, and Mareb bus is in critical maximum limit.

Corresponding to the contingencies Mareb-Banialhareth is the only 400kV transmission line, which links between Mareb power station, and

Bani.alhareth substation, and its outage is the only case causes blackout for the system.

According to result, it is observed the minimum voltage is in Asser Node 0.875pu corresponding to the contingency number one “Banialharth-Dahban”, and it is not the only case which is under the limit, and the maximum voltage occured in MarebBB “slack-bus” 1.0547pu corresponding to the contingency nomber14 “ Hizyaz-Dhamar”, this contingency separates the system into two parts, which cause black out of the majority of the system.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion:

This dissertation presents a study which covers, Newton-Raphson power flow analysis, and contingency analysis by using DigSILENT powerfactory version15 software for Yemen national grid(YNG) with the base of load 1161 MW ,44-bus system as a case study the contingency for outage of single transmission line, the criteria for the nodes are $\pm 5\%$ and 60% component loading. Corresponding to the simulation results of the N-1 contingency analysis, some important points clarified as:

- Mareb-BaniAlharith is the only 400kV transmission line, and the outage of this line is the only case causes blackout in the system.
- One important thing observed in the simulation of the Yemen national grid (YNG), the generator loading, most of the diesel generation seek the maximum loading 60%.
- DigSILENT powerfactory softwere is very effective in such studies, where Steady-state analysis in PowerFactory covers the normal operation and the contingency analysis.

5.2 Recommendations:

Yemen National Grid basically depend on Mareb Gas Station “Slack-bus” which its generation doesn’t seek 450MVA, and the load demand is large in compared with the generation, therefore the coming points are important to be considered:

- The link between the grid with the Slack-bus is only one transmission line “Mareb-BaniAlharith”, outage of this line causes blackout, the system will be more secure if another link applied between Mareb and another stations, with more than one link the system may avoid the state of blackout.
- Several of substations transformers are over-loaded and the load demand increases daily, therefore expanding of this substations will solve the problems of the increasing in load demand.
- The advanced techniques of contingency analysis, such as artificial Neural Network should handle, which give more accurate and reliable results.
- the study can be extended to investigate the effect of including FACTS controllers.

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APPENDICES

Appendix (A):

Table A.1: Yemen National Grid(YNG) Line Data

NO	Line code	Rated voltage	Length of line	R(Ω) per Km	X(Ω) per km	Y(mho) *E-06 per km
1	MARIB-BANIALHARETH 1	400	200	0.0436	0.287	4.23
2	BANIALHARETH-DAHBAN	132	132	24	0.0429	0.3
3	DAHBAN-DAHBAN	132	5	0.0674	0.384	2.86
4	BANIALHARETH-HIZYAZ1	132	36	0.0429	0.3	3.92
5	HIZYAZ-SANAA1	132	30	0.0674	0.384	2.86
6	SANAA1-DAHBAN 1	132	15	0.0674	0.384	2.86
7	DAHBAN -AMRAN 1	132	24.5	0.0674	0.384	2.86
8	HIZYAZ-DHAMAR 1	132	84	0.0674	0.384	2.86
9	DHAMAR-IBB 1	132	80.8	0.0674	0.384	2.86
10	IBB-TAIZ 1	132	52.2	0.0674	0.384	2.86
11	RASKAT-HOD 1	132	27.75	0.0674	0.384	2.86
12	RASKAT-BAJ 1	132	42.2	0.0674	0.384	2.86
13	BAJ-DAHM 1	132	152.3	0.0674	0.384	2.86
14	BAJ-JARAHI 1	132	110	0.0674	0.384	2.86
15	JARAHI-MUK 1	132	112.2	0.0674	0.384	2.86
16	MUK-BARH 1	132	54.5	0.0674	0.384	2.86
17	BARH-TAIZ 1	132	51	0.0674	0.384	2.86
18	TAIZ-RAHIDA 1	132	41.3	0.0674	0.384	2.86
19	RAHIDA-N DOUKIM 1	132	55.2	0.0674	0.384	2.86
20	N DOUKIM-HABILAIN 1	132	39.7	0.0674	0.384	2.86
21	N DOUKIM-HISWA 1	132	56.5	0.0674	0.384	2.86
22	HISWA-JAAR	132	70	0.0674	0.384	2.86

23	HISWA S/S-HISWAPst	33	1.1	0.0618	0.11	91.8
24	MANSORA-HISWA	33	7.4	0.618	0.11	91.8
25	SHENAZ-MANSORAH	33	9.45	0.602	0.10475	76.8
26	BLOCK80-MANSORAH	33	1.4	0.062	0.1101	81.3
27	KHR MAKS-MANSORAH	33	8.4	0.102	0.09905	97.6
28	BLOCK80-KHR MAKS	33	9.5	0.102	0.09904	97.6
29	KHR MAKS-SHENAZ	33	1.9	0.102	0.09916	116

Appendix (B):

Table B.1: Yemen National Grid Bus Data

Generator code	nomber of machines	Rated power(MVA)	Rated Voltage(Kv)	Rated power factor	Maximum active power(MW)	maximum reactive power
MARIB G	3	167	15.75	0.8	133.6	100.2
RASKATEEB G	5	41.25	11	0.8	33	24.75
MUKHA G	4	50	13.8	0.8	40	30
HISWA G	5	31.25	10.5	0.8	25	18.75
HISWAG6	1	75	10.5	0.8	60	45
DHABAN1 G	3	6.56	11	0.8	5.25	3.936
DHABAN2 G	5	7.5	11	0.8	6	4.5
SANA'A G	2	6.56	11	0.8	5.248	3.936
HIZYAZ1G	6	6.65	11	0.8	5.32	3.99
HIZYAZ2 G	10	12.625	11	0.8	10.1	7.575
MANSORAH1 G	8	10.2	11	0.8	8.16	6.12
MANSORAH2 G	7	12.625	11	0.8	10.1	7.575
KHOR MAK 1	7	6.6	11	0.8	5.28	3.96
KHOR MAK 2	4	2.75	11	0.8	2.2	1.65
TAIZ 1	1	33.3	11	0.8	26.64	19.98
ALHALI 1	1	32.939	11	0.8	26.3512	19.7634
JA'AR 1	2	7	11	0.8	5.6	4.2

Appendix (C):

Table C.1: Two winding transformers data

nomber	Transformer name	Nomber of trans	higher voltage side	lower voltage side	rated power(MVA)	Short circuit reactance PU
1	Sana'a Tr1	3	132	33	60	9.90
2	Sana'a PS Tr1	2	33	11	20	14.76
3	Dhban1G1	3	33	11	6.6	6
4	Dhban2G1	5	33	11	8	8.35
5	Hiziaz Tr1	2	132	33	63	14.24
6	Hiziaz1 GT1	6	34.5	11	8	8.33
7	Hiziaz2 GT1	10	34.5	11	14	9.13
8	Dahban Tr1	2	132	33	63	14.24
9	Dahban Tr2		132	33	63	14.24
10	Marib GT1	3	400	15.75	140	15
11	Marib ITB1	2	400	33	7.5	10
12	Amran Tr1	2	132	33	25	10
13	Dhamar Tr2	3	132	33	45	10.6
14	Dhamar Tr3		132	33	45	10.38
15	Hiswa GT1	5	36.75	10.5	40	10.6
16	Hiswa GT6	1	132	10.5	85	10.5
17	Mansoura1 GT1	6	34.5	11	10.6	7.95
18	Mansoura2 GT1	7	34.5	11	14	9.13
19	Mukha GT1	4	144	13.8	48	12
20	Mukha ITB1	2	132	33	25	10
21	Taiz	2	132	33	45	10
22	Al Barh	2	132	33	25	10
23	Rahidah	2	132	33	25	10
24	Ibb	3	132	33	31.5	9.95
25	Raskatib GT1	5	144	11	40	12.2
26	Raskatib ITB1	2	132	33	25	9.15
27	Hodeidah Tr1	2	132	33	60	9.83
28	Bajil Tr1	2	132	33	25	10
29	Jarahi Tr1	2	132	33	15	10.2

Appendix (D): Yemen National Grid Single Line Diagram