CHAPTER ONE

INTRODUCTION

1.1 Background:

Power system security may be looked upon as the probability of the systems operating point remaining within acceptable ranges, given the probabilities of changes in the system (contingencies) and its environment.

Contingency analysis is the study of the outage of elements such as transmission lines, transformers and generators, and investigation of the resulting effects on line power flows and bus voltages of the remaining system. It represents an important tool to study the effect of elements outages in power system security during operation and planning. Contingencies referring to disturbances such as transmission element outages or generator outages may cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the operating constraints. Consequently, planning for contingencies forms an important aspect of secure operation.

Contingency analysis allows the system to be operated defensively. Many of the problems which occur in the power system can cause serious troubles within a short time if the operator could not take fast corrective action. Therefore, modern computers are equipped with contingency analysis programs which model the power system and are used to study outage events and alert the operators of potential overloads and voltage violations.

The most difficult methodological problem to cope within contingency analysis is the accuracy of the method and the speed of solution of the model used. The operator usually needs to know if the present operation of the system is secure and what will happen if a particular outage occurs. Approximate models can be used as the DC load flow with respect to megawatt flows. When voltage is concern, full AC load flow analysis is required. The literature reviews in contingency analysis gave information about many methods that can be used to perform the contingency analysis. For seek of accuracy, full AC load flow analysis is performed post each outage using the outage simulation to obtain post-outage line flows and bus voltages. Operations personnel must recognize which line or generator outages will cause power flows or voltages to go out of their limits. In order to predict the effects of outages, contingency analysis technique is used. Contingency analysis procedures model a single equipment failure event, that is one line or one generator outage, or multiple equipment failure events, that is two transmission lines, a transmission line and a generator, one after another in sequence until all credible outages have been studied. For each outage tested, the contingency analysis procedure checks all power flows and voltage levels in the network against their respective limits [1].

1.2 Project Objectives:

(1) Study the contingency analysis for bulk power system network.

(2) Find the overloads or voltage violations under such contingencies.

(3) Identify the if the Sudanese National Grid secure or not.

1.3 Statement of Problem:

Power system contingency events affect the reliability of power services. If not well managed, the entire system may be driven into a disastrous state. The system security may be in danger and their consequences may become severe and harsh to the system operations. With exception of the scheduled outages, most components outages in power systems are probabilistic events.

1.4 Methodology:

(1) Applying load flow to the network by using (Newton Raphson) method under steady state.

(2) Screening contingencies on the network and ranking the most sever contingencies by using software (DIGSILENT) Powerfactory.

1.5 Project Outlines:

Chapter 1: represents general literature, project objectives statement of the problem, project layout and methodology.

Chapter 2: represents a general introduction to power system and contingency analysis

Chapter 3: represents a general introduction to load flow and contingency methods.

Chapter 4: represents the results and simulation of partial Sudanese National Grid by using DIGSILENT Program.

Chapter 5: represents the project conclusion and recommendations.

CHAPTER TWO

CONTINGENCY ANALYSIS

2.1 Introduction:

Contingencies are defined as potentially harmful disturbances for the steady state operation of an electrical network.

2.2 Power System Security:

Up until now we 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.

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.

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.

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. 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. An example of the type of event sequence that can cause a blackout might start with a single line being opened due to an insulation failure; the remaining transmission circuits in the system will take up the flow that was flowing on the now-opened line. If one of the remaining lines is now too heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed a cascading outage. Most power systems are operated such that any single initial failure event will not leave other components heavily overloaded, specifically to avoid cascading failures.

2.3 Factors Affecting Power System Security:

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. 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.

In our study, we will not be concerned with all the events that can cause trouble on a power system. Instead, we will concentrate on the possible consequences and remedial actions required by two major types of failure events: transmission-line outages, generation-unit failures and transformer failures. Transmission-line failures 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. Generation failures can also cause flows and voltages to change in the transmission system, with the addition of dynamic problems involving system frequency and generator output.

2.4 Contingencies Analysis:

In general terms, contingency analysis can be defined as the evaluation of the security degree of a power system. Contingency analysis is generally related to the analysis of abnormal system conditions. This is a crucial problem, both in planning and in daily operation. A common criterion is to consider contingencies as a single outage of any system element (generator, transmission line, transformer or reactor) and evaluate the post-contingency state. This is known as the N−1 security criterion. Other contingencies to be taken into account are simultaneous outages of double-circuit lines that share towers in a significant part of the line path.

Contingency analyses are used to determine the state of the network after an outage of one (N−1) or multiple elements (N−k). Therefore, a load flow must be performed for each selected contingency. This chapter deals with the most basic but typically used contingency analysis, deterministic contingency analysis.

2.5 Contingency Analysis: Detection of Network Problems

The following statements shows the different outages (contingencies) of elements namely; generator, transmission lines and transformer respectively.

2.5.1 Generation Outages:

When a generator suffers a forced outage, it causes changes in other generators as well as changes in the transmission system.

Effect on Other Generations When a generator fails, its power output is lost, and the result is an imbalance between total load plus losses and total generation. This imbalance results in a drop in frequency, which must be restored. To restore frequency back to its nominal value (50Hzor 60Hz), other generators must make up the loss of power from the outaged generator. The proportion of the lost power made up by each generator is strictly determined by its governor droop characteristic.

Effects on Transmission. When generation is lost, much of the made up power will come from tie lines, and this can mean line flow limit or bus voltage limit violations. In summary, the system must monitor two things to be sure generator outages do not cause problems when one is lost: check spinning reserve at all times to be sure it is adequate and model generator outages and their effect on transmission flows and voltages.

2.5.2 Transmission 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.

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 [3].

Contingency analysis and reliability evaluation of Sudan's electrical network will be performed using the load flow method. The result of this analysis will be used to determine the security level of the Sudan's electrical network. There are two methods for load flow:

2.5.3 DC Load Flow Solution

Direct Current Load Flow (DCLF) gives estimations of lines power flows on AC Power systems. DCLF looks only at active power flows and neglects reactive power flows. This method is non-iterative and absolutely convergent but less accurate than AC Load Flow (ACLF) solutions.

DCLF is used wherever repetitive and fast load flow estimations are required. In DCLF, nonlinear model of the AC system is simplified to a linear form through these assumptions:

- Line resistances (active power losses) are negligible i.e. $R \ll X$.
- Voltage angle differences are assumed to be small i.e. $\sin(\delta) = \delta$ and $\cos(\delta) = 1$.
- Magnitudes of bus voltages are set to 1.0 per unit (flat voltage profile).
- Tap settings are ignored.

Based on the above assumptions, voltage angles and active power injections are The variables of DCL.

2.5.4 AC Load Flow Solution

More accurate than DC Load Flow (DCLF) solutions.so it's perfect method will be performed Contingency analysis and reliability evaluation of electrical network because it looks at both active and reactive power.

CHAPTER THREE

LAOD FLOW AND CONTINGENCY METHODS

3.1 Introduction to Load Flow:

The power system is assumed to be operating under balanced condition and can be represented by single line diagram. The power system network contains hundreds of buses and branches with impedances specified in per-unit on a common MVA base. Power flow studies commonly referred to as long 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 analysis such as transient stability, dynamic stability, contingency and state estimation.

Network equations can be formulated in variety of forms. However, node voltage method is commonly used for power system analysis. The network equations which are in the nodal admittance form results in complex linear simultaneous algebraic equations in terms of node currents. The load flow result gives the bus magnitude and phase angle and hence the power flow through the transmission lines, line losses and power injection at all the busses.

3.1.1 Bus Classifications:

Four quantities are associated with each bus. These are voltage magnitude $|V|$, phase angle δ, real power P and reactive Q. in a load flow study, two out of four quantities are specified and the remaining two quantities are to be classified into three categories.

Slack bus: Also known as swing bus and taken as a 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.

Load bus: 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.

Voltage controlled buses: Also known as generator buses or regulated buses or PV 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.

Table 3.1: Bus Classification

Bus type	Specified quantities	Unknown quantities
Slack bus	$\lvert V \rvert, \delta$	P,Q
Load bus	P,Q	$\lvert V \rvert, \delta$
Voltage bus	P, $\lvert V \rvert$	Q, δ

3.1.2 Bus Admittance Matrix:

In order to obtain the bus-voltage equations, consider the simple 4-bus power system as shown in figure below

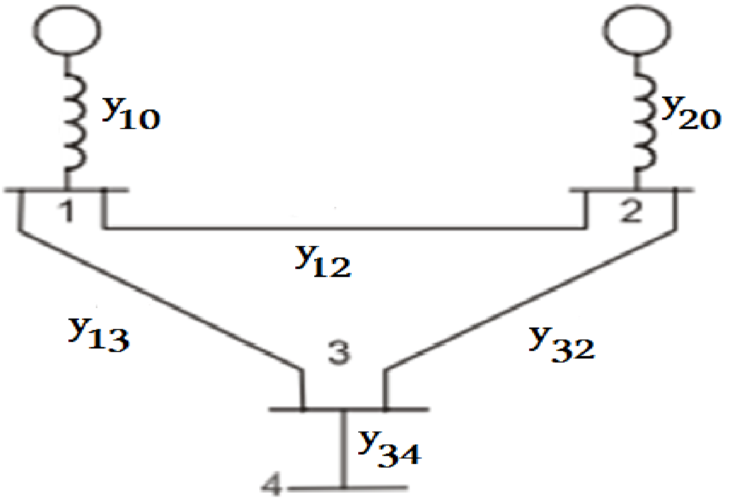

Figure (3.1): The impedance diagram of sample 4-bus power system

for simplicity resistance of the line are neglected and the impedances shown in above figure are expressed in per-unit on common MVA base.

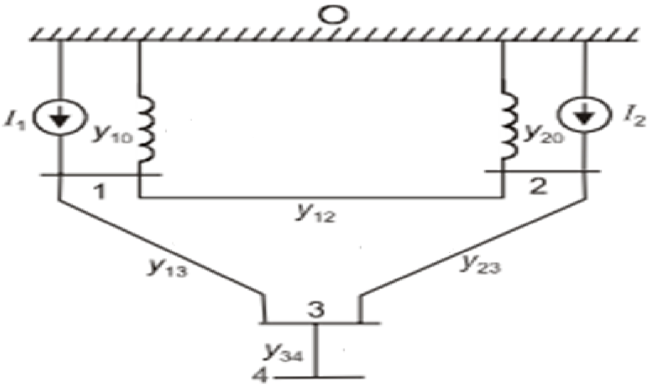

Figure (3.2): The admittance diagram of figure (3.1)

Applying KCL to the independent nodes 1, 2, 3, 4 we have,

$$I_1 = y_{10}V_1 + y_{12}(V_1 - V_2) + y_{13}(V_1 - V_3)$$

$$I_2 = y_{20}V_2 + y_{12}(V_2 - V_1) + y_{23}(V_2 - V_3)$$

$$0 = y_{23}(V_3 - V_2) + y_{13}(V_3 - V_1) + y_{34}(V_3 - V_4)$$

$$0 = y_{34}(V_4 - V_3)$$

Rearranging the above equations, we get

$$I_1 = (y_{10} + y_{12} + y_{13})V_1 - y_{12}V_2 - y_{13}V_3$$

$$I_2 = -y_{12}V_1 + (y_{20} + y_{12} + y_{23})V_2 - y_{23}V_3$$

$$0 = -y_{13}V_1 - y_{23}V_2 + (y_{13} + y_{23} + y_{34})V_3 - y_{34}V_4$$

$$0 = -y_{34}V_3 + y_{34}V_4$$

Let,

$$Y_{11} = (y_{10} + y_{12} + y_{13})$$

$$Y_{22} = (y_{20} + y_{21} + y_{23})$$

$$Y_{33} = (y_{31} + y_{32} + y_{34})$$

$$Y_{44} = y_{43}$$

$$Y_{12} = Y_{21} = -y_{12}$$

$$Y_{13} = Y_{31} = -y_{13}$$

$$Y_{23} = Y_{32} = -y_{23}$$

$$Y_{34} = Y_{43} = -y_{43}$$

The node equations reduce to

$$\mathrm{I}_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$$

$$\mathrm{I}_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4$$

$$\mathrm{I}_3 = Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + Y_{34}V_4$$

$$\mathrm{I}_4 = Y_{41}V_1 + Y_{42}V_2 + Y_{43}V_3 + Y_{44}V_4$$

Above equations can be written in matrix form,

$$\begin{bmatrix} \mathrm{I}_1 \\ \mathrm{I}_2 \\ \mathrm{I}_3 \\ \mathrm{I}_4 \end{bmatrix} = \begin{bmatrix} \mathrm{Y}_{11} & \mathrm{Y}_{12} & \mathrm{Y}_{13} & \mathrm{Y}_{14} \\ \mathrm{Y}_{21} & \mathrm{Y}_{22} & \mathrm{Y}_{23} & \mathrm{Y}_{24} \\ \mathrm{Y}_{31} & \mathrm{Y}_{32} & \mathrm{Y}_{33} & \mathrm{Y}_{34} \\ \mathrm{Y}_{41} & \mathrm{Y}_{42} & \mathrm{Y}_{43} & \mathrm{Y}_{44} \end{bmatrix} \begin{bmatrix} \mathrm{V}_1 \\ \mathrm{V}_2 \\ \mathrm{V}_3 \\ \mathrm{V}_4 \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

Or in general

$$\mathrm{I}_{\mathrm{bus}} = \mathrm{Y}_{\mathrm{bus}}\mathrm{V}_{\mathrm{bus}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

$$\mathrm{V}_{\mathrm{bus}} \equiv vector\ of\ bus\ voltages$$

$\mathrm{I}_{\mathrm{bus}}$ ≡vector of the injected currents

$\mathrm{Y_{bus}}$ ≡admittance matrix

Diagonal element of Y matrix:

$$Y_{ii} = \sum_{k=0}^{n} y_{ik} \;, j \neq i \text{ ………………(3.4)}$$

Off-diagonal element of Y matrix:

$$Y_{ik} = Y_{ki} = -y_{ik} \text{ …………………..(3.5)}$$

$$\mathrm{V_{bus}} = \mathrm{Y_{bus}^{-1}}\ \mathrm{I_{bus}} \qquad (3.6)$$

3.1.3 Bus Loading Equations:

Consider i- th bus of a power system as shown infigure(3.3)Transmission lines arerepresented by their equivalent p models π models. yi0 is the total charging admitance at bus i.

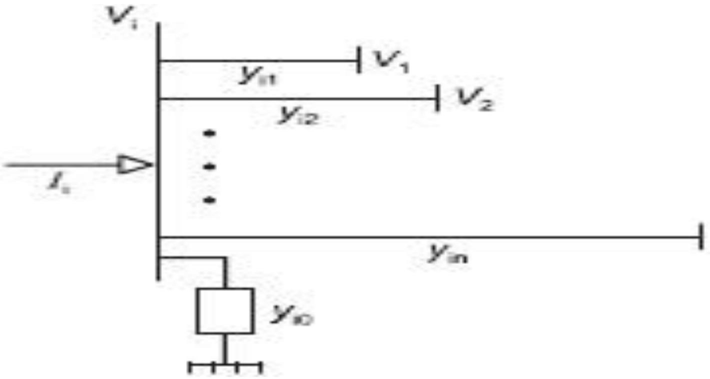

Figure (3.3): i-th bus of a power system

Net injected current $\mathbf{I}_\mathrm{i}$ into the bus i can be written as:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i \; - y_{i1}V_1 - y_{i1}V_2 - \cdots - y_{i1}V_n$$

(3.7)

Let us define

$$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in}$$

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

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

$\vdots$

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

$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n$.................(3.8)

Or

$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k$....................................(3.9)

The real and reactive power injected at the bus$i$ is

$$Pi - jQi = V_i * I_i$$

$$I_i = \frac{P_i - jQ_i}{v_i^*}$$

(3.10)

From eqns. (3.9) and (3.10) we get

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k \text{.........(3.11)}$$

$$Y_{ii}V_i = \frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k\right] \text{... ... .(3.12)}$$

3.1.4 Calculation of Net Injected Power:

From eqn. (3.11), we get

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$P_i - jQ_i = v_i^* \left[Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \ldots\ldots\ldots\ldots\ldots\ldots(3.13)$$

$$\therefore P_i - jQ_i = |V_i|^2|Y_{ii}|\cos\theta_{ii} + j|V_i|^2|Y_{ii}|\sin\theta_{\mathrm{ii}}$$

$$+\sum_{\substack{k=1 \\ k\neq i}}^{n}|Y_{ik}||V_i||V_k|\cos(\theta_{ik} + \delta_k - \delta_i) + \mathrm{j}\sum_{\substack{k=1 \\ k\neq i}}^{n}|Y_{ik}||V_i||V_k|\sin(\theta_{ik} + \delta_k - \delta_i)$$

(3.14)

separating real and imaginary part of equation (3.14)

$P_i = \sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\cos(\theta_{ik} + \delta_k - \delta_i)$ …………………………………..(3.15)

And

$Q_i = -\sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\sin(\theta_{ik} + \delta_k - \delta_i)$ ………………………………….(3.16)

3.1.5 Newton-Raphson Method:

The Newton-Raphson method is a powerful method of solving non-linear algebraic equations. It works faster and is sure to converge in most cases as compared to the GS method.

Given a set of nonlinear equation:

$$y_1 = f_1(x_1, x_2, \ldots x_n)$$
$$y_2 = f_2(x_1, x_2, \ldots x_n)$$

$$\vdots$$

$$y_n = f_n(x_1, x_2, \ldots x_n) \;\ldots\ldots\ldots\ldots(3.17)$$

And the initial estimate for the solution factor

$$x_1^{(0)}, x_2^{(0)}, \ldots x_n^{(0)}$$

Assuming,

$$\Delta x_1, \Delta x_2, \ldots., \Delta x_n$$

Are the corrections required for $x_1^{(0)}$, $x_2^{(0)}$,... $x_n^{(0)}$ respectively, so that the equation (3.17) are solved :

$$y_1 = f_1(x_1^{(0)} + \Delta x_1, x_2^{(0)} + \Delta x_2, \ldots x_n^{(0)} + \Delta x_n)$$
$$y_2 = f_2(x_1^{(0)} + \Delta x_1, x_2^{(0)} + \Delta x_2, \ldots x_n^{(0)} + \Delta x_n)$$
$$\vdots$$
$$y_n = f_n\left(x_1^{(0)} + \Delta x_1, x_2^{(0)} + \Delta x_2, \ldots x_n^{(0)}\ \Delta x_n\right) \ldots(3.18)$$

Each equation of the set (3.18) can be expanded by Taylor's series for a function of two or more variable, by neglecting H.O.T, the linear set of equation resulting in matrix form as follows:

$$\therefore \begin{bmatrix} y_1 - f_1(x_1^{(0)}, x_2^{(0)}, \ldots x_n^{(0)}) \\ y_2 - f_2(x_1^{(0)}, x_2^{(0)}, \ldots x_n^{(0)}) \\ \vdots \\ \vdots \\ \vdots \\ y_n - f_n(x_1^{(0)}, x_2^{(0)}, \ldots x_n^{(0)}) \end{bmatrix} = \begin{bmatrix} \left.\frac{\partial f_1}{\partial x_1}\right|_0 & \left.\frac{\partial f_1}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_1}{\partial x_n}\right|_0 \\ \left.\frac{\partial f_2}{\partial x_1}\right|_0 & \left.\frac{\partial f_2}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_2}{\partial x_n}\right|_0 \\ \cdots & \cdots & \cdots & \cdots \\ \left.\frac{\partial f_n}{\partial x_1}\right|_0 & \left.\frac{\partial f_n}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_n}{\partial x_n}\right|_0 \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \vdots \\ \vdots \\ \Delta x_n \end{bmatrix} \ldots.(3.19)$$

Or D=JR ....(3.20)

J≡Jacobain matrix

R≡The change vector Δx_i

In equation (3.20) may be written in iterative form:

$$\mathrm{D}^{(\mathrm{p})} = \mathrm{J}^{(\mathrm{p})}\mathrm{R}^{(\mathrm{p})}$$

$\therefore \mathrm{R}^{(\mathrm{p})} = \left[\mathrm{J}^{(\mathrm{p})}\right]^{-1}\mathrm{D}^{(\mathrm{p})}$ (3.21)

The new value of x_i is calculated from

$\therefore x_i^{(p+1)} = x_i^{(p)} + \Delta x_i^{(p)}$ (3.22) The process is repeated until two successive values for each x_i differ only by a specified tolerance. In this process J can be calculated in each iteration.

3.1.6 Load Flow Using Newton-Raphson Method:

Newton-Raphson (NR) method is more suitable and practical for large power systems. The 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.

Rewriting equations (3.15) and (3.16):

$$P_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k| \cos(\theta_{ik} + \delta_k - \delta_i) \qquad (3.23)$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}||V_i||V_k| \sin(\theta_{ik} + \delta_k - \delta_i) \qquad (3.24)$$

By expanding eqns. (3.23) and (3.24) in Taylor-series and neglecting H.O.T

$$\therefore \left[\begin{array}{c} \Delta P_2^{(p)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta P_n^{(p)} \\ \hline \Delta Q_2^{(p)} \\ \vdots \\ \vdots \\ \Delta Q_n^{(p)} \end{array}\right] \left[\begin{array}{ccc|ccc} \left[\frac{\partial P_2}{\delta_2}\right]^{(p)} & \cdots & \left[\frac{\partial P_2}{\delta_n}\right]^{(p)} & \left[\frac{\partial P_2}{\partial|V_2|}\right]^{(p)} & \cdots & \left[\frac{\partial P_2}{\partial|V_n|}\right]^{(p)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \left[\frac{\partial P_n}{\delta_2}\right]^{(p)} & \cdots & \left[\frac{\partial P_n}{\delta_n}\right]^{(p)} & \left[\frac{\partial P_n}{\partial|V_2|}\right]^{(p)} & \cdots & \left[\frac{\partial P_n}{\partial|V_n|}\right]^{(p)} \\ \hline \left[\frac{\partial Q_2}{\delta_2}\right]^{(p)} & \cdots & \left[\frac{\partial Q_2}{\delta_n}\right]^{(p)} & \left[\frac{\partial Q_2}{\partial|V_2|}\right]^{(p)} & \cdots & \left[\frac{\partial Q_2}{\partial|V_n|}\right]^{(p)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \left[\frac{\partial Q_n}{\delta_2}\right]^{(p)} & \cdots & \left[\frac{\partial Q_n}{\delta_n}\right]^{(p)} & \left[\frac{\partial Q_n}{\partial|V_2|}\right]^{(p)} & \cdots & \left[\frac{\partial Q_n}{\partial|V_n|}\right]^{(p)} \end{array}\right] \left[\begin{array}{c} \Delta\delta_2^{(p)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta\delta_n^{(p)} \\ \hline \Delta|V_2|^{(p)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta|V_n|^{(p)} \end{array}\right]$$

(3.25)

Bus 1 in above eqn. assumed to be slack bus, and this eqn. can be written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.26)$$

3.2 Sensitivity Factors

In any practical sized power system, there is a very large number of elements. Hence, for carrying out contingency analysis, outages of all these elements (preferably) need to be carried out one-by-one corresponding to any particular operating condition. these outage cases should be studied with the help of full AC load flow solutions. However, analysis of thousands of outage cases with full AC power flow technique will involve a significant amount of computation time and as a result, it might not be possible to complete this entire exercise before the new operating condition emerges. Therefore, instead of using full non-linear AC power flow analysis, approximate, but much faster techniques based on linear sensitivity factors are used to estimate the post contingency values of different quantities of interest.

The linear sensitivity factors approximately estimate the changes in different line flows for any particular outage condition without the need of full AC power flow solution.

Basically, there are two types of sensitivity factors and these are:

a. Generation outage sensitivity factor (GOSF)

b. Line outage sensitivity factor (LOSF)

3.2.1 The generation outage sensitivity factor

The generation outage sensitivity factor is defined by:

$$\propto_{ij}^{k} = \frac{\Delta f_{ij}}{\Delta P_k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.27)$$

Where, $\propto_{ij}^{k} \rightarrow$ GOSF of line ‘i-j’ for generation change at bus ‘k’

$\Delta f_{ij\rightarrow}$ Change in power flow in line ‘i-j’

$\Delta P_{k\rightarrow}$ Change in generation at bus ‘k’

The factor $\propto_{ij}^{k}$ denotes the sensitivity of the line flow on line ‘i-j’ due to change in generation at bus ‘k’. In equation (3.27), it is assumed that the generation lost at bus ‘k’ would be exactly compensated by the reference or slack bus. Now, if the generation at bus ‘k’ was generating an amount of power equal to P_k^0, then to represent the outage condition, $\Delta P_k = -P_k^0$. Hence, the new power flow over the line ‘i-j’ would be given as,

$$f_{ij}^{n} = f_{ij}^{0} + \Delta f_{ij} = f_{ij}^{0} + \alpha_{ij}^{k}\Delta P_k = f_{ij}^{0} - \alpha_{ij}^{k} P_k^0 \qquad (3.28)$$

However, it should be noted that for any particular line ‘i-j’, the factors $\propto_{ij}^{k}$ and $\propto_{ij}^{m}$ (for generation outage at bus ‘m’) are different and therefore need to be pre-calculated separately. Once these factors are pre-calculated and stored, the new values of line flow over any line can easily be estimated very quickly from equation (3.28). If the new power flow over any line is found to be more than the corresponding limit, then the operator can be alerted for taking an appropriate pre-emptive action.

In equation (3.28), it is assumed that the lost generation at bus ’k’ would be taken up by the slack bus. However, it is also quite possible that the lost generation would be compensated by all the remaining ‘on-line’ generators combined, in which, each of the ‘on-line’ generators would take up some fraction of the lost generation in some particular ratio. One of the most frequently used methods assumes that the ‘on-line’ generators share the lost generation in proportion to their maximum MW rating. Thus, the proportion of generation picked up by generation ‘g’ is given by,

$$\gamma_{gk} = \frac{P_g^{max}}{\sum_{\substack{a=1 \\ \neq k}}^{M} P_a^{max}} \qquad ,g \neq k \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.29)$$

Where, M → Total number of generators in the system

$\gamma_{gk} \rightarrow$ Proportionality factor for generation 'g' to pick up generation when unit 'k' fails

P_a^{max} → Maximum MW rating for generator 'a'.

Now, as the sensitivity factors shown in equation (3.27) are linear in nature, the effects of simultaneous generation change in several generators on a particular line can be obtained by following superposition principle. Hence, the new line flow in the line 'i-j' becomes,

$$f_{ij}^{(n)} = f_{ij}^{(0)} + \alpha_{ij}^{k}\Delta P_k - \sum_{a=1}^{M} \alpha_{ij}^{a}\Delta P_a \gamma_{gk} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.30)$$

In equation (3.30) it is assumed that no remaining 'on-line' generation hits the generation limit.

3.2.2 Line Outage Distribution Factors:

The line outage distribution factors are also defined similarly. The LOSF is defined by,

$$\beta_{ij,mn} = \frac{\Delta f_{ij}}{f_{mn}^{(0)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.31)$$

Where, $\beta_{ij,mn}$ → Line outage distribution factor for line 'i-j' under outage of line 'm-n'.

$f_{mn}^{(0)}$ → Power flow over line 'm-n' in the pre-outage condition.

Therefore, for the outage of line 'm-n', the new flow over line 'i-j' is given by,

$$f_{ij}^{(n)} = f_{ij}^{(0)} + \beta_{ij,mn} f_{mn}^{(0)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.32)$$

Again, as we will show later, the factors $\beta_{ij,mn}$ are constant as they are dependent only on the line parameters. Therefore, they would be pre-calculated and stored in the memory. As a result, for the outage of any line ‘m-n’, the new power flows over all the other lines can be estimated very quickly.

3.3 Contingency Ranking

Therefore, the development of a contingency ranking algorithm which would rank contingencies based upon their relative severity is desirable. The contingencies can be ranked based upon their effects on line loading or bus voltages.

A variety of algorithms are developed which can be classified into two groups: The performance index (*PI*) based method which utilizes a wide system scalar performance index to quantify the severity of each case by calculating their *PI* values and ranking them accordingly. The other is the screening method which is based on approximate power flow solutions to eliminate those non-critical contingencies. With the advancement of artificial intelligence, expert systems and fuzzy theory are proposed to estimate the severity of various contingencies. Also artificial neural networks approaches based on (*PI*) have been proposed for contingency selection.

System performance indices are not unique and obtain different forms depending on the parameters that are of most importance to the engineer. However, in selecting a *PI*, physical properties of the system should be taken into consideration. The most common form of system performance indices gives a measure of the deviation from rated values of system variables such as line flows, bus voltages and bus power injections.

The ranking technique utilizes a system wide scalar *PI* to quantify the severity of each contingency with actually calculating the post contingency line flows and bus voltages using full AC load flow analysis. Contingencies are ranked in the order of their performance index values and processed starting with the most severe contingency at the top of the list proceeding down the ranking to the less severe ones. The performance indices are calculated for contingency cases with real flow violations and voltage violations. The masking problem is successfully addressed by changing the exponent of the performance index from 2 to higher values. The post contingency line flows and bus voltages are obtained from the load flow solution after the application of the outage simulation. The exponent (m) of the performance index is changed in the range from 2 to 30 to avoid masking errors. Outages are then ranked on the basis of their corresponding performance indices. In this study the contingencies are ranked on the basis of line loading.

For the active line flow ranking, it is straight forward; the performance index will be the accumulation of the post contingency line flow over the line limit. Any overloaded line will make the fraction greater than one. This will increase the value of the performance index, and so specify the lines which need to be paid more attention. If there are many lines operating near their limit the value of the Active Power Loading Performance Index (APLPI) will increase while there may be another case which is one line overloaded but the value of the APLPI is small. This occurs with small values of (m) and leads to miss-ranking where severe contingencies appear as not severe and vice versa. This error is known as masking error and it decreases as the value of (m) increases.

The system performance index is a measure that can be used to evaluate relative severity of a contingency. Due to the weak coupling between real power and reactive power equations, two separate performance indices are defined. A contingency may be severe in the point view of line loading but do not affect the system bus voltages and vice versa.

3.3.1 Active Power Loading Performance Index (*APLPI*):

APLPI is the active power loading performance index corresponding to line real power flow violations. It gives measure of line MW overloads and formulated by,

$$APLP = \sum_{i=1}^{NL} W_{pi} \left(\frac{P_{ipc}}{P_{ilim}}\right)^{2m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.33)$$

Where:

P_{ipc}: The post-contingency active power flow on line (i)

P_{ilim}: The active power flow limit on line (i)

W_{pi}: The weight factor of active power flow on line (i)

NL: Number of transmission lines.

m: Is a positive integer.

Contingencies are ranked according to their relative severity using the *APLPI*. The most severe contingencies are ranked at the top of the list and the non-severe contingencies at the end.

Generally, results of contingency analysis give an idea about weak lines whose capacity must be increased mainly in projects of transmission system improvements to withstand contingencies, and to ensure secure operation during contingencies.

Network weaknesses are the lines or transformers which always become overloaded in case of different outages.

3.4 PowerFactory Overview:

The calculation program PowerFactory, as written by DIgSILEN, is a computer aided engineering tool for the analysis of transmission, distribution, and industrial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization.

“DIgSILENT " is an acronym for “DIgital SImuLation of Electrical NeTworks". DIgSILENT Version 15.1 was the world’s first power system analysis software with an integrated graphical single-line interface. That interactive single-line diagram included drawing functions, editing capabilities and all relevant static and dynamic calculation features.

3.4.1 AC Load Flow Method

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

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

In both formulations, the resulting non-linear equation systems must be solved by an iterative method.

PowerFactory 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.

3.4.2 Executing Contingency Analyses:

The contingency analysis module available in PowerFactory offers two distinct contingency analysis methods:

Single Time Phase Contingency Analysis:

The non-probabilistic (deterministic) assessment of failure effects under given contingencies, within a single time period.

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.

To access the various contingency analysis related functions within PowerFactory , click on the icon ▼ Change Toolbox and select "Contingency Analysis".

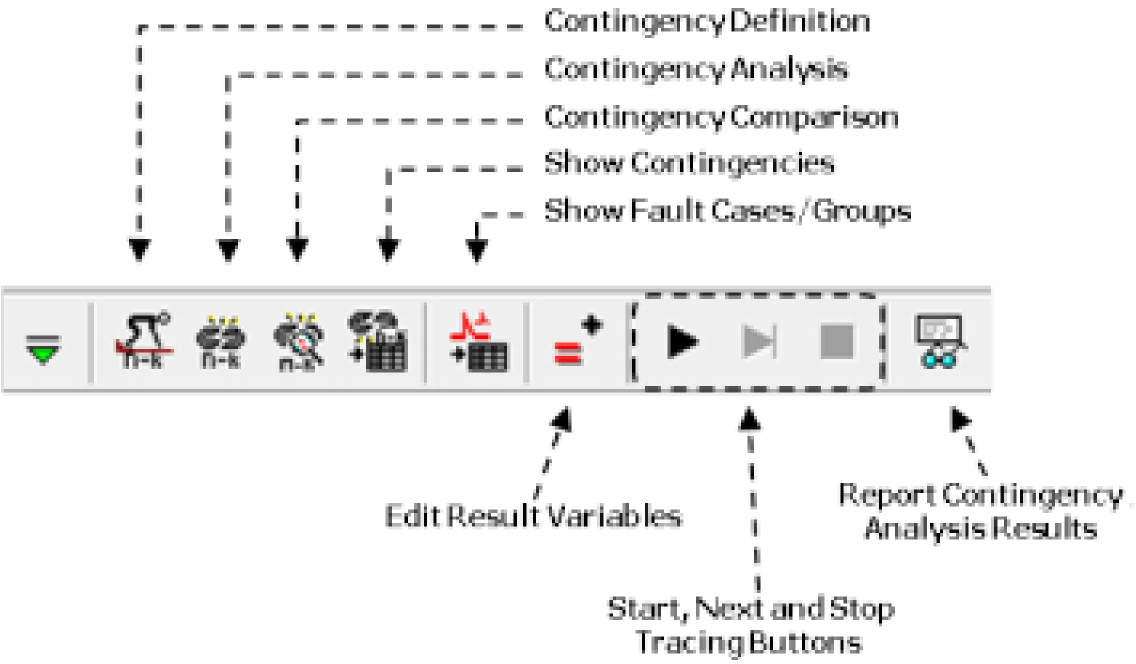

Figure 3.4, shows the Contingency Analysis Toolbar, with all the related functions

CHAPTER FOUR

SIMULATION AND RESULTS ANALYSIS

4.1 Introduction:

The voltage profile of the entire system is presented from the load flow simulation as shown in table (4.2), it can be noticed that there are seven buses are under voltage and nine lines are over-loaded. The model analysis method has been successfully applied to the partial power system network shown in appendix (A), a power flow program based on POWERFACTORY (DIGSILENT) is developed to:

- Calculate the power flow solution.

- Contingency analysis based on model analysis.

- Screening and assessment of Sudanese National Grid.

4.2 Case Study:

The network which has been studied is Sudan electrical power system network. It contains of 81 transmission lines, 53 loads, 7 synchronous machines,15 2-winding transformers, 82 bus bars, external grid and 10 shunts have been tabulated in table (4.1).

Table 4.1: The statistics of the power system network components:

Number	Type	Number of units
1	Line	81
2	Load	53
3	Synchronous machine	7
4	2-winding transformer	15
5	Bus bar	82
6	External grid	1
7	Shunt	10

4.2 Power Flow Results:

Table 4.2: The Bus Bars Load Flow Results:

Bus number	Bus name	Voltage (kv)	Voltage(p.u)	Angle (degree)
1	MWP500	500	1	0
2	ATB5	501.18	1.002	-3.73
3	MRK5	495.27	0.991	-7.51
4	KAB5	497.8	0.996	-8.22
5	WHL2	217.33	0.988	-8.94
6	WWA2	224.2	1.019	-8.24
7	DEB2-B1	224.49	1.02	-6.48
8	DEB2-B2	229.48	1.043	-5.25
9	DON2	225.36	1.024	-7.92

10	MWT2	226.71	1.031	-2.99
11	MWP2	228.25	1.038	-1.6
12	ATB2	204.04	0.927	-9.12
13	SHN2	213.55	0.971	-13.48
14	MRK2	219.99	1	-19.08
15	GAM2	216.82	0.986	-20.16
16	KAB2	218.16	0.992	-16.63
17	FRZ2	219.6	0.998	-16.36
18	GER2	220	1	-16.42
19	IBA2	219.46	0.998	-18.62
20	MHD2	218.94	0.995	-19.68
21	KLX2	219.01	0.995	-19.4
22	JAS2	216.54	0.984	-20.65
23	GAD2	217.03	0.986	-20.88
24	SOB2	218.58	0.994	-19.47
25	NHAS2	212.43	0.966	-23.49
26	MAR2	212.76	0.967	-24.14
27	MSH2	219.6	0.998	-20.44
28	RBK2	220	1	-20.34
29	SNJ2	216.14	0.982	-23.73
30	SNG2	218.99	0.995	-23.1
31	ROS2	220	1	-18.57
32	RNK2	221.74	1.008	-19.51
33	HWT2	219.98	1	-23.61
34	OBD2	219.71	0.999	-23.41
35	UMR2	221.2	1.005	-21.82

36	TND2	221.59	1.007	-21.28
37	DBT2	220.43	1.002	-24.05
38	ZBD2	220.16	1.001	-24.33
39	FUL2	220.59	1.003	-24.76
40	BBN2	221.03	1.005	-24.88
41	GDF2	218.88	0.995	-24.01
42	GRB2	217.76	0.99	-24.51
43	SHK2	218.82	0.995	-24.07
44	NHLF2	217.72	0.99	-24.61
45	ARO2	219.22	0.996	-24.87
46	KSL2	218.99	0.995	-24.86
47	HUD	219.25	0.997	-19.34
48	UTP2	218.92	0.995	-24.08
49	SHD2	220	1	-24.06
50	KHE1	108.2	0.984	-26.32
51	IZB1	106.13	0.956	-24.99
52	IBA1	106.92	0.972	-24.55
53	KHN1	110	1	-25.84
54	KUK1	108.49	0.986	-26.17
55	IZG1	107.97	0.982	-25.98
56	MHD1	107.26	0.975	-25.75
57	FAR1	102.96	0.936	-26.61
58	AFR1	103.79	0.944	-26.19
59	KLX1	104.61	0.951	-25.74
60	LOM1	104.58	0.951	-25.94
61	SHG1	105.28	0.957	-26.06

62	MUG	105.62	0.96	-26.28
63	BNT1	106.03	0.964	-26.19
64	OMD1	106.17	0.965	-26.19
65	GAM1	108.38	0.985	-25.23
66	JAS1	110.32	1.003	-24.47
67	BAG1	102.01	0.927	-23.83
68	SOB1-B1	103.68	0.943	-25.07
69	GAD1-B2	102.41	0.931	-23.51
70	NHAS1	114.16	1.038	-25.67
71	OHAS1	113.81	1.035	-25.81
72	GND1	113.45	1.031	-26.03
73	MAR1-B1	113.05	1.028	-26.79
74	MAN1	111.9	1.017	-27.63
75	ORBK1	111.28	1.012	-25.17
76	SNJ1	111.34	1.012	-25.08
77	HAG1	111.63	1.015	-26.59
78	SNP1	110	1	-25.08
79	MIN1	104.29	0.948	-26.14
80	FAO1	110.23	1.002	-27.2
81	GDF1	111.19	1.011	-25.54
82	GRB6	66	1	-25.38

Discussion of Buses Results:

From the load flow results shown in table (4.2), it can be noticed that there are seven buses are out of tolerance ±5(under voltage) which are shaded with (blue) colour, and the other buses within limits.

Table 4.3: Line Flow Results:

Name	Type	Loading [%]	Bus bar	Active power [MW]	Reactive power [MVAR]	Power factor [-]	Current	
							K.A	P.U
MWT2-DEB2 B1	Line	29.18	7	54.725	-6.88	-0.99	0.142	0.289
			10	55.355	-9.916	0.98	0.143	0.292
MWP2-MWT2	Line	44.53	10	-85.163	-10.58	-0.99	0.219	0.445
			11	85.537	7.495	1	0.217	0.443
MWP2-DEB2 B2	Line	26.09	8	-44.145	0.881	-1	0.111	0.226
			11	44.682	-23.792	0.88	0.128	0.261
ATB2-SHN2	Line	101.46	12	143.866	140.688	0.71	0.569	1.015
			13	139.998	108.016	-0.79	0.478	0.852
SHN2-FRZ2	Line	62.62	17	104.802	92.088	-0.75	0.367	0.508
			13	106.734	128.631	0.64	0.452	0.626
MRK2-MHD2	Line	69.24	14	186.044	32.393	0.99	0.496	0.687
			20	185.522	-38.595	-0.98	0.5	0.692
MRK2-HUD	Line	80.51	14	203.294	84.108	0.92	0.577	0.8
			47	202.991	-86.447	-0.92	0.581	0.805
KAB2-FRZ2	Line	28.65	16	-55.904	-54.572	-0.72	0.207	0.286
			17	56.047	40.199	0.81	0.181	0.251
KAB2-IBA2	Line	148.16	16	337.906	136.836	0.93	0.965	1.482
			19	335.132	137.564	-0.93	0.953	1.464
GER2-FRZ2	Line	52.92	18	-35.109	139.252	-0.24	0.377	0.522
			17	35.182	140.948	0.24	0.382	0.529
	Line	82.26	19	219.025	32.464	-0.99	0.583	0.807

GER2-IBA2			18	221.109	-47.839	0.98	0.594	0.823
IBA2-KLX2	Line	123.67	19	337.738	-32.048	1	0.893	1.237
			21	336.619	31.02	-1	0.891	1.235
ATB5-MWP5	Line	27.02	1	246.837	147.488	0.86	0.332	0.27
			2	245.204	-79.991	-0.95	0.297	0.242
KLX2-SOB2	Line	79.44	24	146.199	-20.295	-0.99	0.39	0.794
			21	146.372	18.501	0.99	0.389	0.793
JAS2-GAM2	Line	44.68	15	93.485	-11.25	0.99	0.251	0.447
			22	-93.31	1.272	-1	0.249	0.443
JAS2-RBK2	Line	23.8	28	21.096	3.782	0.98	0.056	0.078
			22	-20.939	-60.932	-0.32	0.172	0.238
GAD2-JAS2	Line	17.76	22	31.189	-36.576	0.65	0.128	0.178
			23	-31.142	22.883	-0.81	0.103	0.142
GAD2-NHAS2	Line	73.69	23	127.882	24.773	0.98	0.347	0.706
			25	126.656	-40.758	-0.95	0.362	0.737
SOB2-GAD2	Line	80.2	24	146.199	20.295	0.99	0.39	0.794
			23	145.622	-26.105	-0.98	0.394	0.802
NHAS2-MAR2	Line	27.2	25	44.147	-21.516	0.9	0.133	0.272
			26	-44.047	7.946	-0.98	0.121	0.247
MAR2-SNJ2	Line	30.43	26	-26.86	-48.042	-0.49	0.149	0.304
			29	27.009	26.976	0.71	0.102	0.208
MSH2-RBK2	Line	9.64	27	-6.989	-25.534	-0.26	0.07	0.096
			28	6.994	-16.969	0.38	0.048	0.067
RBK2-RNK2	Line	19.49	32	34.744	-23.707	0.83	0.11	0.152
			28	-34.601	-40.93	-0.65	0.141	0.195
RBK2-TND2	Line	26.12	28	44.807	-56.14	0.62	0.189	0.261
			36	-44.563	12.698	-0.96	0.121	0.167
SNJ2-SNG2	Line	45.08	29	-60.968	-56.062	0.74	0.221	0.451
			30	61.218	43.992	0.81	0.199	0.405
MRK5-MWP5	Line	71.12	1	680.765	330.447	0.9	0.874	0.711
			3	671.773	285.219	-0.92	0.851	0.692
	Line	58.62	31	104.318	-33.693	0.95	0.288	0.586

SNG2-ROS2			30	102.786	-6.756	-1	0.272	0.553
SNG2-HWT2	Line	19	33	-29.444	7.667	-0.97	0.08	0.111
			30	29.538	-42.822	0.57	0.137	0.19
ROS2-RNK2	Line	24.25	31	35.349	-56.555	0.53	0.175	0.243
			32	-35.147	1.322	-1	0.092	0.127
HWT2-GDF2	Line	15.12	41	-27.835	-30.618	-0.67	0.109	0.151
			33	27.898	-8.625	0.96	0.077	0.106
OBD2-DBT2	Line	10.26	34	19.794	-20.062	0.7	0.074	0.103
			37	-19.733	2.608	-0.99	0.052	0.072
UMR2-OBD2	Line	15.07	35	39.824	-12.289	0.96	0.109	0.151
			34	-39.551	-11.716	-0.96	0.108	0.15
TND2-UMR2	Line	17.05	36	43.555	-18.258	0.92	0.123	0.171
			35	-43.453	-12.828	-0.96	0.118	0.164
DBT2-ZBD2	Line	5.44	37	13.483	-6.547	0.9	0.039	0.054
			38	-13.466	-6.523	-0.9	0.039	0.054
ZBD2-FUL2	Line	7.26	38	10.106	-17.241	0.51	0.052	0.073
			39	-10.084	-6.353	-0.85	0.031	0.043
FUL2-BBN2	Line	4.97	39	3.364	-13.296	0.25	0.036	0.05
			40	-3.36	-2.503	-0.8	0.011	0.015
KAB5-MRK5	Line	31.23	3	282.434	169.062	0.86	0.384	0.312
			4	282.002	136.025	-0.9	0.363	0.296
GDF2-ROS2	Line	15.66	43	-42.786	-2.036	-1	0.113	0.157
			41	42.797	-1.157	1	0.113	0.156
GDF2-SHD2	Line	14.01	41	-37.801	-6.397	-0.99	0.101	0.14
			49	38	6.397	0.99	0.101	0.14
GRB2-NHLF2	Line	5.98	44	-12.029	-8.021	-0.83	0.038	0.053
			42	12.034	-10.962	0.74	0.043	0.06
GRB2-KSL2	Line	17.11	42	16.729	-43.474	0.36	0.124	0.171
			46	-16.668	6.572	-0.93	0.047	0.065
SHK2-GRB2	Line	18.45	43	42.114	0.505	1	0.111	0.154
			42	-42.017	-27.487	-0.84	0.133	0.184
	Line	4.02	43	0.001	-10.984	0	0.029	0.04

SHK2-UTP2			48	0	0	-0.78	0	0
KSL2-ARO2	Line	6.3	46	0.002	-17.25	0	0.045	0.063
			45	0	0	-0.68	0	0
HUD-GAM2	Line	82.13	47	202.991	86.447	0.92	0.581	0.805
			15	202.022	-93.459	-0.91	0.593	0.821
WHL2-WWA2	Line	20.46	5	-14.36	-40.758	-0.33	0.115	0.205
			6	14.547	0.608	1	0.037	0.067
IBA1-IZB1	Line	59.47	52	68.208	39.782	0.86	0.426	0.591
			51	-68.006	-39.992	-0.86	0.429	0.595
KHN1-IBA1	Line	189.41	53	104.639	237.32	-0.4	1.361	1.886
			52	106.883	229.466	0.42	1.367	1.894
KHN1-IZG1	Line	98.9	53	49.905	125.319	0.37	0.708	0.918
			55	-49.296	-124.04	-0.37	0.714	0.989
KUK1-KHE1	Line	72.19	50	-81.917	-53.127	-0.84	0.521	0.722
			54	82.004	53.168	0.84	0.521	0.721
KUK1-KHN1	Line	199.51	53	130.734	228.287	0.5	1.381	1.993
			54	239130.	224.717	-0.5	1.382	1.995
IZG1-MHD1	Line	60.84	56	22.047	-77.621	0.31	0.439	0.608
			55	-24.893	77.478	-0.31	0.435	0.603
MHD1-OMD1	Line	84.32	64	-86.613	-70.848	-0.77	0.609	0.843
			56	86.958	71.368	0.77	0.606	0.839
AFR1-FAR1	Line	46.83	58	50.425	32.666	0.84	0.334	0.463
			57	-50.266	-33.255	-0.83	0.338	0.468
KLX1-KUK1	Line	179.48	54	3.614	150.831	0.02	0.803	1.783
			59	-2.378	146.429	-0.02	0.808	1.795
KLX1-AFR1	Line	61.02	58	-67.628	-41.143	-0.85	0.44	0.61
			59	67.841	41.02	0.86	0.438	0.606
KLX1-LOM1	Line	70.16	59	90.698	-13.852	0.99	0.506	0.702
			60	-90.62	13.893	-0.99	0.506	0.701
KLX1-SOB1 B2	Line	97.63	68	6.572	-28.299	0.23	0.162	0.976
			59	-6.301	28.334	-0.22	0.16	0.967
	Line	55.16	61	-5.153	71.7	-0.07	0.394	0.546

LOM1-SHG1			60	5.276	-71.911	0.07	0.398	0.552
SHG1-MUG	Line	28.18	61	21.76	-30.027	0.59	0.203	0.282
			62	-21.715	29.205	-0.6	0.199	0.276
SHG1-JAS1	Line	87.72	66	83.059	84.185	0.7	0.619	0.858
			61	-81.522	-81.733	-0.71	0.633	0.877
MUG-BNT1	Line	67.92	63	53.842	71.789	0.6	0.489	0.677
			62	-53.751	-71.771	-0.6	0.49	0.679
OMD1-BNT1	Line	13.39	63	-5.296	-16.942	-0.3	0.097	0.134
			64	5.301	16.418	0.31	0.094	0.13
GAM1-BNT1	Line	103.67	65	108.537	87.579	0.78	0.743	1.029
			63	107.615	-85.435	-0.78	0.748	1.037
BAG1-GAD B2	Line	50.46	69	43.754	-3.824	1	0.248	0.505
			67	-43.562	3.971	-1	0.248	0.504
SOB1 B2-BAG1	Line	99.33	68	-6.572	28.299	-0.23	0.162	0.976
			67	7.072	-28.207	0.24	0.165	0.993
GAD B2-OHAS1	Line	104.6	69	-8.984	-29.402	-0.29	0.173	1.046
			71	11.238	29.688	0.35	0.161	0.972
OHAS1-NHAS1	Line	51.44	71	-57.71	-44.992	-0.79	0.371	0.514
			70	57.779	44.736	0.79	0.37	0.512
OHAS1-GND1	Line	22.04	72	-27.821	-14.253	-0.89	0.159	0.22
			71	27.858	12.813	0.91	0.156	0.216
OHAS1-MAR1 B1	Line	25.25	71	7.526	-3.372	0.91	0.042	0.252
			73	-7.434	1.57	-0.98	0.039	0.234
MAR1 B1-HAG1	Line	44.26	77	-3.566	-13.723	-0.25	0.073	0.443
			73	3.638	1.92	0.88	0.021	0.127
MAR1 B1-FAO1	Line	28.64	80	-6.888	-5.887	-0.76	0.047	0.286
			73	7.03	3.669	0.89	0.04	0.244
MAN1-MAR1 B1	Line	20.76	73	10.955	1.739	0.99	0.057	0.196
			74	-10.886	-4.058	-0.94	0.06	0.208
ORBK1-SNJ1	Line	5.54	75	-0.336	-1.476	-0.22	0.008	0.047
			76	0.336	-1.739	0.19	0.009	0.055
	Line	85.77	76	17.158	21.039	0.63	0.141	0.85

SNJ1-SNP1			78	-16.95	-21.118	-0.63	0.142	0.858
HAG1-SNP1	Line	38.57	77	-4.028	9.686	-0.38	0.054	0.327
			78	4.247	-11.41	0.35	0.064	0.386
SNP1-MIN1	Line	57.68	79	-14.384	-9.552	-0.83	0.096	0.577
			78	14.998	8.153	0.88	0.09	0.541
GDF1-FAO1	Line	15.04	80	-4.133	-0.652	-0.99	0.022	0.103
			81	-4.225	-4.521	0.68	0.032	0.15
DON2-WWA2	Line	15.91	6	-14.547	-42.151	-0.33	0.115	0.159
			9	14.577	-26.523	0.48	0.078	0.107
DON2-DEB2 B1	Line	14.31	9	-21.163	-2.27	-0.99	0.055	0.111
			7	21.269	-17.133	0.78	0.07	0.143
DON2-DEB2 B2	Line	24.56	9	-43.735	-17.356	-0.93	0.121	0.246
			8	44.145	-0.881	1	0.111	0.226

Discussion Lines Flow Results:

From the load flow results shown in table (4.3), it can be noticed that there are eight lines are overloaded above acceptable limit (80%) which are shaded with (red) color, and the other lines are within limits. The below chart show the loading lines.

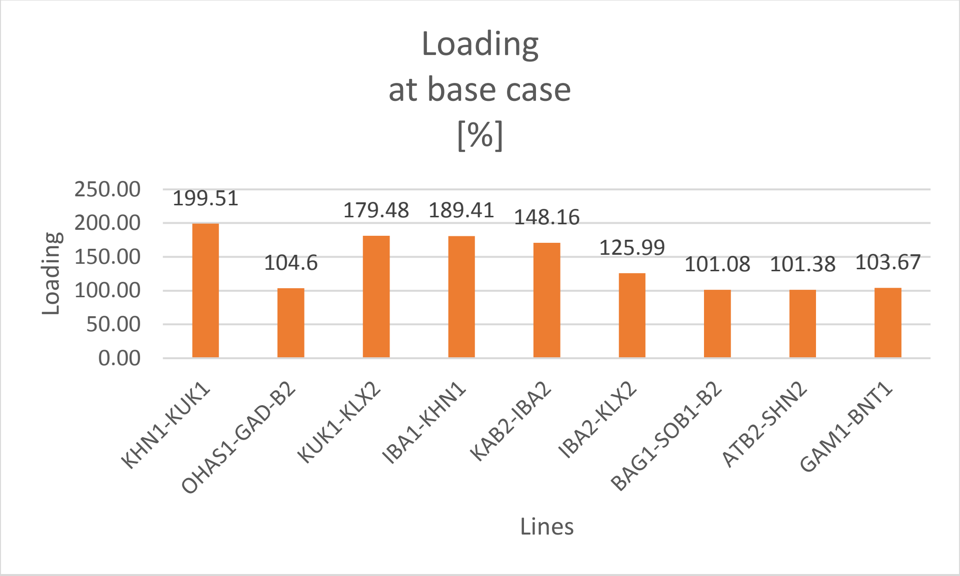

Figure 4.1: Graphical chart of the maximum loading at base case

4.3 Contingency Analysis Results:

4.3.1 Transmission Lines Outages:

From the graphical chart (4.2) of the maximum loading of transmission lines after several contingencies have been applied. The results show that the line (OHAS1-GAD-B2) which its loading at base case (103.53%) was affected with several outages, and the worst case was the outage of (GAD2-NHAS2) led the loading to become (189.13%), and the line of (KHN1-KUK1) is already out of loading limits at base case.

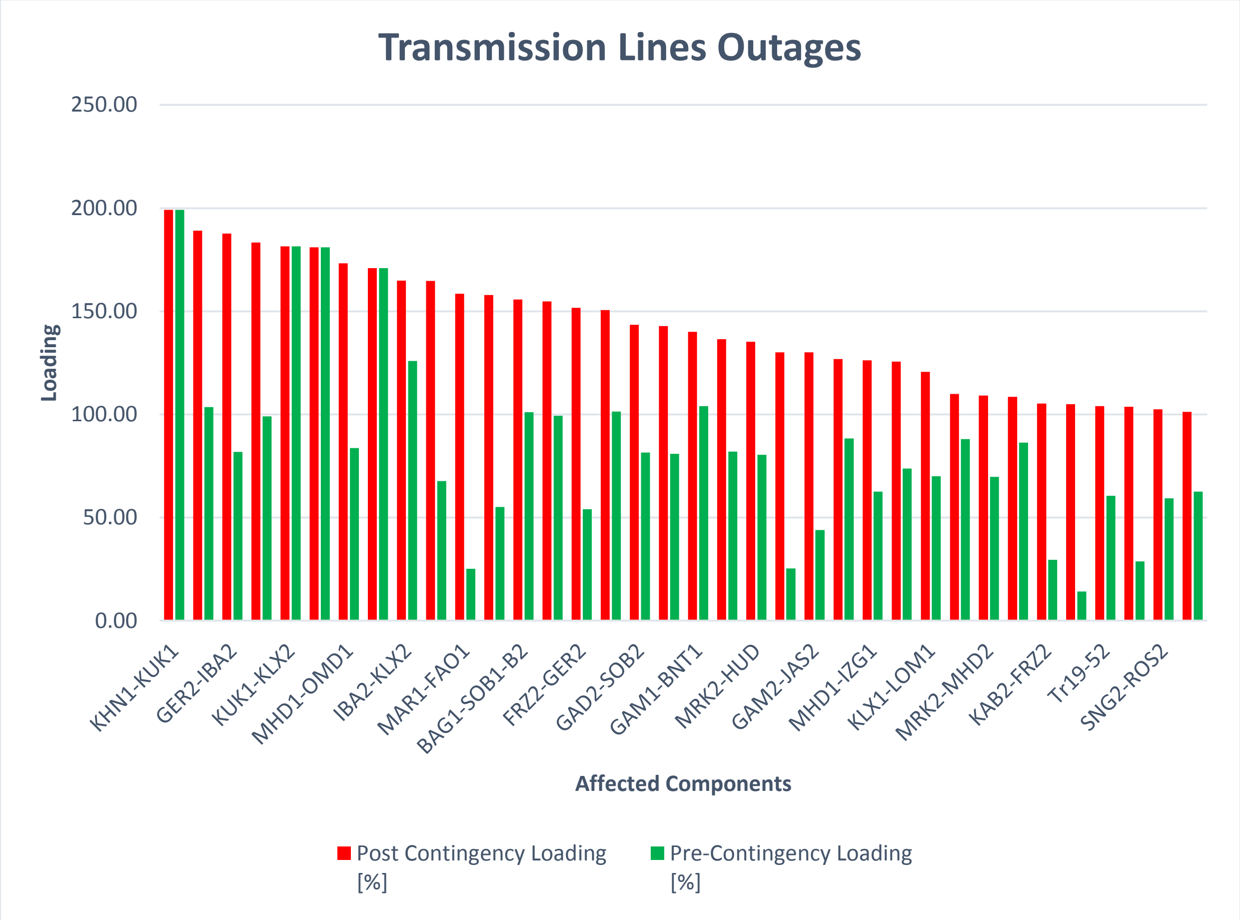

Figure 4.2: Graphical chart of transmission lines outages

4.3.2 Transformer Outages:

From the graphical chart (4.3) of the maximum loading of transmission lines after several contingencies have been applied. The results show that the line (KAB2-IBA2) which its loading at base case (170.91%) was affected with outage of transformer (Tr3-14) which connected between (MRK5) bus and (MRK2) bus, and its loading has become (298.56%).

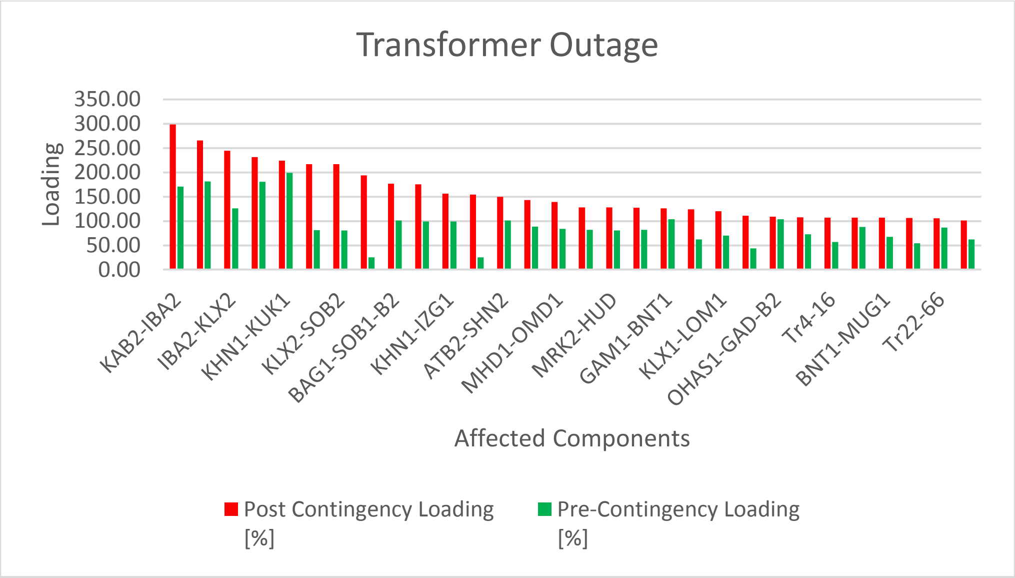

Figure 4.3: Graphical chart of transformer outages

4.3.3 Generator Outages:

From the graphical chart (4.4) of the maximum loading of components after generator outages have been applied. The results show that the line (KHN1-KUK1) which its loading at base case (199.14%) was the most affected element with outage of generator (Mac-BB18) which represents (GER2), and led the loading to become worse than it was (218.86%).

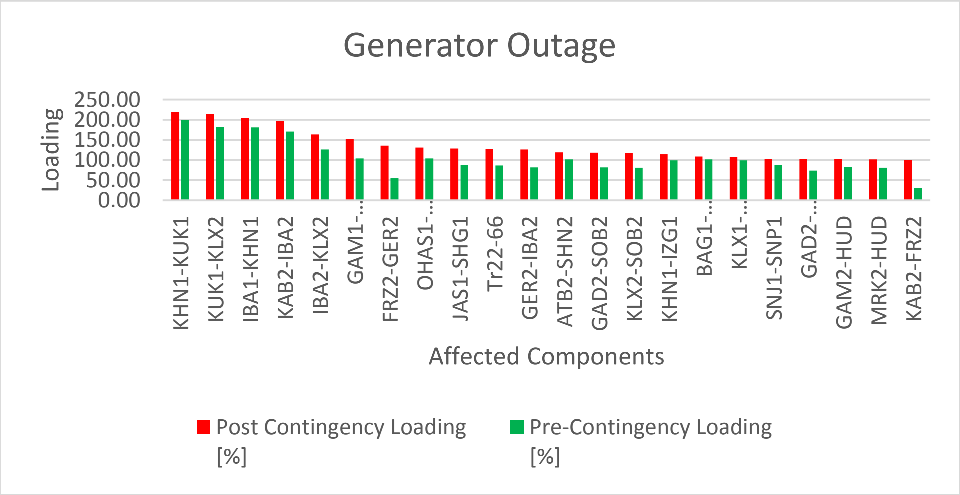

Figure 4.4: Graphical chart of generator outages

4.4 Buses Analysis:

4.4.1 Maximum Voltages:

Table 4.4: Maximum Voltages:

Component	Voltage Max. [p.u.]	Voltage Step [p.u.]	Voltage Base [p.u.]	Contingency Name
KAB5	1.09	0.10	1.00	MRK2-KAB2
JAS1	1.09	0.09	1.00	JAS1-SHG1
GAM1	1.08	0.10	0.99	GAM1-BNT1
NHAS1	1.07	0.03	1.04	OHAS1-NHAS1
OHAS1	1.06	0.02	1.03	OHAS1-GAD-B2
ORBK1	1.06	0.04	1.01	SNJ1-SNP1
SNJ1	1.06	0.04	1.01	SNJ1-SNP1
GND1	1.05	0.02	1.03	OHAS1-GAD-B2

Discussion on the Results:

From the contingency analysis results shown in table (4.4.1), it can be noticed that there are seven buses are over voltage exceeded the tolerance (+5%) and they are (KAB5, JAS1, GAM1, NHAS1, OHAS1, ORBK1 and SNJ1) respectively, and there is one bus equal to the tolerance (critical).

4.4.2 Minimum Voltages:

Table 4.5: Minimum Voltages:

Component	**Voltage Min. [p.u.]**	**Voltage Step [p.u.]**	**Voltage Base [p.u.]**	**Contingency Name**
WHL2	0.72	-0.27	0.99	MWT2-BEB2-B1
DEB2-B1	0.72	-0.30	1.02	MWT2-BEB2-B1
WWA2	0.75	-0.27	1.02	MWT2-BEB2-B1
DON2	0.76	-0.26	1.02	MWT2-BEB2-B1
ATB2	0.84	-0.09	0.93	MWP5-ATB5
KHE1	0.84	-0.14	0.98	KHN1-KUK1
KUK1	0.84	-0.14	0.99	KHN1-KUK1
IZB1	0.85	-0.12	0.97	IBA1-KHN1
FAR1	0.86	-0.08	0.94	KHN1-KUK1
IBA1	0.86	-0.12	0.97	IBA1-KHN1
SHN2	0.86	-0.11	0.97	SHN2-FRZ2
AFR1	0.86	-0.08	0.94	KHN1-KUK1
KLX1	0.87	-0.08	0.95	KHN1-KUK1
DEB2-B2	0.87	-0.17	1.04	MWT2-BEB2-B1
SOB1-B2	0.88	-0.07	0.94	KHN1-KUK1

LOM1	0.88	-0.07	0.95	KHN1-KUK1
BAG1	0.88	-0.04	0.93	KHN1-KUK1
ATB5	0.88	-0.12	1.00	MWP5-ATB5
NHAS2	0.89	-0.07	0.96	GAD2-NHAS2
GAD-B2	0.89	-0.04	0.93	KHN1-KUK1
SHG1	0.90	-0.06	0.96	KHN1-KUK1
GND1	0.90	-0.13	1.03	OHAS1-NHAS1
OHAS1	0.90	-0.13	1.03	OHAS1-NHAS1
MAR2	0.91	-0.06	0.97	GAD2-NHAS2
IZG1	0.91	-0.07	0.98	KHN1-IZG1
MUG1	0.91	-0.05	0.96	KHN1-KUK1
MHD1	0.92	-0.06	0.97	KHN1-IZG1
OMD1	0.92	-0.05	0.96	KHN1-IZG1
BNT1	0.92	-0.04	0.96	KHN1-KUK1
FAO1	0.93	-0.07	1.00	MAR1-FAO1
SNJ2	0.94	-0.05	0.98	SNJ2-SNG2
GAM1	0.95	-0.04	0.99	KHN1-KUK1
MIN1	0.95	0.00	0.95	Base Case
MAN1	0.95	-0.06	1.01	GAD2-NHAS2
NHAS1	0.95	-0.09	1.04	GAD2-NHAS2

Discussion on Results:

From the contingency analysis results shown in table (4.4.2), it can b noticed that there are thirty-one buses are beneath the tolerance (-5%), and four buses are equal to the tolerance (critical), namely; (GAM1, MIN1, MAN1 and NHAS1) respectively.

4.5 Determinations of the Network Weakness:

Generally, results of contingency analysis give an idea about weak lines whose capacity must be increased mainly in projects of transmission system improvements to withstand contingencies, and to ensure secure operation during contingencies. Network weaknesses are the lines or transformers which always become overloaded in case of different outages. Based on the probability of outage occurrence, the network weakest element is the line (OHAS1-GAD2-B2), (75) different outage cases lead to this line overload. It is found that the highest percentage loading is (189.13 %). Table (4.6) shows the second weakest element which is line (IBA2-KLX2), where (75) different outage cases lead to this line overload with highest percentage loading equal to (164.86 %). Table (4.6) shows the network weaknesses ranked based on number of outages lead to lines overload starting with the weakest element besides each element highest percentage loading. Table 4.6: the network weaknesses ranked based on number of outages lead to lines overload

Overloaded element		Number of outages lead to overload	Highest percentage loading (%)
From	To		
OHAS1	GAD2-B2	75	189.13
IBA2	KLX2	75	164.86
GAM1	BNT1	70	140.00
BAG1	SOB1-B2	51	155.78
KHN1	IZG1	26	183.40

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION:

Contingency analysis has been performed for Sudanese National Grid and the weakness of the transmission system and the bus voltage violations have been detected based on DIGSLIENT POWER FACTORY software.

In this work, the contingency selection and ranking which are important for contingency analysis have been done based on the number of the probability of outages occurrence, and loading violations.

Hence the Sudanese National Grid has been found not secure, because; a wide number of elements of transmission lines and transformers are suffered from overloading, as well as some buses suffering from overvoltage and others from under voltages. The weakest elements in the network are namely; the line (OHAS1-GAD2-B2), the line (IBA2-KLX2), the transformer (Tr22-66), the buses of (KAB5) and (WHL2) respectively.

5.2 RECOMMENDATIONS:

(1) Implementation of multiple contingencies (n-k).

(2) Effect of contingency on voltage stability.

(3) Performed contingency analysis using DC load flow method.

(4) Suggestion the new transmission lines and transformers capacities which ensures better power system security.

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