CHAPTER ONE

INTRODUCTION

1.1 Background

Electrical energy is the most important form of energy in the present world. It is an energy that drives the economy of any society or country and makes the common citizen happy. Electricity is been generated from the power station, needs to be transmitted to the end users, through transmission and distribution lines. This transmitted energy is not without losses, but the capacity to transmit at minimal losses is what this project concerns to [1].

Growing populations and industrialization create huge need for electrical energy, unfortunately electricity is not always used in large demand in the same location it is been generated. So, long cables or wires are used to transmit the generated electricity either through Underground or Overhead system method, which is referred to as Transmission of Electrical Energy. This transmission is not takes place without encountering losses, which is the soul aim of this project.

The losses are either Technical losses or Non-technical Losses, the technical losses, which includes the; Corona loss, Joule effect, Magnetic Losses, and skin effect. While the Non-technical (commercial) losses include, theist of electricity, vandalism to electrical substation ns, poor meter reading, poor accounting and record keeping, etc.

There could be no best way, by explaining the various methods of analyzing calculations on how to solve these technical losses, and also explaining measures to be taken to make sure that transmission losses can be reduced to be areas minimum.

Transmission of power and energy must be done at minimum technical and non-technical losses which are referred as Total Losses during transmission [2].

1.2 Problem Statement

Supplying power from sources to consumer points produce loss in supplied power, with the expanding of power system's grids, the losses also being much more, this losses effect in power system efficiency.

1.3 Objectives

The main objective of this project is reducing transmission system’s losses in Sudanese electricity Grid.

1.4 Methodology

In order to achieve project’s objectives the following tasks were used:

Task 1: Studying the data base of Sudanese electricity Grid that has been given.

Task 2: Analyzing the total performance of the Grid in order to figure out the areas that have most transmission systems losses.

Task 3: Using the modern techniques have been chosen to handle the losses problems in the same areas have been discovered.

Task4: computer program has been developed in case of show and implement the results in each single technique and making comparison between them to specify the best one.

1.5 Layout of the Project

This project contains five chapters. Chapter one is introduction that includes General view about losses reduction techniques in transmission systems and its importance, problem statement, objectives, methodology and layout of the project. Chapter two is literature-reviews of losses reduction techniques in transmission systems, chapter three is about the modern techniques have been chosen to handle the transmission systems and the simulation of the techniques.

Chapter four presents the analysis of simulation results. Chapter five includes the conclusion and recommendations.

CHAPTER TWO

LITRATURE REVIEW

2.1 Introduction

In electricity supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users. Total losses have two components: technical and non-technical. Metering and billing for electricity actually consumed by users is integral to commercial management of an electricity utility. Another critical task is collection of the billed amounts. Effective performance in both functions is critical to ensure the financial viability of the company. From the operational point of view, metering-billing and collection are separate functions and they require specific management approaches.

Optimization of technical losses in electricity transmission and distribution grids is an engineering issue, involving classic tools of power systems planning and modeling. The driving criterion is minimization of the net present value (sum of costs over the economic life of the system discounted at a representative rate of return for the business) of the total investment cost of the transmission and distribution system plus the total cost of technical losses. Technical losses are valued at generation costs [3].

Table 1.1:Transmisson and distribution losses percentages in some countries.

Country	Year	
	2000 (percentage)	2011 (percentage)
India	27 %	22%

Brazil	17%	16%
Maxico	13%	15%
China	7%	5.5%
Korea	4.5%	3%
Chile	7%	6.8%

2.2 Technical losses

Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub transmission and distribution of power. Technical losses on distribution systems are primarily due to heat dissipation resulting from current passing through conductors and ferromagnetic losses in transformers. Losses are inherent to the distribution of electricity and cannot be eliminated. The major part of this loss is heat dissipation or (I^2R) loss in the distribution conductors. Since this loss depends upon the value of current, it is the maximum during peak load. Other causes of the technical loss are low power factor, phase imbalance, improper joints. This loss difference between in the transformer output and the sum of all invalid consumption losses occur on sub transmission lines, distribution lines, station transformers, distribution transformers and secondary services to customers. Transformer losses include no-load losses that are independent of transformer loading and load losses that are dependent on the loading [4].

2.3 Main Reasons for Technical Losses

There are many reasons for Technical Losses such as

2.3.1 Lengthy Distribution lines

One of the major reasons for loss is- Lengthy Distribution lines. It is good to take note here that the longer stretch of surface area through electricity transmission leads to more wear and tear and erosion and ultimately, loss of electricity in practically 11 KV and 415 volts lines, in rural areas are extended over long distances to feed loads scattered over large areas. Thus the primary and secondary distributions lines in rural areas are largely radial laid usually extend over long distance, this results in high line resistance and therefore high (I^2R) losses in the line. This can be attributed to the fact that electricity generation centers and supply centers are not located within easy reach of each other. This leads to longer transmission lines and ultimately, larger losses in electricity through transmission.

2.3.2 Inadequate Size of Conductors of Distribution lines

The size of the conductors should be selected on the basis of KVA x KM capacity of standard conductor for a required voltage regulation, but rural loads are usually scattered and generally fed by radial feeders. The conductor size of these feeders should be adequate.

2.3.3 Installation of Distribution transformers away from load centers

Distribution Transformers are not located at load center on the secondary distribution system. In most of case distribution transformers are not located centrally with respect to consumers. Consequently, the farthest consumers obtain an extremity low voltage even though a good voltage levels maintained at the transformers secondary. This again leads to higher line losses. The reason for the line losses increasing as a result of decreased voltage at the consumers end therefore in order to reduce the voltage drop in the line to the farthest consumers, the distribution transformer should be located at the load center to keep voltage drop within permissible limits.

2.3.4 Low Power Factor of Primary and secondary distribution system

In most LT distribution circuits normally the Power Factor ranges from 0.65 to 0.75. A low Power Factor contributes towards high distribution losses. For a given load, if the Power Factor is low, the current drawn in high and the losses proportional to square of the current will be more. Thus, line losses owing to the poor PF can be reduced by improving the Power Factor. This can be done by application of shunt capacitors.

Shunt capacitors can be connected either in secondary side (11 KV side) of the 33/11 KV power transformers or at various point of Distribution Line. The optimum rating of capacitor banks for a distribution system is 2/3rd of the average KVAR requirement of that distribution system. The vantage point is at 2/3rd the length of the main distributor from the transformer. A more appropriate manner of improving this PF of the distribution system and thereby reduce the line losses is to connect capacitors across the terminals of the consumers having inductive loads. By connecting the capacitors across individual loads, the line loss is reduced from 4 to 9% depending upon the extent of PF improvement.

2.3.5 Load Factor decreasing

Power consumption of customer varies throughout the day and over seasons. Residential customers generally draw their highest power demand in the evening hours. Same commercial customer load generally peak in the early afternoon. Because current level (hence, load) is the primary driver in distribution power losses, keeping power consumption more level throughout the day will lower peak power loss and overall energy losses. Lower power and energy losses are reduced by raising the load factor, which, evens out feeder demand variation throughout feeder. Companies use pricing power to influence consumers to shift electric-intensive activities during off-peak times such as, electric water and space heating, air conditioning, irrigating, and pool filter pumping.

2.3.6 Inadequate transformer size and selection

Distribution transformers use copper conductor windings to induce a magnetic field into a grain-oriented silicon steel core. Therefore, transformers have both load losses and no-load core losses. Transformer copper losses vary with load based on the resistive power loss equation (P loss = I^2R). For some utilities, economic transformer loading means loading distribution transformers to capacity-or slightly above capacity for a short time-in an effort to minimize capital costs and still maintain long transformer life. However, since peak generation is usually the most expensive, total cost of ownership studies should take into account the cost of peak transformer losses. Increasing distribution transformer capacity during peak by one size will often result in lower total peak power dissipation-more so if it is overloaded.

Transformer no-load excitation loss (iron loss) occurs from a changing magnetic field in the transformer core whenever it is energized. Core loss varies slightly with voltage but is essentially considered constant. Fixed iron loss depends on transformer core design and steel lamination molecular structure. Improved manufacturing of steel cores and in traducing amorphous metals (such as metallic glass) have reduced losses of cores.

2.3.7 Balancing three phase loads

Balancing 3-phase loads periodically throughout a network can reduce losses significantly. It can be done relatively easily on overhead networks and consequently offers considerable scope for cost effective loss reduction, given suitable incentives.

2.3.8 Switching off transformers

One method of reducing fixed losses is to switch off transformers in periods of low demand. If two transformers of a certain size are required at a substation during peak periods, only one might be required during times of low demand so that the other transformer might be switched off in order to reduce fixed losses. This will produce some offsetting increase in variable losses and might affect security and quality of supply as well as the operational condition of the transformer itself.

2.3.9 Harmonic

Harmonics are defined as sinusoidal voltage and current waveforms at integer multiples of the fundamental power frequency. Harmonics leads to the increase of power quality disturbances and losses in distribution systems. Because of the load characteristics, harmonics have an increasing effect on technical losses of the lines and transformers.

2.4 Types of technical losses

There are two type of technical losses

2.4.1 Permanent (Fixed) Technical losses

Fixed losses do not vary according to current. These losses take the form of heat and noise and occur as long as a transformer is energized. Between 1/4 and 1/3 of technical losses on distribution networks are fixed losses. Fixed losses on a network can be influenced in the ways set out below.

- **Corona losses**

Air is not a perfect insulator and even under normal condition, the air contains a number of free electrons and ions. Consider two large parallel conducting planes. When an electron gradient is set up between them, the electrons and ions acquire motion by this electric field and they maintain a very small current between the conducting planes .this current is negligible when the electric field intensity is less than 30KV/cm. But when the electric field intensity or potential gradient reaches the critical value of 30 KV/cm, the air in the immediate vicinity of conductors no more remains a dielectric and at this intensity the ions attain high velocity and on striking another neutral molecule dislodge one or more electron from the neutral molecule this produce a new electron and a positive ion which in turn are accelerated and collide with other air molecule to ionize them further.

Thus the number of charge particles goes on increasing rabidly If a uniform field intensity is assumed between the electrodes such condition are produced everywhere in the gap, as a result of this ,the saturation is reached. Therefore the air becomes conducting, hence a complete electric break down occurs and arc is established between the two electrodes. When an alternating potential deference is applied across two conductors whose spacing large compassion with the diameter, then the surrounding the conductor is subjected to electro-static stresses. This stress or intensity is a maximum at the surface of the conductor and the decrease in inverse proportion to the distance from the center of the conductor. If this potential deference is gradually increased, a point will be reached when a faint luminous glow of violet color will make its appearance, and at the same time a hissing noise will be heard. This phenomenon is called corona and is accompanied by the formation of ozone, as is indicated by the characteristics dour of this gas. This luminous glow is due to the fact that the atmospheric air around the conductor becomes conducting due to electrostatic stress. If the potential difference is raised still further, the glow and the noise will increase in intensity until eventually a spark over will take place. If the conductors are perfectly uniform and smooth, the glow will be uniform along their length, otherwise the rough points of the conductors will appear brighter with conductors only a short distance apart in comparison with their diameter the spark-over may take place before there is any luminous glow is observed [5].

Means of reducing Power Loss due to Corona are:

- The using of bundle conductors reduces corona loss.
- Spacing between conductors is selected so that corona is tolerable.
- Since the shape of conductors affect corona loss, cylindrical shape conductors have uniform field that reduces corona loss than any other shape.
- The voltage stress and electric field gradient should be minimized which can be accomplished by using good high voltage design practices. Using conductors with large radii reduce corona loss.
- Void free solid conductors and insulators should be used [6].

● Leakage Current Losses

There are two types of leakage current ac leakage and dc leakage, DC leakage current usually applies only to end-product equipment, not to power supplies. Ac leakage current is caused by a parallel combination of capacitance and dc resistance between a voltage source (ac line) and the grounded conductive parts of the equipment. The leakage caused by the dc resistance usually is insignificant compared to the ac impedance of various parallel capacitances. The capacitance may be intentional or unintentional. Some examples of unintentional capacitances are spacing on printed wiring boards, insulations between semi conductors and grounded heat sinks, and the primary-to-secondary capacitance of isolating transformers within the power supply.

● Dielectric Losses

Dielectric losses result from the heating effect on the dielectric material between the conductors. Power from the source is used in heating the dielectric. The heat produced is dissipated into the surrounding medium. When there is no potential difference between two conductors, the atoms in the dielectric material between them are normal and the orbits of the electrons are circular. When there is a potential difference between two conductors, the orbits of the electrons change. The excessive negative charge on one conductor repels electrons on the dielectric toward the positive conductor and thus distorts the orbits of the electrons. A change in the path of electrons requires more energy, introducing a power loss.

2.4.2 Variable Technical losses

Variable losses vary with the amount of electricity distributed and are more precisely, proportional to the square of the current. Consequently, a 1% increase in current leads to an increase in losses of more than 1%. Between 2/3 and 3/4 of technical (or physical) losses on distribution networks are variable losses. By increasing the cross sectional area of lines and cables for a given load, losses will fall. This leads to a direct trade-off between cost of losses and cost of capital expenditure. It has been suggested that optimal average utilization rate on a distribution network that considers the cost of losses in its design could be as low as 30 per cent [7].

There are several types of variables technical losses such as:

- Joule losses in lines in each voltage level
- Impedance losses
- Losses caused by contact resistance

2.5 Non-Technical (Commercial Losses)

Non-Technical losses are caused by actions external to the power system or are caused by loads and condition that the Technical losses computation failed to take into account. Non- Technical losses are more difficult to measure because these losses are often unaccounted for by the system operators and thus have no recorded information. On the other hand, it occurs as a result of theft, metering inaccuracies and unmetered energy. NTLs, by contrast, relate mainly to power theft in one form or another. Theft of power is energy delivered to customers that is not measured by the energy meter for the customer. This can happen as a result of meter tampering or by bypassing the meter. Losses due to metering inaccuracies are defined as the difference between the amount of energy actually delivered through the meters and the amount registered by the meters.

2.5.1 Main Reasons for Non-Technical Losses

There are many reasons of Non-Technical Losses:

- Tampering with meters to ensure the meter recorded a lower consumption reading.
- Errors in technical losses computation.
- Tapping (hooking) on LT lines.
- Arranging false readings by bribing meter readers.
- Stealing by bypassing the meter or otherwise making illegal connections.
- By just ignoring unpaid bills.
- Faulty energy meters or un-metered supply.
- Errors and delay in meter reading and billing.
- Non-payment by customers [8].

CHAPTER THREE

Loss reduction techniques

3.1 Introduction

This chapter discusses the techniques which have been used to reduce transmission power losses in Sudanese national electrical grid which has been modeled using NEPLAN software.

To have a general view about the network losses, Load Flow analysis has been used.

3.2 Load flow analysis

The power flow (load-flow) analysis involves the calculation for power flow and voltages of a transmission network for specified terminal or bus conditions. Such calculations are required for the analysis of steady state as well as dynamic performance of power systems. In this section power flow analysis is described as it applies to the steady state performance of the power system. Associated with each bus are four quantities: active power P, reactive power Q, voltage magnitude V, and voltage angle θ, and at each bus two of the above four quantities are specified [9].

The method has been applied in order to have Load flow analysis done is Newton-Raphson method.

3.3 Adding small generation station

Appropriate size and location of distributed generation (DG) play a significant role in minimizing power losses in distribution systems. This section represents techniques to minimize power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point of DG. Sensitivity analysis for power losses in terms of DG size and DG operating point has been performed. The proposed sensitivity indices can indicate the changes in power losses with respect to DG current injection. The proposed techniques have been developed with considering load characteristics and representing loads with constant impedance and constant current models, separately. The optimal size and location of DG in a distribution feeder can be obtained through the developed techniques, with minimum effort. The proposed techniques have been tested on a practical long radial system and results are reported. Test results have proven that up to eighty-six percent of real power loss can be reduced with a DG of optimal size, located at optimal place in the feeder.

A new emerging trend of distribution networks is to use small generating units, known as distributed generation (DG), operating in parallel with the main grid. This kind of distribution networks has enabled DG to support power systems in fulfilling their requirements to increase power output as well as quality of power supply. DG has potential to alter power flows, system voltages, and the system performance. In order to maximize benefits from the DG system, proper DG planning is necessary.

Determining an optimal DG size and its DG location are critical issues that are addressed in this section. The main purpose of DG technique is maximizing voltage support through optimal sizing and location of it. A new methodology is developed to determine an optimal DG size for a certain DG penetration and an optimal DG location on the distribution feeder for optimizing system voltages. The developed technique is tested on a long radial feeder of a practical system called DG technique as it mentioned.

Utilizing of Distributed Generation (DG) to produce electricity has become an increasingly attractive choice for both utility and customers. Traditional options of power utilities to compensate the rapid growth in electricity demand are transmission expansion, substation capacity upgrade and/or DG integration [10].

Among these options, DG appears to be the most perspective one. It does not only relieve the burden of supplying loads from distribution system, but also satisfies the customer's requirements of reliable and continuous power supply, as well as an availability of instantaneous electricity sources when power interruptions occur. Moreover, together with the ongoing efforts to reduce capital investments and operating cost of DG, it is believed that DG can potentially become one of the most effective-cost solutions [11].

For decades, small generation has been used as a backup or stand-by power source to supply electricity for small personal customers during grid power outages. The most common type of DG for this purpose is diesel generation. Nowadays, the recent advances in DG technologies have made this power solution possible not only to serve individual customers but also support the entire network in parallel with the grid. DG technologies can be categorized into two groups:

(i) Non-renewable energy technologies and

(ii) Renewable energy technologies.

The first group consists of internal combustion engines, gas turbines, micro turbines, etc.

The second group produces electricity using renewable energy sources, i.e. solar energy, wind energy, tidal energy, wave energy, geothermal energy, bio-energy, etc. Although DG has relatively small size compared with central generation, it is large enough to satisfy electricity requirements of a group of local customers.

Conventional, purpose of distribution systems is to distribute power to the customers. These customers are designed to operate as passive network elements and do not generate any power.

However, the current trend of introducing DG into distribution systems makes customers no longer “passive” – they become rather “active”. Possibilities of positive impacts of DG include voltage profile improvement, system loss reduction, system stability and reliability improvement, etc. Among all key issues, the choice of the DG size and DG location is of a great importance [12].

3.4 FACTS devices

The rapid development of power electronics technology provides exciting opportunities to develop new power system equipment for better utilization of existing systems. During the last decade, a number of control devices under the term "Flexible AC Transmission Systems" (FACTS) technology have been proposed and implemented. FACTS devices can be effectively used for power flow control, loop-flow control, load sharing among parallel corridors, voltage regulation, and enhancement of transient stability and mitigation of system oscillations [13].

3.4.1 FACTS devices benefits

FACTS devices enable the transmission owners to obtain one or more of the Following benefits:

- Power flow control.
- Increase of transmission capability.
- Voltage control.
- Reactive power compensation, stability improvement.
- Power quality improvement.

Because the voltage, current, impedance, real power, and reactive power are interrelated, each controller has multiple attributes of what they can do in terms of controlling the voltage, power flow, stability and so on. These controllers can have multiple open loop and closed loop controls to accomplish multiple benefits [14].

3.5 Unified Power Flow Controller (UPFC)

This controller is connected as shown in Figure 3.1. It is a combination of STATCOM and SSSC which are coupled via a common dc link to –allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. These are controlled for provide concurrent real and reactive series line compensation without an external energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently, simultaneously or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive line flows. The UPFC may also provide independently controllable shunt reactive compensation [15].

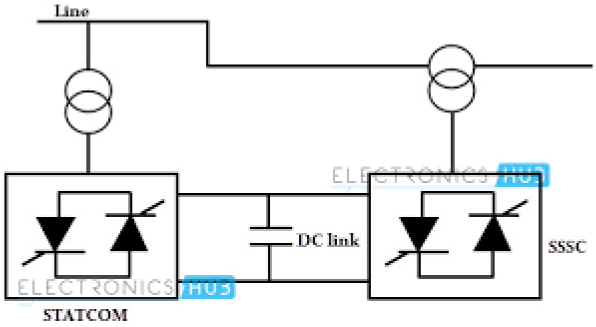

Figure 3.1: Unified power Flow Controller (UPFC)

3.6 Optimal location for UPFC

Distribution networks experience distinct change from a low to high load level every day. Hence, a major concern in power distribution networks is the problem of voltage stability.

A power system is said to have a situation of voltage instability when a disturbance causes a progressive and uncontrollable decrease in voltage level. Power system stability is the ability of the system to maintain acceptable levels of voltage at all the buses of the system following a disturbance [13].

Several methods have been used to analyze the performance of the system stability like the PV Curves, QV Curves, Sensitivity Analysis, and Modal

Analysis. An accurate knowledge of how close the actual system's operating point is from the voltage stability limit is essential to operators. Therefore, voltage stability index was developed for voltage stability studies. These indices provide reliable information about proximity of voltage instability in a power system. Usually, an index value varies between 0 and 1. Line voltage stability indices (LVSI) thus provide information about the system stability by determining the most severe line in the system for stability analysis studies. The value of these indices indicate the closeness of the system towards instability, if the index value is closer to 1 it shows that the system is on the verge of instability, if index value is greater than 1, the system has crossed its stability limit leading to a condition of voltage collapse which can ultimately cause blackout of the system. Flexible AC Transmission System (FACTS) can be used to enhance the system stability thereby reducing the seriousness of the system. FACT devices should be installed at the most appropriate location i.e. on the most critical line as determined by the indices. The advantage of using FACT controllers be it series or shunt is that the power flow through the line is enhanced and the voltage profile of the system is also improved. FACT controller provides compensation in the transmission line in which it is installed by modifying the value of line reactance, upfc helps in enhancing the voltages of the buses between which it is placed to analyze and enhance the stability of the system using line voltage stability indices and installing it in the most critical transmission line.

There are many indices which use the elements of the admittance matrix and some system variables such as bus voltages and power flow through lines such as VCPI, L-index, L_{mn}, LQP and FVSI.

L_{mn} have a better response when the increased is just from reactive power flow is higher than the active power flow. Due to high reactive power flow in

Sudanese electrical network L_{mn} is used to identify the weakest line in the network [16].

3.7 Line Stability Index (l_{mn}) calculation

Most of line stability indices are formulated based on the power transmission concept in a single line. A single line in an interconnected network is illustrated in Figure 3.2.

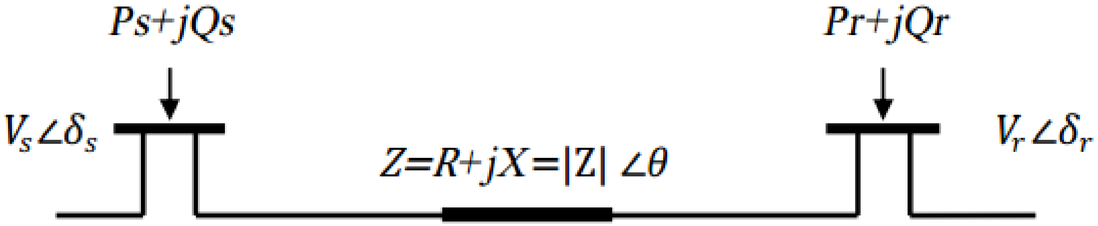

Figure 3.2: Two bus system

Where,

Vs, Vr: are the sending end and receiving end voltages.

δs, δr: are the phase angles at the sending and receiving end.

Z: is the line impedance.

R: is the line resistance.

X: is the line reactance.

θ: is the line impedance angle.

Ps, Qs: are the active and reactive powers at the sending end.

Pr, Qr: are the active and reactive powers at the receiving end.

This index proposed in [16] is based on the concept of power flow through a single line and adopting the technique of reducing a power system network into a single line.

The line current ($Iline$) is calculated by

$$Iline = \frac{Vs - Vr}{z} \tag{3.1}$$

The ($Iline$) also can be determined by using the receiving apparent power given as:

$$Iline = \left(\frac{S}{Vr}\right)^{*} = \frac{\Pr - jQr}{V\angle -\delta r} \tag{3.2}$$

Rearranging equation (3.1) and (3.2) yields

$$\Pr - jQr = \frac{|Vs||Vr|\angle(\phi - \delta s + \delta r)}{z} - \frac{|Vr|^2\angle\phi}{z} \tag{3.3}$$

If this equation is separated in real and reactive power, then,

$$\Pr = \frac{|Vs||Vr|\cos(\phi - \delta s - \delta r)}{z} - \frac{|Vr|^2\cos\phi}{z} \tag{3.4}$$

$$Qr = \frac{|Vs||Vr|\sin(\phi - \delta s - \delta r)}{z} - \frac{|Vr|^2\sin\phi}{z} \tag{3.5}$$

Defining $\varepsilon = \varepsilon t - \varepsilon s$ and solving equation 3.5 for Vs, then,

$$Vr = \frac{Vs.\sin(\phi - \delta) \pm \sqrt{(vs.\sin(\phi - \delta))^2 - (4xQ)}}{2\sin(\phi)} \tag{3.6}$$

$$Vs.\sin(\phi - \delta) \text{ -4xQ} \geq 0 \tag{3.7}$$

$$Lmn = \frac{4xQ}{(Vs.\sin(\phi - \delta))^2} \leq 1 \tag{3.8}$$

As long as L_{mn} remains less than one the system is stable, once the value of L_{mn} exceeds one, the system reaches its voltage collapse point.

3.8 UPFC Parameter Setting

Load flow analysis has been done and its results at the suggested optimal locations are used to adjust the power flow parameters setting for the UPFC, which are the control value of the active line flow, control value of the reactive line flow, and control value of the voltage magnitude at the sending bus. If the range of these parameters does not specified correctly, UPFC failed to control the active and reactive power flow at the selected values, Consequently the power flow program will not converge to the solution.

3.9 Criteria for optimal location of UPFC

The following criteria have been used for optimal placement of UPFC.

- The branches having transformers have not been considered for the UPFC placement.
- The line having the highest value of L_{mn} is considered the best location for UPFC, followed by other lines having less value.
- if two or more cascaded lines in a radial network are considered as the best location, then the line having the highest value of L_{mn} of this network is considered as the best location for UPFC placement.

3.10 Software developments

- To simplify the study, commercial software NEPLAN has been
- implemented to introduce UPFC"s in the system and to obtain the power flow results. NEPLAN is one of the most complete planning, optimization and simulation tool for transmission, distribution, generation and industrial networks.
- It is used in more than 80 countries by more than 600 companies, such as small and large electrical utilities, industries and universities.

- NEPLAN includes power flow, optimal power flow, reliability, protection systems, harmonic analysis, transient stability, power quality and models of various FACTS devices. All operations can be assessed by means of graphical user interfaces.
- The connection of UPFC in NEPLAN is shown in figure 3.3.

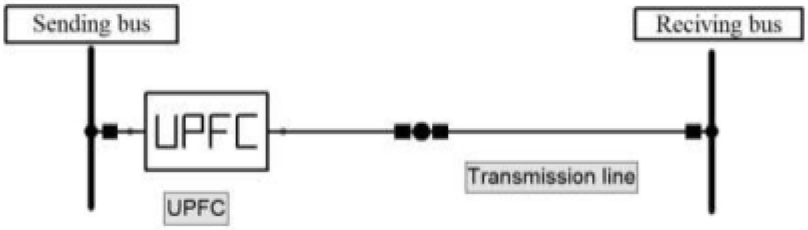

Figure 3.3 Schematic symbol of UPFC in NEPLAN

CHAPTER FOUR

SIMULATION AND RESULT

4.1 Sudanese electrical network

The real network of Sudanese electrical power grid was chosen as a model, the network includes two voltage levels 500 kV and 220 kV, where 110 kV and 33 kV voltage levels were represented as loads.

The power generated comes from three power plants (MARAWI, GARRI, and ROSAIRS)

The data has been taken at peak load condition (shown in appendix A), the total load of the system is 1102 MW and 592.5MVAr, the total power generated is 1182.588 MW, -674.76 MVAr, and the total losses at base case are 26.588 MW.

The network has the following characteristics:

Table 4.1: network characteristics

Number of busses	23
Number of lines	44
Power plants	3
Loads	17
3 Winding transformer	7

The data has been represented is shown in figure 4.1:

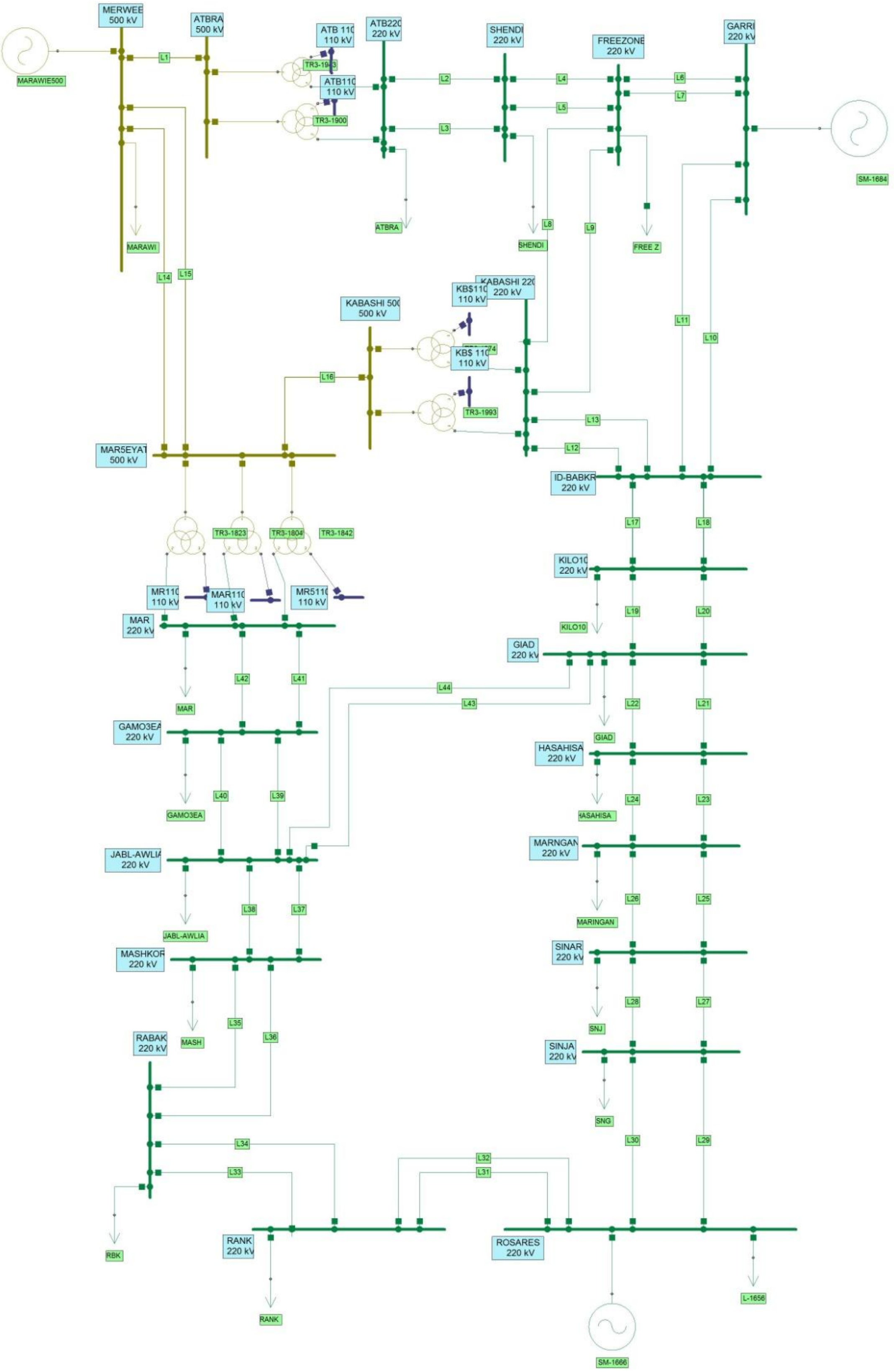

Figure 4.1: Sudanese electrical network

4.2 load flow results

The load flow results for 500 and 220 voltage levels were illustrated on tables 4.2 and 4.3.

Table 4.2: Bus voltages and angles at base case

Bus No.	Bus Name	Voltage (kV)	Angle(degree)
1	MARAWI	500	0
2	ATBARA 500	503.946	-3.4
3	ATBARA 220	218.295	-7.1
4	SHENDI	218.274	-9
5	FREE ZONE	215.832	-10
6	GARRI	215.6	-10
7	MARKHYAT500	503.19	-6.9
8	MARKHYAT220	216.064	-11.6
9	JAMMOEYA	212.752	-13.7
10	JABLAWLYA	212.056	-15
11	MSHKOR	217.733	-18.1
12	RABAK	218.961	-19.9
13	ALRANK	221.103	-20.7
14	ROSAIRS	220	-20
15	SINJA	206.981	-22.5
16	SINNAR	204.925	-22.3
17	MARINGAN	202.779	-21
18	HASAHESA	204.275	-19.2
19	GIAD	210.693	-14.9
20	KILO 10	212.55	-12.4
21	EIDBABIKER	214.045	-11.5
22	KABBASHI 500	501.267	-7.3

23	KABBASHI 220	216.194	-10.3

Table 4.3: Lines losses

Line No.	From	To	P loss(MW)	Q loss(Mvar)
1	MARAWI	ATBARA	1.4237	-231.03
2	ATBARA	SHENDI	0.2703	-26.15
3	ATBARA	SHENDI	0.2703	-26.15
4	FREEZONE	SHENDI	0.1214	-21.682
5	FREEZONE	SHENDI	0.1214	-21.682
6	GARRI	FREEZONE	0.0077	-0.9197
7	GARRI	FREEZONE	0.0077	-0.9197
8	FREEZONE	KABASH220	0.0247	-7.1637
9	FREEZONE	KABASH220	0.0247	-7.1637
10	GARRI	EIDBABIKER	0.3857	-9.6225
11	GARRI	EIDBABIKER	0.3857	-9.6225
12	KABASH220	EIDBABIKER	0.5619	-3.1635
13	KABASH220	EIDBABIKER	0.5619	-3.1635
14	MARAWI	MARKHYT500	3.8013	-319.19
15	MARAWI	MARKHYT500	3.8013	-319.19
16	MARKHYT500	KABASHI500	0.164	1.5791
17	EIDBABIKER	KILO 10	0.6675	0.3955
18	EIDBABIKER	KILO 10	0.6675	0.3955
19	KILO 10	GIAD	0.9892	-0.212
20	KILO 10	GIAD	0.9892	-0.212
21	GIAD	HASAHESA	1.4585	-2.761
22	GIAD	HASAHESA	1.4585	-2.761

23	HASAHESA	MARINGAN	0.3687	-4.5017
24	HASAHESA	MARINGAN	0.3687	-4.5017
25	MARINGAN	SINNAR	0.1323	-9.1914
26	MARINGAN	SINNAR	0.1323	-9.1914
27	SINNAR	SINJA	0.0447	-5.7734
28	SINNAR	SINJA	0.0447	-5.7734
29	ROSAIRS	SINJA	0.6503	-19.588
30	ROSAIRS	SINJA	0.6503	-19.588
31	ROSAIRS	RANK	0.0333	-32.441
32	ROSAIRS	RANK	0.0333	-32.441
33	RABAK	RANK	0.0597	-32.177
34	RABAK	RANK	0.0597	-32.177
35	MASHKOR	RABAK	0.3176	-19.537
36	MASHKOR	RABAK	0.3176	-19.537
37	JABLAWLIA	MASHKOR	0.7777	-24.484
38	JABLAWLIA	MASHKOR	0.7777	-24.484
39	JAMMOEYA	JABLAWLIA	0.4171	-5.5017
40	JAMMOEYA	JABLAWLIA	0.4171	-5.5017
41	MARKHYAT	JAMMOEYA	1.3732	-1.3325
42	MARKHYAT	JAMMOEYA	1.3732	-1.3325
43	JABLAWLIA	GIAD	0.0389	-6.4241
44	JABLAWLIA	GIAD	0.0389	-6.4241
Total losses			26.588	-1332.292

4.3 Losses reduction by adding small generation

First of all optimal location for generation has been detected and voltage has been taken as standard in order to detect the buses which are not within the limit (±5%) and consider it as a weak busbar.

Reference to the results that have been obtained from the load flow analysis, there are five buses not within the limits.

Table 4.4: The weakest buses in the network

Bus name	Voltage(KV)
MARNGAN	202.779
HASAHISA	204.275
SINNAR	204.924
SINJA	206.981
GIAD	210.693

In order to detect the optimal power rating for generation station, series of load flow analysis with increased generation power rating at detected locations have been done until the minimum power losses with a minimum power rating has been reached.

Generator with power rating (250 MW) has been inserted at each area, by applying load flow analysis each time, and observing the effect on total network power losses which had been illustrated on table 4.5, it had been noticed that the best location for adding generation station is MARNGAN

Table 4.5: impact of adding generation on the network losses

Area	Total network losses
MARNGAN	10.286
SINAR	11.105
HASAHISA	11.22

SINJA	12.060345
GIAD	15.038

By adding generation station at MARNGAN and applying load flow analysis the lines losses have been illustrated at table 4.6.

Table 4.6: impact of adding generation on line losses

Line No.	From	To	P loss(MW)	Qloss(Mvar)
1	MARAWI	ATBARA500	0.8872	-236.66
2	ATBARA220	SHENDI	0.0265	-27.263
3	ATBARA220	SHENDI	0.0265	-27.263
4	FREEZONE	SHENDI	0.037	-22.093
5	FREEZONE	SHENDI	0.037	-22.093
6	GARRI	FREEZONE	0.29	-0.8247
7	GARRI	FREEZONE	0.29	-0.8247
8	FREEZONE	KABASH220	0.0718	-7.0022
9	FREEZONE	KABASH220	0.0718	-7.0022
10	GARRI	EIDBABIKER	0.1931	-10.605
11	GARRI	EIDBABIKER	0.1931	-10.605
12	KABASH220	EIDBABIKER	0.196	-4.906
13	KABASH220	EIDBABIKER	0.196	-4.906
14	MARAWI	MARKHYT500	1.7584	-343.61
15	MARAWI	MARKHYT500	1.7584	-343.61
16	MARKHYT500	KABASHI500	0.0743	0.694
17	EIDBABIKER	KILO 10	0.242	-1.5866
18	EIDBABIKER	KILO 10	0.242	-1.5866
19	KILO 10	GIAD	0.2156	-4.5504
20	KILO 10	GIAD	0.2156	-4.5504

21	GIAD	HASAHESA	0.0105	-11.345
22	GIAD	HASAHESA	0.0105	-11.345
23	HASAHESA	MARINGAN	0.1808	-6.502
24	HASAHESA	MARINGAN	0.1808	-6.502
25	MARINGAN	SINNAR	0.2823	-9.9131
26	MARINGAN	SINNAR	0.2823	-9.9131
27	SINNAR	SINJA	0.0568	-6.4059
28	SINNAR	SINJA	0.0568	-6.4059
29	ROSAIRS	SINJA	0.0481	-23.859
30	ROSAIRS	SINJA	0.0481	-23.859
31	ROSAIRS	RANK	0.3215	-31.398
32	ROSAIRS	RANK	0.3215	-31.398
33	RABAK	RANK	0.0301	-33.076
34	RABAK	RANK	0.0301	-33.076
35	MASHKOR	RABAK	0.0634	-21.453
36	MASHKOR	RABAK	0.0634	-21.453
37	JABLAWLIA	MASHKOR	0.2924	-27.593
38	JABLAWLIA	MASHKOR	0.2924	-27.953
39	JAMMOEYA	JABLAWLIA	0.0293	-7.595
40	JAMMOEYA	JABLAWLIA	0.0293	-7.595
41	MARKHYAT	JAMMOEYA	0.4729	-5.6758
42	MARKHYAT	JAMMOEYA	0.4729	-5.6758
43	JABLAWLIA	GIAD	0.1042	-6.4883
44	JABLAWLIA	GIAD	0.1042	-6.4883
Total losses			10.286	-1463.816

Figure 4.2 show a graphic comparison between the losses in the lines before and after adding a small generation station.

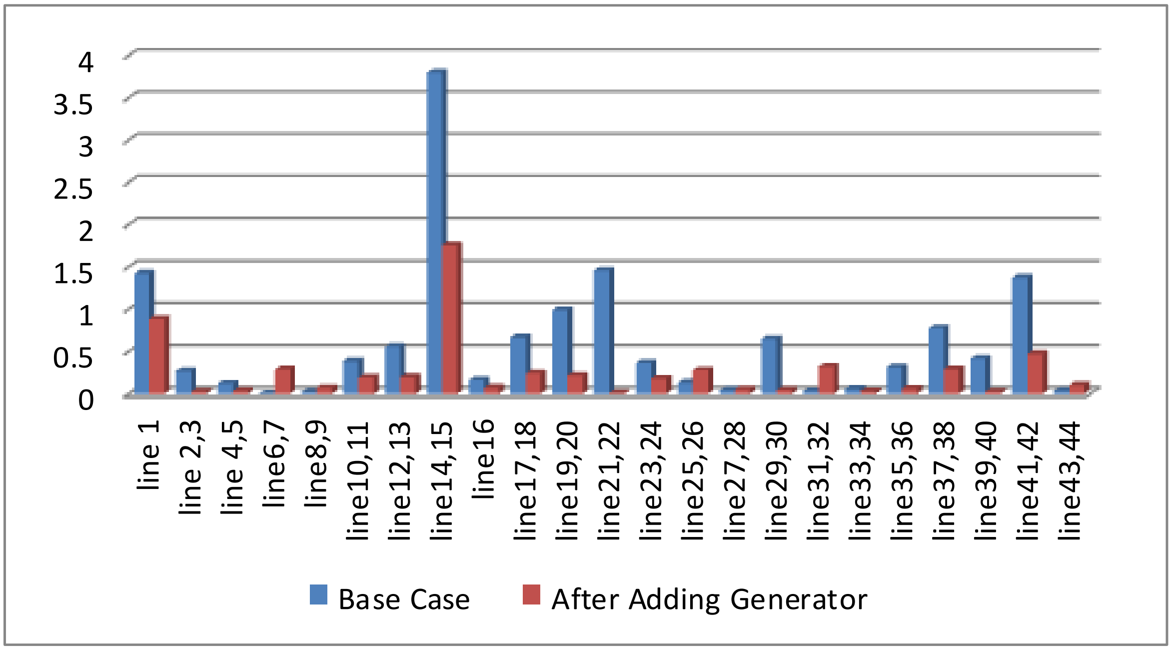

Figure 4.2: line losses in base case and after adding generator

4.4 Losses reduction using UPFC

First of all the weakest line in the network has been detected by using the line stability index and considered as the optimal location for adding the UPFC.

After the line stability index calculations have been done, the results were illustrated at table 4.7.

Table 4.7: Lmn calculations

Line No.	Vs (KV)	δs (deg.)	δr (deg.)	Qr(MVAr)	Lmn
1	500	0	-3.4	0	0
2	218.292	-7.1	-9	13	0.000351
3	218.292	-7.1	-9	13	0.000351
4	218.274	-9	-10	5	0.000134

5	218.274	-9	-10	5	0.000134
6	215.832	-10	-10	68.673	0.001868
7	215.832	-10	-10	68.673	0.001868
8	215.832	-10	-10.3	0	0
9	215.832	-10	-10.3	0	0
10	215.6	-10	-11.5	0	0
11	215.6	-10	-11.5	0	0
12	216.194	-10.3	-11.5	0	0
13	216.194	-10.3	-11.5	0	0
14	500	0	-6.9	0	0
15	500	0	-6.9	0	0
16	503.19	-6.9	-7.3	0	0
17	214.045	-11.5	-12.4	71	0.001978
18	214.045	-11.5	-12.4	71	0.001978
19	212.55	-12.4	-14.9	24	0.000903
20	212.55	-12.4	-14.9	24	0.000903
21	210.693	-14.9	-19.2	43	0.001673
22	210.693	-14.9	-19.2	43	0.001673
23	204.275	-19.2	-21	53	0.002148
24	204.275	-19.2	-21	53	0.002148
25	202.779	-21	-22.3	24	0.000983
26	202.779	-21	-22.3	24	0.000983
27	204.924	-22.3	-22.5	45	0.001791
28	204.924	-22.3	-22.5	45	0.001791
29	200	-20	-22.5	45	0.001913
30	200	-20	-22.5	45	0.001913
31	200	-20	-20.7	27	0.00086

32	200	-20	-20.7	27	0.00086
33	218.961	-19.9	-20.7	27	0.000718
34	218.961	-19.9	-20.7	27	0.000718
35	217.733	-18.1	-19.9	40	0.001086
36	217.733	-18.1	-19.9	40	0.001086
37	212.056	-15	-18.1	4.5	0.00013
38	212.056	-15	-18.1	4.5	0.00013
39	212.752	-13.7	-15	45	0.001274
40	212.752	-13.7	-15	45	0.001274
41	216.064	-11.6	-13.7	70	0.001934
42	216.064	-11.6	-13.7	70	0.001934
43	210.693	-14.9	-15	45	0.001286
44	210.693	-14.9	-15	45	0.001286

From above result it has been noticed that the weakest lines are (23, 24) which were connecting between HASAHISA and MARNGAN.

4.5 UPFC parameter

The load flow analysis has been used to determine the steady-state operating conditions of the power network, voltage magnitudes, and active /reactive power flow in the location which has been detected.

The voltage regulation (Vset) has been adjusted to a suitable value on which the minimum limit for losses has been reached. The UPFC parameters are shown in table 4.8.

Table 4.8: The UPFC parameters

P(MW)	Q(MVAR)	Vset (%)
60.557	0.073	97.85

After inserting the UPFC to the network with detected parameters, losses became **25.347** MW, and the affection on the line losses was illustrated on table 4.9.

Table 4.9: impact of adding UPFC on line losses

Line No.	With UPFC		Without UPFC	
	Ploss(MW)	Qloss(MVAr)	P loss(MW)	Q loss(Mvar)
1	1.4109	-231.19	1.4237	-231.03
2	0.2622	-26.201	0.2703	-26.15
3	0.2622	-26.201	0.2703	-26.15
4	0.1167	-21.721	0.1214	-21.682
5	0.1167	-21.721	0.1214	-21.682
6	0.0156	-0.8846	0.0077	-0.9197
7	0.0156	-0.8846	0.0077	-0.9197
8	0.0513	-7.0752	0.0247	-7.1637
9	0.0513	-7.0752	0.0247	-7.1637
10	0.3897	-9.6759	0.3857	-9.6225
11	0.3897	-9.6759	0.3857	-9.6225
12	0.5302	-3.644	0.5619	-3.1635
13	0.5302	-3.644	0.5619	-3.1635
14	3.8351	-320.57	3.8013	-319.19
15	3.8351	-320.57	3.8013	-319.19
16	0.1635	1.5736	0.164	1.5791
17	0.6254	0.1654	0.6675	0.3955
18	0.6254	0.1654	0.6675	0.3955
19	0.9976	-0.3264	0.9892	-0.212
20	0.9976	-0.3264	0.9892	-0.212
21	1.3702	-4.0078	1.4585	-2.761
22	1.3702	-4.0078	1.4585	-2.761

23	0.4066	-4.938	0.3687	-4.5017
24	0.4066	-4.938	0.3687	-4.5017
25	0.0864	-10.180	0.1323	-9.1914
26	0.0864	-10.180	0.1323	-9.1914
27	0.0082	-6.3108	0.0447	-5.7734
28	0.0082	-6.3108	0.0447	-5.7734
29	0.4067	-21.4	0.6503	-19.588
30	0.4067	-21.4	0.6503	-19.588
31	0.6592	-32.489	0.0333	-32.441
32	0.6592	-32.489	0.0333	-32.441
33	0.0333	-32.775	0.0597	-32.177
34	0.0333	-32.775	0.0597	-32.177
35	0.2813	-20.178	0.3176	-19.537
36	0.2813	-20.178	0.3176	-19.537
37	0.6894	-25.7	0.7777	-24.484
38	0.6894	-25.7	0.7777	-24.484
39	0.4247	-5.6882	0.4171	-5.5017
40	0.4247	-5.6882	0.4171	-5.5017
41	1.3217	-1.7395	1.3732	-1.3325
42	1.3217	-1.7395	1.3732	-1.3325
43	0.0086	-6.8023	0.0389	-6.4241
44	0.0086	-6.8023	0.0389	-6.4241

Figure 4.3 shows a graphic comparison between losses in the lines before and after adding UPFC.

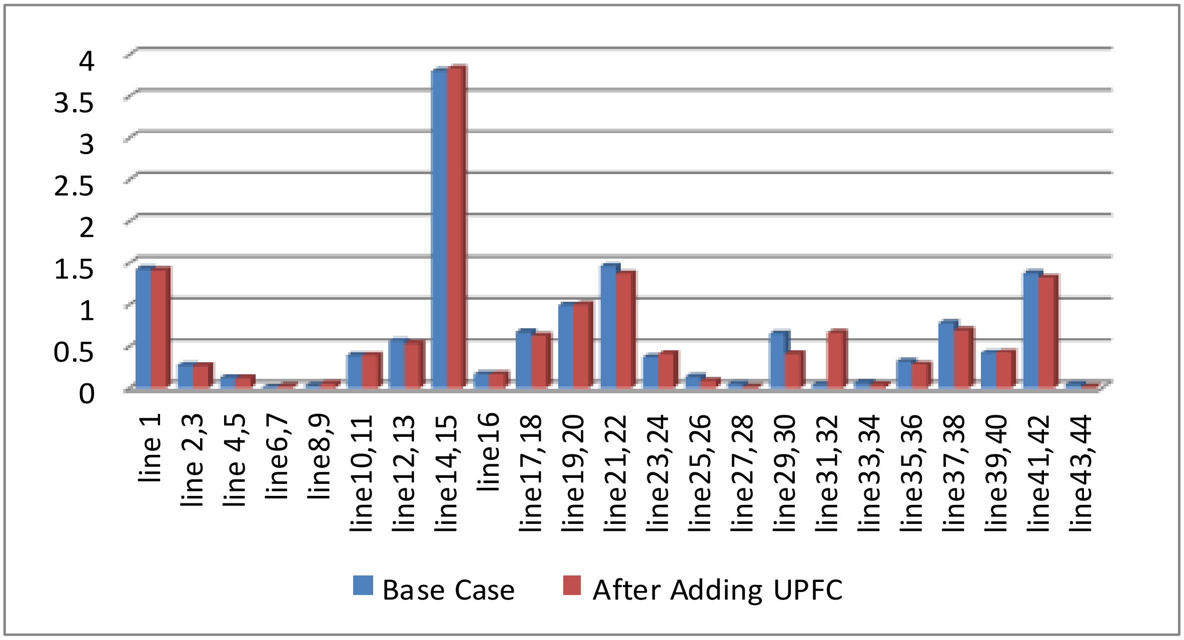

Figure 4.3: lines losses in base case and after adding UPFC

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this project two techniques have been used in order to reduce transmission losses in Sudanese electrical network.

NEPLAN software is used to simulate the Sudanese electrical grid and to obtain power flow results which were the main indicator to detect the weakest bus bar in the network.

The bus voltage limit violations are confined within ±5% of the nominal voltage.

The best location for adding small generation was MARNGAN and by adding generation station at it, the losses have been reduced by more than 50% of its value at base case.

The optimal location for UPFC is achieved by considering of the line stability index (Lmn) in order to detect the weakest line in network.

It has been found that the optimal location for generation and UPFC is the same.

A load flow analysis considering the minimization of active power losses as an objective has been developed to set the power flow parameters for the UPFC.

It has been noticed that UPFC reduced the total losses in the network, but on the other hand increased losses in some lines such as line (31&32), line (23&24), line (14&15) and line (6&7).

Now days Sudanese electrical company is prepare to add a new thermal power station in BAGEER with capacity 800 MW, which is near to MARENGAN, this proves that our results very close to reality even virtually identical.

5.2 Recommendation

1. In this project only the transmission parts (500 & 220 voltage levels) of Sudanese electrical grid has been taken as a case study, this can be extended for all parts and voltage level of network
2. UPFC devices have been studied. This can be extended for the placement of some other types of FACTS controllers, such as TCSC and SVC.
3. Many others techniques can be used to reduce losses such as RECONFIGURATION technique.

REFERENCES

[1] Engr. H. S. Labo, “Current status and future outlook of the transmission network”, Jan. 2010

[2] M S Bhalla, “Transmission and Distribution Losses (Power)”

[3] Reducing Technical and Non-Technical Losses in the Power Sector.

[4] Real Time Study on Technical Losses in Distribution System Mohsin Mahmood1, Om Shivam2, Pankaj Kumar3, Gopal Krishnan4 UG Scholar, Department of EEE, Dr. MGR Educational & Research Institute, Chennai 95, India ,PG Scholar (Part Time), Department of EEE, Dr. MGR Educational & Research Institute, Chennai-95, India4.

[5] Electrical power systems, DEBAPRIYA DAS.

[6] Power loss due to Corona on High Voltage Transmission Lines.

[7] Minimization of power loss in distribution networks by different techniques “international journal of electrical and electronics engineering 5:1 2010.”

[8] Technical and Non-Technical Losses in Power System and Its Economic Consequence in Indian Economy J.

[9] P.Kundur “Power System Stability and Control” McGraw-Hill, New York, 1994

[10] R.E. Brown ,Pan Jiuping, Feng Xiaoming, and K. Koultev, “Siting Distributed Generation to Defer T&D Expansion”, Transmission and Distribution Conference and Exposition, 2001

[11] P.P. Barker and R.W. de Mello,” Determining the Impact of Distributed Generation on Power System: Part1-Radial Distribution Systems”, 2000. Seattle Washington.

[12] S.K Salman,”The impact of Embedded Generation on Voltage Regulation and losses of Distribution Networks” London 1996.

[13] Flexible Ac Transmission Systems (FACTS) Edited by Yong Hua Song and Allan T. Johns Published by The Institution of Engineering and Technology, London, United Kingdom First edition ©1999 The Institution of Electrical Engineers.

[14] E. Ache, C.R. Fuerte-Esquivel, H. Ambriz-Perez, and C. Angeles-Camacho, “FACTS: Modeling and Simulation in Power Network”, Chichester, U.K.:Wiley, 2004.

[15] Modern Power System Analysis, D P Kothari, I J Nagrath

[16] “An Assessment of Voltage Stability based on Line Voltage Stability Indices and its Enhancement Using TCSC” Merlyn Mathew, Sudeshna Ghosh, D.Suresh Babu, Dr. A.A. Ansari