CHAPTER 1
INTRODUCTION

1.1 Introduction:-

Security Assessment is a term used to describe the process of ensuring system operating security. Typically, power systems operating in any condition are considered secure. That means the system will remain in a secure operating state if any single event or failure occurs. In a secure state all system parameters are operating as desired with all voltages within their specified limits, no power lines overloaded all loads on line and being provided with power.

Security of power system supply has been always a key factor in the development of the electric industry. Adequacy, quality of supply, stability, reliability and voltage collapse along with costs have been always carefully considered when planning the future of the electric power system. Since 1982, when world's deregulation process started, the introduction of competition at generation level brought new challenges, while the proper operation of the electric power system still require physical coordination between non cooperative agents. The increasing development of supervisory control and data acquisition system, the growing number of market participants, and the development of more complex market schemes have been more and more relying on Information Technologies. It is defined as the ability of the power system to withstand disturbances caused by faults and unscheduled removal of equipment without further loss of facilities or cascading like transmission elements outages or generators outages that can cause sudden and large changes in both the configuration and the state of the system **[1].**

1.2 Back Ground Studies:-

The blackout happened of the Northeastern US and Canada brought about methods for ensuring security and similar methods have been adopted by all countries whose economics have become more dependent on the reliable supply electricity. These methods as described above have worked well for vertically integrated utilizes that were responsible for generating, transmitting and distributing electricity to customers. As the structure of the electric supply industry around the world is changed to foster more competition, it has to be done without compromising security of supply to the customers. Thus the methods developed over time must be adapted to the new structure. This has been recognized in all the countries that are changing the rules that regulate the power industry and the responsibility to maintain overall system security is being largely assigned to the entity in charge of operating the transmission grid (while the reliability of supply to the individual customer will remain with the distribution company or the retail supplier). However, the authority of the transmission grid operator, especially over the generating companies and electricity traders, is evolving over time, but the ability of the operator maintains security will affected by this authority **[2].**

1. 3 Thesis Objectives:-

The main objectives of this thesis are:-

1-To study reactive power different performance indices in determining severe contingencies.

2 -To study power system security assessment of the National Grid of Sudan transmission system.

1.4 Statement of Problem:-

In this thesis, the proposed security assessment is then, implemented on Sudan National Grid.

Security Assessment is a term used to describe the process of ensuring system operating security. Typically, power systems operating in any condition are considered secure. That means the system will remain in a secure operating state if any single event or failure occurs. In a secure state all system parameters are operating as desired with all voltages within their specified limits, no power lines overloaded all loads on line and being provided with power.

Power system security is the ability to maintain the power flow from the generators to the customers, especially under disturbed conditions. Since disturbances can be small or large, localized or widespread, the planning and design of the power system must achieve a certain level of security. To secure the system against more severe disturbances requires more expensive designs; hence, the design criteria are chosen to meet an appropriate level of security. In the more developed countries, the customer is often willing to pay more for minimizing the interruption of power, whereas in the less developed countries the scarcity of capital and other reasons keep the level of power system security lower.

Computerized analytical tools have enhanced the planning and design of this large power networks. Enough generation must be available at all times to meet the load demand.

Thus, generator units must be managed in such a way that planned outages of units, as well as forced outages, should not result in a shortage of generation. The installed generation capacity has obviously to be greater than the maximum demand, and it has to meet specific security criteria. If a generator is forced out, the remaining generators on-line must have enough excess capacity to make up for the loss. This excess capacity is called spinning reserve. In addition, there must be some generation capacity that could be brought on-line rapidly, say within 10-15 minutes. This is known as ready reserve. All systems have criteria for maintaining spinning and ready reserves for secure operation.

1.5 Thesis Organization:-

This thesis is organized into six chapters each conversance importance topic related to the power systems security; these chapters can be summarized as follows: -

Chapter one introduces the basic concepts of power system security. **Chapter two** reviews the principles of power system security and the major function of power system security like system monitoring, contingency analysis, security constrained optimal power flow analysis and Factors Affecting Security (Linear sensitivity factors like Shift factors and line outage distribution factor). **Chapter three** gives a general introduction of modern power system element models; also this chapter presents the load flow analysis. **Chapter four** describes contingency analysis and security analysis. **Chapter five** presents the security assessment of National Grid of Sudan which is used as the case study in this thesis, and then the results of the security simulation are discussed and presented. **Chapter Six** focuses on the general conclusions of the thesis and the possible solutions in order to improve of the power system security of the Sudan National Grid and the recommendations for future work are represented.

Chapter Two

Literature Review

2.1 Introduction:-

The power system as a single entity is considered the most complex system ever built. It consists of various equipment with different levels of sophistication, complex and nonlinear loads, various generation with a wide variety of dynamic responses, a large-scale protection system, a wide-area communication network, and numerous control devices and control centers. This equipment is connected with a large network (transformers, transmission lines) where a significant amount of energy transfer often occurs. This system, in addition to the assurance of good operation of its various equipment, is characterized by an important and simple rule electricity should be delivered to where it is required in due time and with appropriate features such as frequency and voltage quality. Environmental constraints, the high cost of transmission investments, and the willing of utilities to optimize their network for more cost effectiveness makes it very difficult to expand or oversize power systems **[3].**

2.2 Security Assessment:-

Security assessment is a term used to describe the process of ensuring system operating security. Typically, power systems operating in any condition are considered secure. That means the system will remain in a secure operating state if any single event or failure occurs. In a secure state all system parameters are operating as desired with all voltages within their specified limits, no power lines overloaded and all loads on line and being provided with power. Modern power systems are often operated near capacity **[2].**

During periods of peak demand, power lines may be loaded to near capacity. Operating a power system near capacity requires quick response by operators in the event of an unexpected change in the system operating configuration. Rapid security assessment is needed in order for the system to continue to operate normally when contingencies occur. As the demand for power increases, existing power grids are being more frequently loaded near to their capacity.

As a result, system operators must rapidly respond to sudden or unexpected changes in the systems operating configuration. For example, wind or lightning may suddenly damage power lines taking them out of service. When contingencies occur, operators must rapidly assess and reconfigure systems if a normal operating state is to be maintained. The rapid assessment is becoming increasingly important; expert systems have been developed to assist operators in making decisions regarding security assessment. When sudden changes occur, there may not be sufficient time for operators to run numerous power flow scenarios. This is where an expert system can be very helpful **[2].**

2.3 Expert Power System:-

An expert system is a computer system that can behave like an expert. In this case, the system will behave like a power system expert. In the event of a failure or sudden change, the expert system can rapidly assess the power system operating condition and provide the operators with a weighted list that indicates which power lines in a network are most critically loaded and which is least critically loaded using knowledge based approach. This greatly reduces the operators work load and can vastly improve response time. The end result is improved system reliability.

2.4 Modern Power System Components:-

A power system can be subdivided into four major parts:

a. Generators. b. Transmission lines and Sub- transmission line.

c. Transformers. d. Loads.

2.4.1 Generators:-

One of the essential components of power system is the three phase AC generator known as the generator excitation system maintains generator voltage and controls the reactive power flow. In a power plant, the power rating of generators can vary from 50MW to 1500MW.

The source of the mechanical power, commonly known as the prime mover, may be hydraulic turbines at waterfalls, system turbines whose energy comes from the burning of coal, gas and nuclear fuel, gas turbines, or occasionally internal combustion engines burning oil.

In a power station several generators are operated in parallel in the power grid to provide the total power needed. They are connected at common point called a bus-bar **[5].**

2.4.2 Transmission line and sub-transmission:-

The purpose of an overhead transmission network is to transmit electric energy from generating units at various locations to the distribution system which ultimately supplies the load. Transmission lines also interconnect neighboring utilities which permits not only economic dispatch of power within regions during normal conditions, but also the transfer of power between regions during emergencies.

High voltage transmission lines are terminated in substations, which are called high-voltage substations, receiving substations, or primary substations. The function of some substations is switching stations. At the primary substations, the voltage is stepped down to a value more suitable for the next part of the journey toward the load. Very large industrials customers may be served from the transmission system.

The portion of the transmission system that connects the high-voltage substations through step-down transformers to the distribution substations is called the sub transmission voltage levels. Typically, the sub transmission voltage level ranges from 69 to 138 kV. Some large industrial customers may be served from the sub-transmission. Capacitor banks and reactor banks are usually installed in the substations for maintaining the transmission line voltage.

2.4.3Transformer:-

The second major component of a power system is the transformer. It transfers a power with very high efficiency from one level of voltage to another level. The power transferred to the secondary is almost the same as the primary, except for the losses in the transformer, and the product VI on the secondary side is approximately the same as the primary side. Therefore, using a step-up transformer of turns ratio a will reduce the secondary current by a ratio of 1/a. this will reduce losses in the line, which makes the transmission of power over long distances possible **[5].**

The insulation requirement and other practical design problems limit the generated voltage to low values, usually 30 kV. Thus, step-up transformers are used for transmission of power. At the receiving end of the transmission lines step-down transformers are used to reduce the voltage to suitable values for distribution or utilization. In modern utility system the power may undergo four of five transformations between generator ultimate users **[5].**

2.4.4 Loads:-

Loads of power systems are divided into industrial, commercial, and residential. Very large industrial loads may be served from the transmission system. Large industrial loads are served directly from the sub transmission network, and small initial are served from the primary distribution network. The industrial loads are composite loads, and induction motors form a high proportion of these load. These composure loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating, and cooling. These loads are independent of frequency and consume negligibly small reactive power **[1].**

The magnitude of load varies throughout the day, and power must be available to consumers on demand. The daily-load curve of a utility is a composite of demands made by various classes of users. The greatest value of load during a 24-hr period is called the peak or maximum demand. Smaller peaking generators may be commissioned to meet peak load that occurs for only a few hours. In order to assess the usefulness of the generating plant the load factor is defined. The load factor is the ratio of average load over a designated period of time to the peak load occurring in that period. Load factors may be given for a day, a month, or a year. The annual load factor is the most useful since a year represents a full cycle of time **[1].**

2.5 System Protection:

In addition to generators, transformers, and transmission lines, other devices are required for the satisfactory operation and protection of a power system. Some protective devices and directly connected to the circuits are called switchgear. They include instrument transformers, circuit breakers, disconnect- switches, fuses and lightning arresters. These devices are necessary to reenergize either for normal operation or on the occurrence of faults. The associated control equipment and protective relays are placed on switchboard in control houses **[4].**

2.6 Power System Security:-

Power system security is the ability to maintain the flow of electricity from the generators to the customers, especially under disturbed conditions. Since disturbances can be small or large, localized or widespread, the planning and design of the power system must achieve a certain level of security. To secure the system against more severe disturbances obviously requires more expensive designs; hence, the design criteria are chosen to meet an appropriate level of security. In the more developed countries, the customer is often willing to pay more for minimizing the interruption of power, whereas in the less developed countries the scarcity of capital and other reasons keep the level of power system security lower **[2].**

The measures of power system security are amounts, duration and frequency of customer outages. Such outages can thus be represented in probabilistic terms, e.g. X hour per year, or 99.9% reliable. Thus the terms reliability and security have been used interchangeably for power systems, although reliability is more often used to refer to the probabilistic measures while security refers to the ability of the system to withstand particular equipment outages without loss of service. Obviously, one way to withstand equipment outages is to have redundant equipment. Providing redundancy in generators, especially when the economies of scale favored fewer and larger units, is an expensive proposition. Moreover, an overlay of computers and communications on the power networks has enabled more secure operation and control. If a generator is forced outage, the remaining generators on-line must have enough excess capacity to make up for the loss. This excess capacity is called spinning reserve. In addition, there must be some generation capacity that could be brought on-line rapidly, say within 10-15 minutes. This is known as ready reserve. All systems have criteria for maintaining spinning and ready reserves for secure operation. Since the probabilities of forced unit outages are well known from historical data, it is possible to calculate the probability of generation being less than the load demand. This loss of load probability is kept within certain criterion, e.g., one day in ten years, by planning for enough capacity and number of units. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken off-line because of auxiliary equipment failure **[2].**

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. Because the specific times at which initiating events that cause components to fail 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 initiating 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 any event occurs on a system that leaves it operating with limits violated, 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. Systems security can be broken down into three major functions that are carried out in an operation control **[2].**

2.7 The Major Function of the Power System Security:-

2.7.1 System Monitoring:-

System monitoring provides the operators of the power system with pertinent up-to-date about system parameter like (voltage, current, load flow, status of circuit breakers, frequency, generator output and transformer tap position) information on the conditions on the power system. Generally speaking, it is the most important function of the three, such systems are usually combined with supervisory control systems that allow operators to control circuit breakers and disconnect switches and transformer taps remotely. Together, these systems are often referred to as SCADA systems [standing for supervisory control and data acquisition system]. The SCADA system allows a few operators to monitor the generation and high voltage transmission systems and to take action to correct overlords or out-of-limit voltages **[5].**

2.7.2 Contingency Analysis:-

The results of contingency analysis allow systems to be operated defensively. Many of the problems that occur on a power system can cause serious trouble within such a quick time period that the operator could not take action fast enough. This is often the case with cascading failures. Because of this aspect of systems operation, modern operations computers are equipped with contingency analysis programs that model possible systems troubles before they arise. These programs are based on a model of the power system and are used to study outage events and alarm the operators to any potential overlords or out-of-limit voltages **[5].**

2.7.3 Security-Constrained Optimal Power Flow:-

The contingency analysis is combined with an optimal power flow which 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 can be divided into four operating states:-

a. Optimal 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.

b. Post contingency:-

This is the state of the power system after a contingency has occurred. Hence assume that this condition has a security violation (line or transformer beyond its flow limit, or a bus voltage outside the limit).

c. Secure dispatch:-

This is the state of the system with no contingency outages, but with corrections to the operating parameters to account for security violations.

d. Secure post-contingency:-

This is the state of the system when the contingency is applied to the base-operating condition

2.8 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:-

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

b. Within the constraints placed on the system operation by reliability considerations, the system will be operated most economically.

What factors affect system operation from a reliability standpoint? The engineering groups who have designed the power system's transmission and generation systems have done so with reliability in mind. This means that adequate generation has been installed to meet the load and that adequate transmission has been installed to deliver the generated power to the load. If the operation of the system without sudden failures or without experiencing unanticipated operating states, there will probably have no reliability problems. However, any piece of equipment in the system can fail, either due to internal causes or due to external causes such as lightning strikes, objects hitting transmission towers, or human errors in setting relays. It is highly uneconomical, if not 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 **[5].**

2.9 Linear 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 linear sensitivity factors. These factors show the approximate change in line flows for changes in generation on the network these factors can be derived in a variety of ways and basically come down to two types:

2.9.1 Generation Shift Factors:-

The generation shift factors represent the change in flow due to increment injection at a generator bus, and corresponding withdraws at the swing bus.

2.9.2 Line Outage Distribution Factors:-

The line outage distribution factors are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost.

Chapter Three

Load Flow Analysis

3.1 Power System Element Models:-

3.1.1 Generator Models:-

The generator is modeled as a constant voltage source behind internal impedance. This is sometimes referred to as the classical generator model shown in figure (3.1). For the application in DC emulation the generator maintains a PV bus behavior. The real power output, P, and the generator terminal voltage, V, are specified and maintained by the model **[6].**

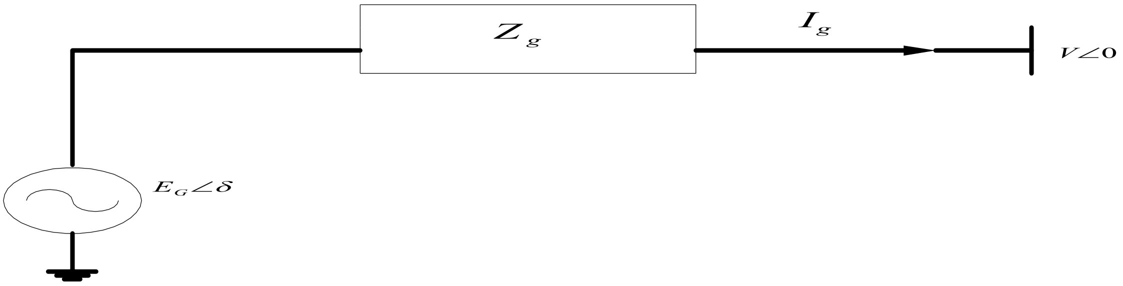


Figure (3.1) Classical generator model.

From figure (3.1) the internal emf is given by:

$\bar{\boldsymbol{E}} = \bar{\boldsymbol{V}} + \overline{\boldsymbol{I_g}}\bar{\boldsymbol{Z}}$ ………………………………………………………….**(3.1)**

Where

E: internal generated emf V: the terminal voltage

3.1.2 Transmission line Models:

a. Short Line Model:

Capacitance may often be ignored without much error if the lines are less than about 80 km long, or if the voltage is not over 69 kV. The short line model is obtained by multiplying the series impedance per unit length by the line length.

$$\boldsymbol{Z = (r + j\omega L)\ell}$$

$$\mathbf{Z = R+jX} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.2)}$$

Where r and L are the per-phase resistance and inductance per unit length, respectively, and ℓ is the line length. The short line model on a per-phase basis is shown in figure (3. 2). V_S and I_S are the phase voltage and current at the sending end of the line, and V_R and I_R are the phase voltage and current at the receiving end of the line.

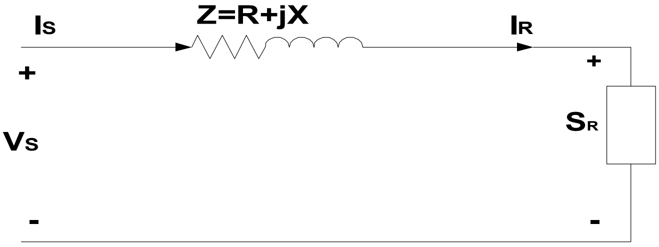


Figure (3.2) Short transmission line model.

If a three-phase load with apparent power $S_{R(3\phi)}$ is connected at the end of the transmission line, the receiving end current is obtained by

$$\boldsymbol{I_R = \frac{S^*_{R(3\phi)}}{3V^*_R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.3)}$$

The phase voltage at the sending end is

$$\boldsymbol{V_S = V_R + ZI_R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.4)}$$

And since the shunt capacitance is neglected. The sending end and the receiving end current are equal. i.e.,

$$\boldsymbol{I_S = I_R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.5)}$$

b. Medium Line Model:

Lines above 80 km and below 250 km in length are termed as *medium length lines*. For medium length lines, half of the shunt capacitance may be considered to be lumped at each end of the line. This is referred to as the *nominal* π-model and is shown in Figure (3.3) Z is the total series impedance of the line and Y is the total shunt admittance of the line given by:

$$\boldsymbol{Y = (g + j\omega c)\ell} \textbf{(3.6)}$$

Under normal conditions, the shunt conductance per unit length, which represents the leakage current over the insulators and due to corona, is negligible and g is assumed to be zero. *C* is the line to neutral capacitance per km, and ℓ is the line length. The sending end voltage and current for the nominal π- model are obtained as follows **[4]**:

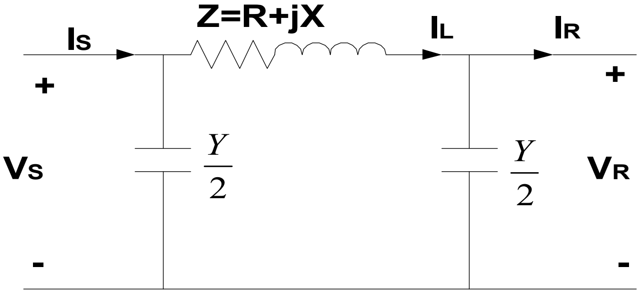


Figure (3.3) Nominal π- model for medium length line.

$$\mathbf{V_S = \left(1 + \frac{ZY}{2}\right) V_R + ZI_R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(\mathbf{3.7})$$

$$\mathbf{I_S = Y\left(1 + \frac{ZY}{4}\right) V_R + \left(1 + \frac{ZY}{2}\right) I_R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(\mathbf{3.8})$$

c. Long Line Model:

If the line is more than 240 km long, the model must consider parameters uniformly distributed along the line. The appropriate series impedance and shunt capacitance are found by solving the corresponding differential equations, where voltages and currents are described as a function of distance and time with the following assumptions:-

1. The line is operating under sinusoidal, balanced, steady-state conditions.
2. The line is transposed.

Figure (3.4) shows long the line model.

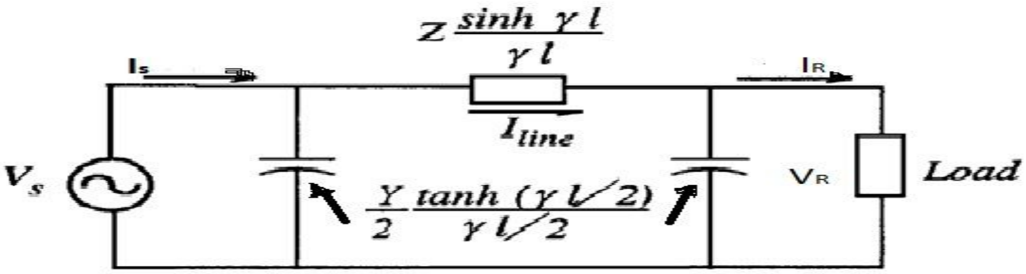


Figure (3.4) Long transmission line model.

The sending end voltage and current can be written as:

$$\boldsymbol{V_S = \cosh\gamma l V_R + Z_C \sinh\gamma l\, I_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.9)}$$

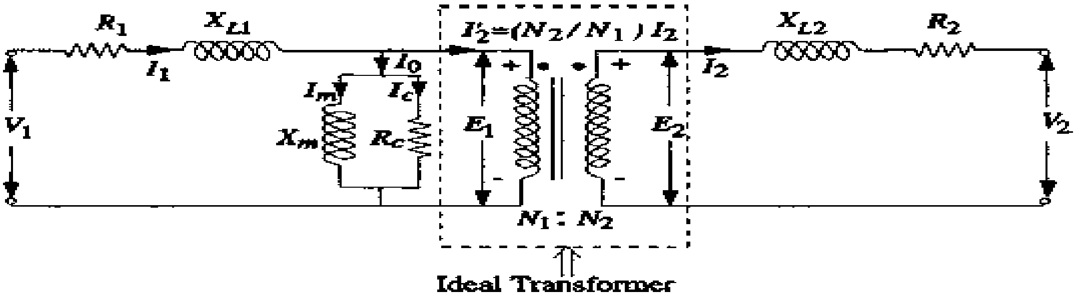
$$\boldsymbol{I_S = \frac{1}{Z_C}\cosh\gamma l V_R + \sinh\gamma l\, I_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.10)}$$

γ: is the propagation constant,Z_C: is characteristic impedance ,V_R:is the receiving end voltage.

3.1.3 Transformer Models:

a. Two Winding Transformer Models:

The basic equivalent circuit of a two-winding transformer with all quantities in physical units is shown in Figure (3.5.a) the magnetizing component is represented by the inductive reactance X_m, whereas the loss component is accounted by the resistance R_c.



Figure(3.5.a) Model of a two windings transformer.

Where

$$Z_P = R_1 + jX_{L1}, Z_S = R_2 + jX_{L2}$$

R_1,R_2 =primary and secondary winding resistances

X_{L1},X_{L2} =primary and secondary winding reactance

N_1,N_2 = number of turn of primary and secondary winding

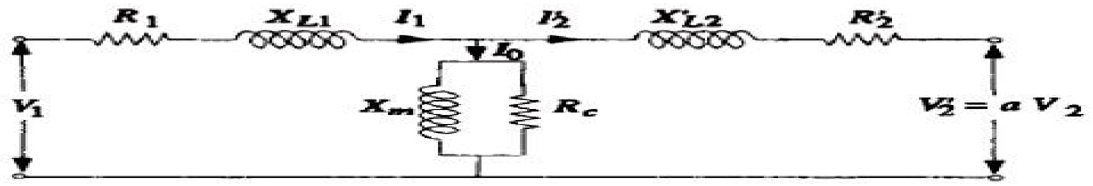


Figure (3.5.b) Model of a two windings transformer.

In equivalent circuit of figure (3.5.b), all quantities are referred to the primary side, where

$$\mathbf{X'_{L2}} = \boldsymbol{X_{L2}}(\frac{N_1}{N_2})^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\textbf{(3.11)}$$

$$\mathbf{R'_{2}} = \boldsymbol{R_{2}}(\frac{N_1}{N_2})^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\textbf{(3.12)}$$

The impedance Z_1 in the primary circuit can be referred to the secondary side 2 as:

$$\mathbf{Z'_{1}} = \boldsymbol{Z_{1}}(\frac{N_2}{N_1})^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\textbf{(3.13)}$$

$$\mathbf{Z'_{2}} = \boldsymbol{Z_{2}}(\frac{N_1}{N_2})^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\textbf{(3.14)}$$

b. Representation of Transformer in Power System:

As seen in the previous section, ohmic values of resistance and leakage reactance of a transformer depend upon whether they are referred on the LV side or HV side. A great advantage is realized by expressing voltage, current, impedance and volt-amperes in per-unit or percentage of base values of these quantities. The per-unit quantities, once expressed on a particular base, are same when referred to either side of the transformer. Thus, the value of per-unit impedance remains same on either side obviating the need for any calculations by using equations (3.13) and (3.14). This approach is very handy in power system calculations, where a large number of transformers, each having a number of windings, are present **[7].**figure (3.6) illustrated per unit equivalent circuit.

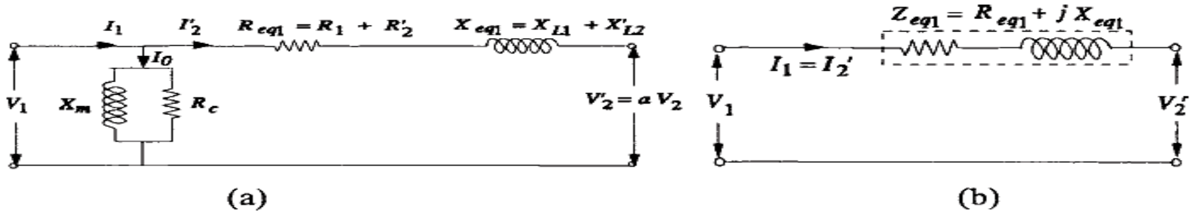


Figure (3.6) Per unit equivalent circuit.

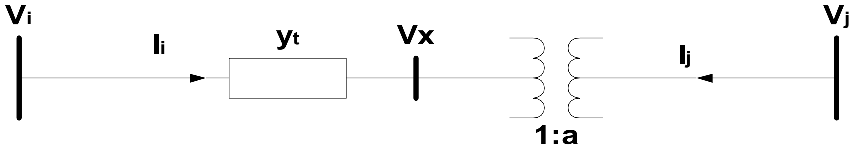
C. Tap Changing Transformers:

Practically all power transformers and many distribution transformers have taps in one or more windings for changing the turn's ratio. This method is the most popular since it can be used for controlling voltages at all levels. There are two types of tap changing transformers.

(i) Off-load tap changing transformers.

(ii) Tap changing under load (TCUL) transformers.

In a tap changing transformer, when the ratio is at the nominal value, the Transformer is represented by series admittance $\boldsymbol{y_t}$ in per unit. With off-nominal ratio, the per unit admittance is different from both sides of the transformer, and the admittance must be modified to include the effect of the off-nominal ratio. Consider a transformer with admittance $\boldsymbol{y_t}$ in series with an ideal transformer representing the off-nominal tap ratio 1: a as shown in figure (3.7). $\boldsymbol{y_t}$ Is the admittance in per unit based on the nominal tum ratio and a is the per unit off-nominal tap position allowing for small adjustment in voltage of usually ±10 percent in the case of phase shifting transformers, a is a complex number. Consider a fictitious bus x between the tum ratio and admittance of the transformer. Since the complex power on either side of the ideal transformer is the same, it follows that if the voltage goes through a positive phase angle shift. The current will go through a negative phase angle shift. Thus, for the assumed direction of currents **[4].**



Figure(3.7) Transformer with tap setting ratio a:1.

$\boldsymbol{I_i = -a * I_i}$..**(3.15)**

$$\boldsymbol{I_j = -\frac{1}{a} * I_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.16)}$$

The current I_i is given by

$$\boldsymbol{I_i = y_t(V_i - V_x)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.17)}$$

Where $\boldsymbol{V_x = \frac{1}{a} V_j}$

Substitute$\boldsymbol{V_x}$ from $\boldsymbol{I_i}$ yeilds

$$\boldsymbol{I_i = y_t V_i - \frac{1}{a} V_j} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.18)}$$

Substituting $\boldsymbol{I_i}$ from $\boldsymbol{I_j}$ yeilds

$$\boldsymbol{I_j = \frac{y_t}{a^*} V_i + \frac{y_t}{|a|^2} V_j} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.19)}$$

We have for the case when a is real, the π-model shown in figure (3.8) represent the

Admittance in equations (3.18) and (3.19). In the π-model, the left side corresponds to the non-tap side and the right side side corresponds to the tap side of the transformer.

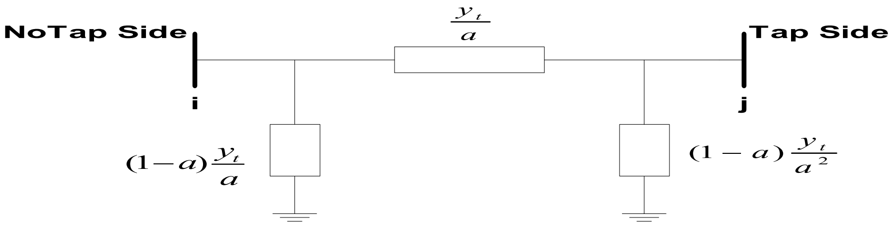


Figure (3.8) Tap changing transformer model.

d. Three Winding Transformer Models:

If the exacting current of a three winding transformer is neglected, it is possible to draw a single-phase equivalent T-circuit as shown in figure (3-9).

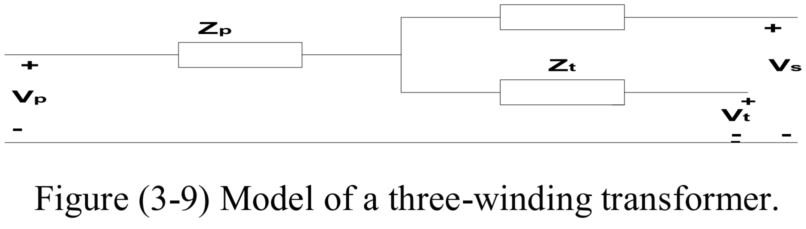


Figure (3-9) Model of a three-winding transformer.

Three short-circuit tests are carried out on a three-winding transformer withN_P, N_S and N_t turns per phase on the three windings, respectively. The three tests are. Similar in that in each case one winding is open, one shorted, and reduced voltage is applied reaming winding. The following impedances arc measured on the side to which the voltage is applied.

Z_{ps} = Impedance measured in the primary circuit with the secondary short-circuited and the tertiary open,

Z_{pt} = Impedance measured in the primary circuit with the tertiary short-Circuited and the secondary open.

Z'_{st} = Impedance measured in the secondary circuit with the tertiary Short-circuited and the primary open.

Referring Z'_{st} to the primary side, we obtain

$$\mathbf{Z}_{st} = \left(\frac{\mathbf{N_P}}{\mathbf{N_S}}\right)^{2} \mathbf{Z'_{st}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{3.20})$$

If $Z_P, Z_s$and Z_t are the Impedances of the three separate windings referred to the primary side, then

$$\left.\begin{aligned} \boldsymbol{Z_{ps}} &= \boldsymbol{Z_P} + \boldsymbol{Z_s} \\ \boldsymbol{Z_{pt}} &= \boldsymbol{Z_P} + \boldsymbol{Z_t} \\ \boldsymbol{Z_{st}} &= \boldsymbol{Z_s} + \boldsymbol{Z_t} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(\mathbf{3.21})$$

Solving the above equations, we have

$$\left.\begin{aligned} \mathbf{Z_p} &= \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{Z_{Ps}} + \mathbf{Z_{pt}} + \mathbf{Z_{st}}) \\ \mathbf{Z_s} &= \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{Z_{Ps}} + \mathbf{Z_{st}} + \mathbf{Z_{pt}}) \\ \mathbf{Z_t} &= \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{Z_{pt}} + \mathbf{Z_{st}} + \mathbf{Z_{ps}}) \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{3.22})$$

3.2 Power Flow Study

In power engineering, the power flow study (also known as load-flow study) is an important tool involving numerical analysis applied to a power system. A power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (voltages, voltage angles, real power and reactive power). It analyzes the power systems in normal steady-state operation. There exist a number of software implementations of power flow studies. In addition to a power flow study, sometimes called the base case, many software implementations perform other types of analysis, such as short-circuit fault analysis, stability studies (transient & steady-state), unit commitment and economic load dispatch analysis. In particular, some programs use linear programming to find the optimal power flow, the conditions which give the lowest cost per kilowatt hour delivered **[4].**

3.2.1 Bus Classifications:

Buses are classified according to which two out of the four variables are specified **[4]**:-

a. Load bus:

In this bus the real and reactive power are specified. It is desired to find out the voltages magnitude and phase angle through load flow solutions. It is required to specify only P and Q at such bus as at a load bus voltage can be allowed to vary within the permissible values.

b. Generator Bus or Voltage Controlled Bus:

Here the voltage magnitude |V| corresponding to the generator voltage and real power P_g corresponds to its rating are specified. It is required to find out the reactive power generation Q_g and phase angle of the bus voltage.

c. Slack (swing) Bus:

For the slack bus, it is assumed that the voltage magnitude |V| and voltage phase δ are known, whereas real and reactive powers P and Q are obtained through the load flow solution.

3.3 Basic Power Flow Equations:

Consider a typical bus of a power system network as shown in figure (3.10),transmission lines are representing by their equivalent π- models where impedance have been converted to per unit admittances on a common MVA base. Application of KCL to this bus result in:

$$\mathbf{I = YV} \quad \text{..} \quad \mathbf{(3.23)}$$

Where

I: is the injected current vector.

Y:is the admittance matrix.

V:is the node voltage vector.

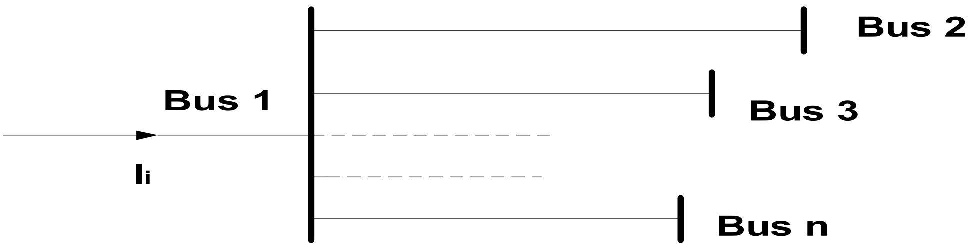


Figure (3.10)n-bus system analysis.

Extending the above relation of the equation (3.23) to an **n** bus system, the node–voltage equation in matrix form is:-

$$\begin{bmatrix} \mathbf{I_1} \\ \mathbf{I_2} \\ \mathbf{I_3} \\ \vdots \\ \mathbf{I_i} \\ \vdots \\ \mathbf{I_n} \end{bmatrix} = \begin{bmatrix} \mathbf{Y_{11}} & \mathbf{Y_{12}} & \cdots & \mathbf{Y_{1i}} & \cdots & \mathbf{Y_{1n}} \\ \mathbf{Y_{21}} & \mathbf{Y_{22}} & \cdots & \mathbf{Y_{2i}} & \cdots & \mathbf{Y_{2n}} \\ \mathbf{Y_{31}} & \mathbf{Y_{32}} & \cdots & \mathbf{Y_{3i}} & \cdots & \mathbf{Y_{3n}} \\ \vdots & \vdots & & \vdots & & \vdots \\ \mathbf{Y_{i1}} & \mathbf{Y_{i2}} & \cdots & \mathbf{Y_{ii}} & \cdots & \mathbf{Y_{in}} \\ \vdots & \vdots & & \vdots & & \vdots \\ \mathbf{Y_{n1}} & \mathbf{Y_{n2}} & \cdots & \mathbf{Y_{ni}} & \cdots & \mathbf{Y_{nn}} \end{bmatrix} \begin{bmatrix} \mathbf{V_1} \\ \mathbf{V_2} \\ \mathbf{V_3} \\ \vdots \\ \mathbf{V_i} \\ \vdots \\ \mathbf{V_n} \end{bmatrix} \ldots\ldots\ldots\ldots(\mathbf{3.24})$$

Or

$$\mathbf{I_i} = \sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{Y_{ij}V_j} \qquad ,\mathbf{i = 1, 2, \ldots\ldots, n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{3.25})$$

The real power and reactive power injected at bus i are given by:

$$\mathbf{P_i - jQ_i = V_i{}^{*}I_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{3.26})$$

Or , from equation (3.25) yeilds

$$\mathbf{P_i - jQ_i = V_i{}^{*}} \sum_{j=1}^{\mathbf{n}} \mathbf{Y_{ij}V_j} \; (\mathbf{3.27})$$

from equation(3.27) yeilds

$$\left[\frac{\mathbf{P_i - jQ_i}}{\mathbf{V_i{}^{*}}}\right] = V_i\mathbf{Y_{ii}} + \sum_{\substack{\mathbf{j=1} \\ j\neq i}}^{\mathbf{n}} \mathbf{Y_{ij}V_j} \quad ,\mathbf{i = 1, 2, \ldots\ldots, n} \ldots\ldots\ldots\ldots\ldots\ldots.(\mathbf{3.28})$$

$$\mathbf{V_i} = \frac{\mathbf{1}}{\mathbf{Y_{ii}}}\left[\frac{\mathbf{P_i - jQ_i}}{\mathbf{V_i{}^{*}}}\right] - \sum_{\substack{\mathbf{j=1} \\ j\neq i}}^{\mathbf{n}} \mathbf{Y_{ij}V_j} \qquad ,\mathbf{i = 1, 2, \ldots\ldots, n} \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{3.29})$$

3.4 Power Flow Solution Methods:

There are four methods can be used to solve power flow equation. The methods are Newton-Raphson, Fast-Decoupled and Gauss-Seidel and DC power flow methods.

3.4 .1 The Gauss-Seidel Method:

The Gauss-Seidel (GS) method is an iterative algorithm for solving a set of non-linear algebraic equations. To start with, a solution vector is assumed, based on guidance from practical experience in a physical situation. To explain how the GS method is applied to obtain the load flow solution, let it be assumed that all buses other than the slack bus are PQ buses. We shall see later that the method can be easily adopted to include PV buses as well. The slack bus voltage being specified, there are (n - 1) bus voltages starting values of whose magnitudes and angles are assumed. These values are then updated through an iterative process. During the course of any iteration, the revised voltage at the i^{th} bus is obtained from equation (3.29) .Which is given by

$$\mathbf{V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{{V_i}^*}\right] - \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij}V_j} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots..(\mathbf{3.30})$$

3.4.2 The Newton-Raphson Method:

For large power system, the Newton –Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration. Since in the power flow problem real power and voltage magnitude are specified for the voltage –controlled buses, the power flow equation is formulated in polar form. This equation can be rewritten in terms of the bus admittance matrix as

$$\boldsymbol{I_i = \sum_{j=1}^{n} Y_{ij} V_j} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (\mathbf{3.31})$$

In the above equation, j includes bus i. expressing this equation in polar form. We have

$$\boldsymbol{I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle(\theta_{ij} + \delta_j\,)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (\mathbf{3.32})$$

The complex power at bus ***i*** is

$$\boldsymbol{P_i - jQ_i = V_i^{\ *} * \ I_i} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \mathbf{(3.33)}$$

Substituting from (3.32) for I_i in (3.33)

$$\mathbf{P_i - jQ_i = |\boldsymbol{V_i}| \angle(-\boldsymbol{\delta}_i) * \sum_{j=1}^{n} |Y_{ij}||V_j| \angle(\boldsymbol{\theta}_{ij} + \boldsymbol{\delta}_j)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (\mathbf{3.34})$$

Separating the real and imaginary parts,

$$\mathbf{P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\big(cos(\boldsymbol{\theta}_{ij} - \boldsymbol{\delta}_i + \boldsymbol{\delta}_j\big)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (\mathbf{3.35})$$

$$\mathbf{Q_i = -\sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \ sin(\boldsymbol{\theta}_{ij} - \boldsymbol{\delta}_i + \boldsymbol{\delta}_j)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (\mathbf{3.36})$$

Equation (3.35) and (3.36) constitute a set of nonlinear algebraic in terms of the independent variables, voltage magnitude in per unit, and phase angle in radians. We have two equations for each load bus, given by (3.35) and (3.36), and one equation for each voltage –controlled bus, given by (3.32). Expanding (3.35) and (3.36) in Taylor's series about the initial estimate and neglecting all higher order terms results in the following set of linear equations**[4].**

$$\begin{bmatrix} \Delta P_2^{(K)} \\ \vdots \\ \Delta P_n^{(K)} \\ \Delta Q_2^{(K)} \\ \vdots \\ \Delta Q_n^{(K)} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2}^{(K)} & \cdots & \frac{\partial P_2}{\partial \delta_n}^{(K)} & \frac{\partial P_2}{\partial |V_2|}^{(K)} & \cdots & \frac{\partial P_2}{\partial |V_n|}^{(K)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_2}^{(K)} & \cdots & \frac{\partial P_n}{\partial \delta_n}^{(K)} & \frac{\partial P_n}{\partial |V_2|}^{(K)} & \cdots & \frac{\partial P_n}{\partial |V_n|}^{(K)} \\ \frac{\partial Q_2}{\partial \delta_2}^{(K)} & \cdots & \frac{\partial Q_2}{\partial \delta_n}^{(K)} & \frac{\partial Q_2}{\partial |V_2|}^{(K)} & \cdots & \frac{\partial Q_2}{\partial |V_n|}^{(K)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_2}^{(K)} & \cdots & \frac{\partial Q_n}{\partial \delta_n}^{(K)} & \frac{\partial Q_n}{\partial |V_2|}^{(K)} & \cdots & \frac{\partial Q_n}{\partial |V_n|}^{(K)} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^{(K)} \\ \vdots \\ \Delta \delta_n^{(K)} \\ \Delta \left|V_2^{(K)}\right| \\ \vdots \\ \Delta \left|V_n^{(K)}\right| \end{bmatrix} \ldots\ldots\ldots.(3.37)$$

In the above equation, bus 1 is assumed to be the slack bus. The Jacobin matrix gives the linearized relationship between small changes in voltage angle $\Delta\ \delta_i^{(K)}$ and voltage magnitude $\Delta\left|V_i^{(K)}\right|$ with the small changes in real and reactive power $\Delta\ P_i^{(K)}$ and $\Delta\ Q_i^{(K)}$.In short form, it can be written is:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.38)$$

3.4.3 The Fast Decoupled Method

The Fast decoupled power flow solution requires more iterations than the Newton-Raphson method, but requires considerably less time per iteration and a power flow solution is obtained very rapidly. This technique is very useful in contingency analysis where numerous outages are to be simulated or a power flow solution is required for on-line control [10]. In the Power system transmission lines have a very high X / R ratio. For such a system, real power changes ΔP are less sensitive to changes in the voltage magnitude and are most sensitive to changes in phase angle $\Delta\delta$. Similarly, reactive power is less sensitive to changes in angle and is mainly dependent on changes in magnitude. Therefore, it is reasonable to set elements $\mathbf{J_{12}}$, and $\mathbf{J_{21}}$ of the matrix to zero. Thus, (3.38) becomes:-

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{Q} \end{bmatrix} = \begin{bmatrix} \boldsymbol{J_{11}} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{J_{22}} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{\delta} \\ \Delta |\boldsymbol{V}| \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.39)}$$

By using simplifications:

$\mathbf{B_{ik}} \ll \mathbf{Q_i},$ and $|V_i|^2 = |V_i|$ and $\boldsymbol{\theta_{ii} - \delta_i + \delta_j \approx \theta_{ii}}$, $\mathbf{|V_j| = 1}$,

And $\boldsymbol{\theta_{ij} - \delta_i + \delta_j \approx \theta_{ij}}$ we get

$$\frac{\Delta \mathrm{P}}{|\mathrm{V_i}|} = -[\mathbf{B}]'\Delta\boldsymbol{\delta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.40)}$$

$$\frac{\Delta \mathrm{Q}}{|\mathrm{V_i}|} = -[\mathbf{B}'']\Delta\mathrm{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.41)}$$

Where $\acute{\mathrm{B}}$ and $\mathrm{B}''$are the part of the bus admittance matrix

3.4.4 The DC Power Flow Method

A significant simplification of the power flow analysis drop the Q-V equations altogether in the fast-decoupled approach results in a completely linear, non-iterative power flow algorithm. Simply assume that all voltage magnitudes, $|V_i|$ equal 1.0 pu The system equation becomes:

$$\begin{bmatrix} \boldsymbol{\Delta_{P_1}} \\ \boldsymbol{\Delta_{P_1}} \\ \vdots \\ \boldsymbol{\Delta_{P_N}} \end{bmatrix} = [\boldsymbol{B}]' \begin{bmatrix} \boldsymbol{\Delta_{\theta_1}} \\ \boldsymbol{\Delta_{\theta_1}} \\ \vdots \\ \boldsymbol{\Delta_{\theta_N}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.42)}$$

The DC power flow is only good for calculating the MW flows on transmission lines and transformers does not solve the problem of MVAR and MVA flows the power flowing on each branch from bus-i to bus-j (line or transformer) is **[4]**:

$$P_{ij} = \frac{1}{x_{ij}}\left(\theta_i - \theta_j\right) \qquad \textbf{(3.43)}$$

Chapter Four

Security Analysis

4.1 Contingency Analysis:-

Contingency analysis indicates to the operator what might happen to the system in the event of unplanned equipment outage. It essentially offers answers to questions such as “what will be the state of the system if an outage on part of the major transmission system takes place?’ The answer might be that power flows and voltages will re-adjust and remain within acceptable limits or those severe overloads and under-voltages will occur with potentially severe consequences should the outage take place. A severe overload, persisting long enough, can damage equipment of the system, but usually relays are activated to isolate the affected equipment once it fails. The outage of a second component due to relay action is more serious and often results in yet more re-adjustment of power flows and bus voltages. This can in turn cause more overloads and further removal of equipment. An uncontrollable cascading series of overloads and equipment removals may then take place, resulting in the shutting down of a significant portion of the system. External contingencies are caused by environmental effects such as lightning, high winds and ice conditions or else are related to some non-weather related events such as vehicle or aircraft coming into contact with equipment, or even human or animal direct contact. These causes are treated as unscheduled, random events, which operators can not anticipate, but for which they must be prepared **[8].**

4.1.1 Security Analysis:-

Security analysis is usually handled for two time frames: static and dynamic. For the static analysis, only a ‘‘fixed picture’’ or a snapshot of the network is considered. The system is supposed to have passed the transient period successfully or be dynamically stable. Therefore, the monitored variables are line flows and bus voltages. Hence, all voltages should be within a predefined secure range, usually around ±5% of nominal voltage (for some systems, such as distribution networks, the range may be wider). If bus voltages drop below a certain level, there will be a risk of voltage collapse in addition to high losses. On the other hand, if bus voltages are too high compared to nominal values, there will be equipment degradation or damage. Furthermore, overload of transmission lines may be followed by unpredictable line tripping that accelerates the degradation of the voltage profile. Line flows are related to circuit overload (lines and transformers) and should keep below a maximum limit, usually settled according to line thermal limits. The dynamic security is related to loss of synchronism (transient stability) and oscillatory swings or dynamic instability. In that case the evolution of essential variables is monitored based upon a required time frame (transient period) **[9].**

4.1.2 An Overview of Security Procedure:-

A security analysis study which is run in an operations center must be executed very quickly in order to be of any use to operators. There are three basic ways to accomplish this:-

a- Study the power system with approximate but very fast algorithms.

b- Select only the important cases for detailed analysis.

c- Use a computer system made up of multiple processors or vector processors to gain speed.

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. 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 5% accuracy. There is no knowledge of MVAR flows or bus voltage magnitudes. 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 in existence today 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 which do not have flow or voltage limit violations. What is needed are ways to eliminate all or most of the no violation cases and only run complete power flows on the "critical" cases. These techniques go under the names of "contingency selection" or "contingency screening". Last of all, it must be mentioned that there are ways of running thousands of contingency power flows if special computing facilities are used.

4.2 AC Power Flow Methods:-

The calculations made by network sensitivity methods are faster than those made by AC power flow methods and therefore find wide use in operations control systems. However, there are many power systems where voltage magnitudes are the critical factor in assessing contingencies. In addition, there are some systems where VAR flows predominate on some circuits, such as underground cables, and an analysis of only the MW flows will not be adequate to indicate overloads. When such situations present themselves, the network sensitivity methods may not be adequate and the operations control system will have to incorporate a full AC power flow for contingency analysis. When an AC power flow is to be used to study each contingency case, the speed of solution and the number of cases to be studied are critical. To repeat what was said before, if the contingency alarms come too late for operators to act, they are worthless. Most operations control centers that use an AC power flow program for contingency analysis use either a Newton-Raphson or the decoupled power flow **[5].**

4.3 Contingency Selection:-

Since contingency process involves the prediction of the effect of individual contingency cases, the above process become very tedious and time consuming when the power system network is large. In order to alleviate the above problem process contingency is used .practically it is found that all the possible outages does not cause the overloads. The process of identifying the contingencies that actually lead to violation of operational limits is known as contingency selection. The contingencies are selected by calculating a kind of severity indices known as Performance Indices (PI) **[5].**

These Indices are calculated using the conventional power flow algorithms, described in chapter four, for individual contingencies. Based on the values obtained the contingencies ranked in a number where the highest value of PI is ranked first. The analysis is then done starting from the contingency that is ranked one and is continued till no severe contingencies are found.

These are two kind of performance index are of great use, the active performance index (PI_P) and reactive power performance index (PI_V).PI_P Reflects violation of line active power flow and is given by equation (4.1).

$$\mathbf{PI_P} = \sum_{\mathbf{i=1}}^{\mathbf{L}} \left(\frac{\mathbf{P_i}}{\mathbf{P_{i\,max}}}\right)^{\mathbf{2m}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{4.1})$$

Where

P_i =is the active power flow on line i.

$P_{i\,max}$ = Maximum active power flow limit on line i

$$\mathbf{P_{i\,max}} = \frac{\mathbf{V_i * V_j}}{\mathbf{X}}$$

V_i= voltage at bus i obtained

V_j= voltage at bus j obtained

X= Reactance of the line connecting bus ‘i’ and bus ‘j’

L=is the total number of transmission lines in the system

m=is a positive integer

Another performance index parameter which is used reactive power performance index corresponding to bus voltage magnitude violation. It mathematically given by equation (4.2).

$$\mathbf{PI_V} = \sum_{\mathbf{i=o}}^{\mathbf{n}} \left[\frac{(\mathbf{V_i - V_{i\,nom}})}{\mathbf{V_{imax} - V_{imin}}}\right]^{\mathbf{2}} \ldots\ldots\ldots\ldots\ldots.(\mathbf{4.2})$$

$\mathbf{V_i}$= voltage of bus i

$\mathbf{V_{imax}}$ And $\mathbf{V_{imin}}$ are maximum and minimum voltage limits

$\mathbf{V_{i\,nom}}$= is average of $\mathbf{V_{imax}}$ and $\mathbf{V_{imin}}$

For calculation of PI_V it required to know the maximum and minimum voltage generally a margin of ± 5% is kept for assigning the limits 1.05 p.u for maximum and 0.95 p.u for minimum.

A flow chart for contingency selection technique is shown in figure (4.1)

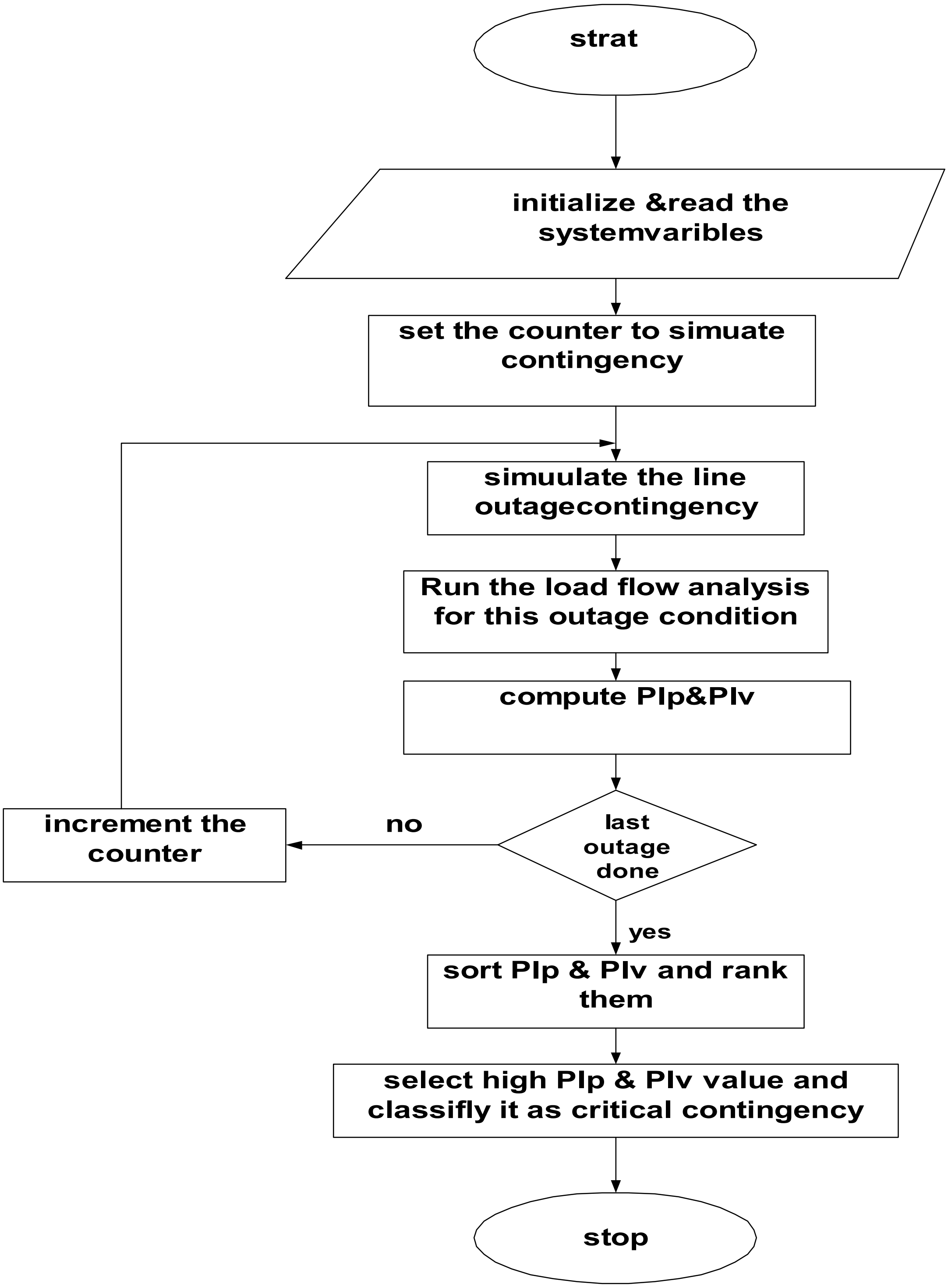


Figure (4.1) Flow chart for contingency selection.

Chapter five

Security Analysis of NG of Sudan (Case Study)

5.1 National Grid Layout Description:

Electricity generation in Sudan was established in 1908, with installed capacity of 100 kW. Then the generation capacity was increased to 3,000 kW. In 1962, the first station was run hydro power plant to generate electricity Sennar reservoir with a capacity of 15 MW. Then added to the water stations discounted Girba station with a capacity of 17.8 MW and Rosaries plant design capacity of 280 MW. The Merowe Dam project is a multipurpose scheme for hydropower generation. With an installed capacity of 1250 MW. The total electricity generation in Sudan for the month of May 2013 about 1.00305 million GWh is shown in figure (5.1).

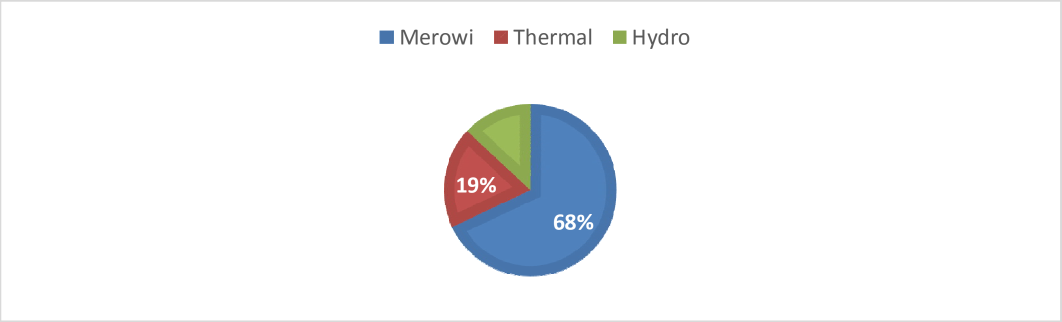


Figure (5.1) Total electric generation in Sudan

5.2 National Grid Data (NG):

Sudan national grid is considered as the case study, single line diagram is shown in figure (A-2) and system data is given in appendix (A).Figure (A-1) represents each power plant which is represented by equivalent machine according to the type and rating of synchronous machines. the transmission lines parameter are given in table A2 and the bus codes are given in table A1 in appendix A. single line diagram showing all system components in symbols form. All system nodes are numbered for easier reference when subjected to computer programming (ETAP) typical rating of system components are different thus it has been found useful to refer all raw data to common base value (kV base, MVA base) a method which is well known as per unit transformation the common base values used are 100MVA, 11kV, 33kV, 110kV, 220kV, and 500kV.

Result and discussion:-

Table (5.1) shows the result of contingency analysis using fast decoupled load flow solution and PI_V for Sudan's net work system have been presented, the algorithm implemented in (ETAP) the main objective is to determine the reactive power performance index which forms an important part of contingency analysis for different bus system.

Table (5.1) PI_v value for each contingency

no	Name of line outage	PI_v
1	Pre contingency (normal)	11.25426
2	MWP--MRK outage	74.63849
3	MWP—ATB outage	44.00814
4	MRK—KAB outage	12.42697
5	ROS—RNK outage	13.98290
6	MRK—MHD outage	11.45473
7	NHS—MAR outage	11.37865
8	GAR—FRZ outage	11.27628
9	ATB—SHN outage	11.45548
10	ROS—SNG outage	10.56273
11	SNG—SNJ outage	9.102136
12	MAR—SNJ outage	8.755360
13	GAR—IBA outage	9.685566
14	MSH—RBK outage	11.14047
15	GAD—KLX outage	11.91398
16	KLX--- IBA outage	12.46591
17	SHN--- FRZ outage	14.51566
18	KAB--- IBA outage	16.00981
39	KHN—IBA outage	11.33829
40	KUK—KHE outage	11.40808
41	KLX—AFR outage	11.50072
42	AFR—FAR outage	11.44488
43	NHS—GAD outage	11.22882
44	NHS—GND outage	11.15437
45	MAR—HAS outage	11.19801
46	HAG—MAR outage	11.10549
47	HAG—SNP outage	11.27611
48	SNJ—SNP outage	11.63533
49	FAO—GDF outage	10.90291
50	LOM—SHG outage	11.19077
51	SHG—MUG outage	11.06046
52	MUG—BNT outage	11.10075
53	KHN—KUK outage	10.64427
54	KLX—KUK outage	10.93691
55	BAG—GAD outage	12.03881
56	NHS—HAS outage	12.84322

19	NSH--- GAD outage	17.65124
20	JAS--- GAM outage	19.03312
21	FRZ--- KAB outage	20.62405
22	SNG--- HWT outage	18.42731
23	HWT--- GDF outage	10.80128
24	GDF--- SHK outage	15.39907
25	SHK--- GER outage	22.97681
26	GER--- KSL outage	26.90063
27	UMR--- OBD outage	8.699544
28	UMR--- TND outage	9.626684
29	MSH--- JAS outage	10.09783
30	WWA--- WHL outage	8.749158
31	WWA---DON outage	21.75663
32	DEB---DON outage	9.003264
33	MWP---DON outage	10.62208
34	MWPT—DEB outage	14.53607
35	MHD---OMD outage	11.37332
36	MHD---IZG outage	11.27112
37	IZG---KHN outage	11.62302
38	IBA---IZB outage	11.31921

57	SNJ—RBK outage	13.18526
58	SHG—JAS outage	14.06781
59	GAM—BNT outage	8.755361
60	KLX—BAG outage	9.386104
61	KLX—LOM outage	13.14734
62	SNP—MIN outage	14.47410
63	GER66—HLF66 outage	8.755360
64	GER66—KL3.66 outage	9.568652
65	GER066—RWS66 outage	9.999930
66	RWS66—GDF066 outage	10.26083
67	GDF110—GDF0-110 outage	11.19307
68	MAN—MAR outage	12.32795
69		
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Figure (5.2), (5.3) shows the PI_v with contingency before ranking; also figure (5.4), (5.5) shows the PI_v with contingency after ranking. And Table (5.2) shows the performance index and contingency ranking.

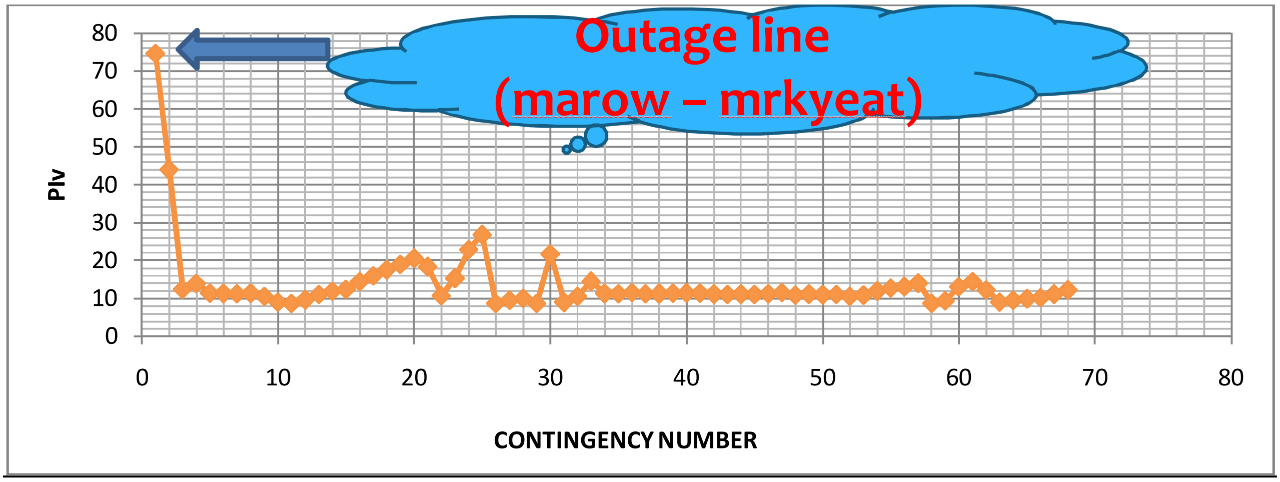
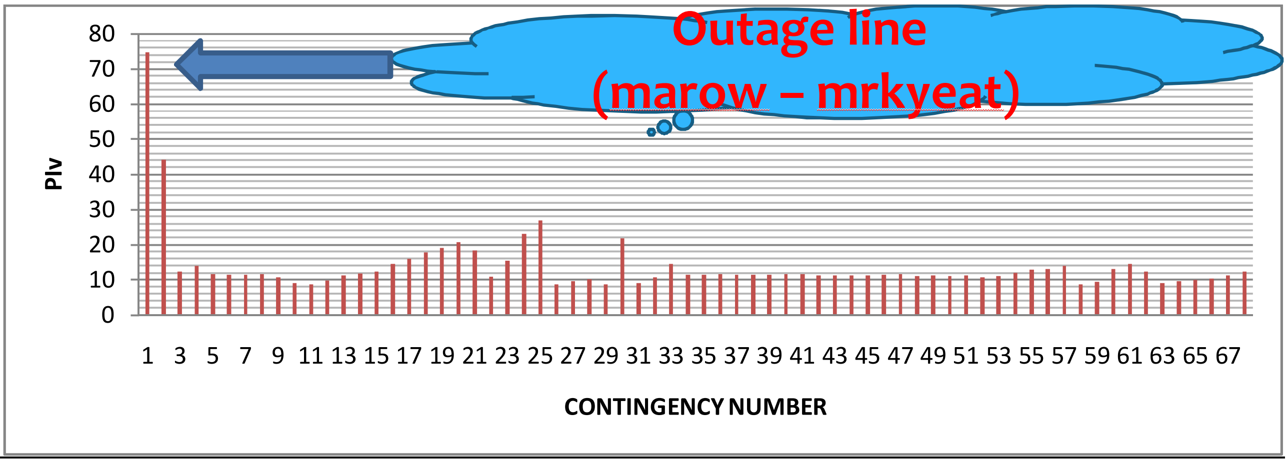
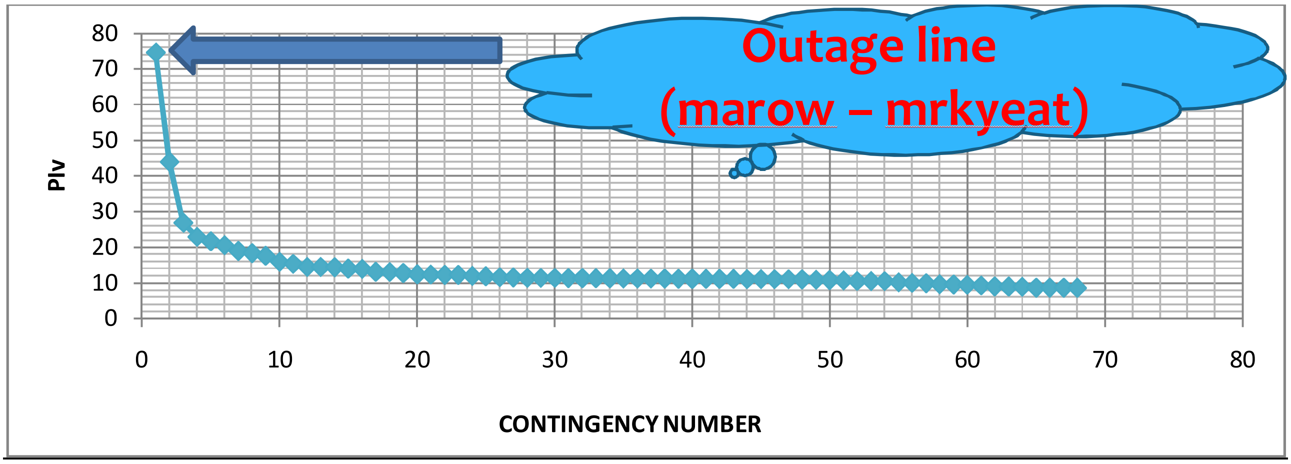


Figure (5.2) Curves represent PI_v with contingency number



Figure(5.3) Values of PI_v for Sudan's net work system



Figure(5.4) Contingency ranking and PI_v of sudan's net work system

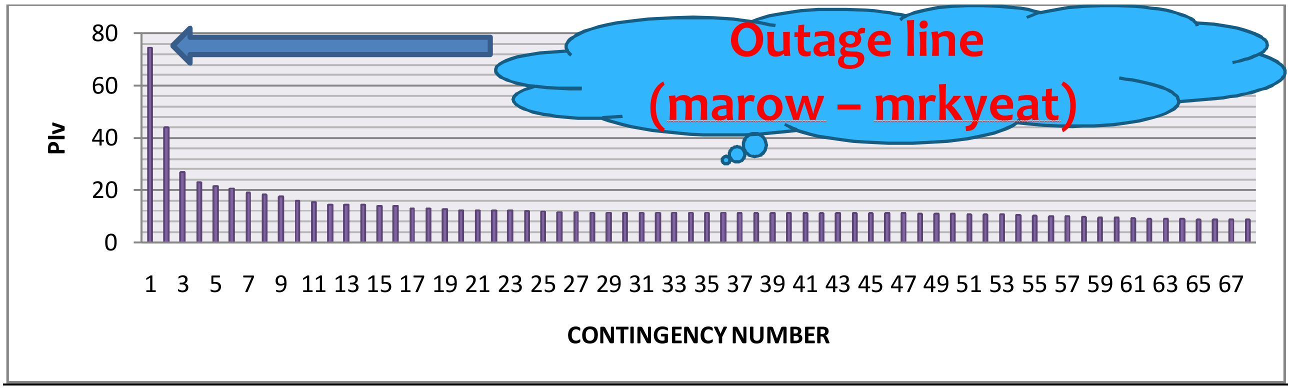


Figure (5.5) Contingency ranking and PI_v of sudan's net work system

The contingency have been ordered by their ranking where the most severe contingency is being ranked 1 and the last has been ranked 68.it is clear from the result of different PI_v that the contingency number 1 which the line outage contingency corresponding to the line connected between buses (Marowe –Mrkyat) is most severe contingency.

Table (5.2) Performance index and contingency ranking

Contingency Number	Line outage name	PI_V	Ranking
1	MWP--MRK outage	74.63849	***1***
2	MWP—ATB outage	44.00814	***2***
3	MRK—KAB outage	12.42697	***22***
4	ROS—RNK outage	13.98290	***16***
5	MRK—MHD outage	11.45473	***33***
6	NHS—MAR outage	11.37865	***34***
7	GAR—FRZ outage	11.27628	***35***
8	ATB—SHN outage	11.45548	***32***
9	ROS—SNG outage	10.56273	***55***
10	SNG—SNJ outage	9.102136	***57***
11	MAR—SNJ outage	8.755360	***65***
12	GAR—IBA outage	9.685566	***56***
13	MSH—RBK outage	11.14047	***36***
14	GAD—KLX outage	11.91398	***24***
15	KLX--- IBA outage	12.46591	***23***
16	SHN--- FRZ outage	14.51566	***14***
17	KAB--- IBA outage	16.00981	***10***
18	NSH--- GAD outage	17.65124	***9***
19	JAS--- GAM outage	19.03312	***7***
20	FRZ--- KAB outage	20.62405	***6***
21	SNG--- HWT outage	18.42731	***8***
22	HWT--- GDF outage	10.80128	***51***
23	GDF--- SHK outage	15.39907	***11***
24	SHK--- GER outage	22.97681	***4***
25	GER--- KSL outage	26.90063	***3***
26	UMR--- OBD outage	8.699544	***66***
27	UMR--- TND outage	9.626684	***58***
28	MSH--- JAS outage	10.09783	***52***
29	WWA--- WHL outage	8.749158	***64***
30	WWA---DON outage	21.75663	***5***
31	DEB---DON outage	9.003264	***59***
32	MWP---DON outage	10.62208	***50***

33	MWPT—DEB outage	14.53607	***12***
34	MHD---OMD outage	11.37332	***30***
35	MHD---IZG outage	11.27112	***31***
36	IZG---KHN outage	11.62302	***24***
37	IBA---IZB outage	11.31921	***29***
38	KHN—IBA outage	11.33829	***28***
39	KUK—KHE outage	11.40808	***27***
40	KLX—AFR outage	11.50072	***26***
41	AFR—FAR outage	11.44488	***37***
42	NHS—GAD outage	11.22882	***38***
43	NHS—GND outage	11.15437	***40***
44	MAR—HAS outage	11.19801	***39***
45	HAG—MAR outage	11.10549	***42***
46	HAG—SNP outage	11.27611	***41***
47	SNJ—SNP outage	11.63533	***25***
48	FAO—GDF outage	10.90291	***43***
49	LOM—SHG outage	11.19077	***44***
50	SHG—MUG outage	11.06046	***45***
51	MUG—BNT outage	11.10075	***46***
52	KHN—KUK outage	10.64427	***49***
53	KLX—KUK outage	10.93691	***48***
54	BAG—GAD outage	12.03881	***21***
55	NHS—HAS outage	12.84322	***19***
56	SNJ—RBK outage	13.18526	***17***
57	SHG—JAS outage	14.06781	***15***
58	GAM—BNT outage	8.755361	***63***
59	KLX—BAG outage	9.386104	***60***
60	KLX—LOM outage	13.14734	***18***
61	SNP—MIN outage	14.47410	***13***
62	GER66—HLF66 outage	8.755360	***62***
63	GER66—KL3.66 outage	9.568652	***61***
64	GER066—RWS66 outage	9.999930	***54***
65	RWS66—GDF066 outage	10.26083	***53***
66	GDF110—GDF0-110 outage	11.19307	***47***
67	MAN—MAR outage	12.32795	***20***

Chapter Six

Conclusion and Recommendations

6.1 Conclusion:-

This work outlines mathematical models for the simulation of transmission line outages so as to carry out a load flow based contingency analysis. The method has been applied to National Sudan's Grid and gives good results in determining the network weaknesses. Result of contingencies analysis shows that:-

The contingency have been ordered by their ranking where the most severe contingency is being ranked 1 and the last has been ranked **68**.it is clear from the result of different PI_v that the contingency number **1** which the line outage contingency corresponding to the line connected between buses (Marowe –Mrkyat) is most severe contingency.

6.2 Recommendations:-

From the results obtained following recommendation for future work can be suggested for future researcher:-

1. Study the possibility of Using automatic load shedding to avoid total black out.
2. Investigation of spinning reserve for large generation as tool for security analysis.
3. Investigation of increasing generation capacity and their geographic distribution to obtain the best security assessment.
4. To study power system security assessment of the National Grid of Sudan generators, and transformer system.
5. Investigation of Correction action.

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