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CONTINGENCY AND SECURITY ANALYSIS FOR POWER SYSTEM NETWORK . CASE STUDY _ NEC GRID

التحليل الافتراضي لمنظومة القدرة الكهربائية
دراسة حالة الشبكة السودانية لنقل الكهرباء

A Thesis submitted in partial fulfillment of the requirements for the degree of M.Sc. in Electrical Engineering (POWER)

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DEDICATION

I would like to dedicate this research to My…

Parents…

Brothers…

Husband….

Sister…

All of my friends…

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I would like to acknowledge with gratitude the contributions of several individuals in the preparation of this research. First and foremost, I wish to thank Almighty Allah who gave me the courage and patience to carry out this work.

I would like also to express my deep thanks and great appreciation to my supervisor D.GEDANI OSMAN for support, guidance throughout this thesis.

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Abstract

The aim of this project is to investigate and understand the load flow analysis for power systems, during abnormal condition using (Ne plane) with the main focus on load flow analysis theories and computer application. The thesis define the power system security and the effect of load flow , contingency analysis to power system security , and how it effect of equipment of power system network .

The thesis investigate Sudan national electricity cooperation during big load period s , then it summaries load flow solution to prevent applied contingency outages to the network and gave a summary, for load flow solutions, to prevent systems from breakdowns , locate the week point, reduce losses and give reliable efficiency and economic operation .

تجريد

الهدف من هذا المشروع هو التحقق و فهم انسياب الاحمال و عمل تحليل افتراضي (افتراض حصول عطل في جزء مؤثر من الشبكة) بإستخدام برنامج (Ne plane) ، مع التركيز على نظريات انسياب الاحمال و التحليل الافتراضي و تطبيقات الحاسوب . تطرق البحث اولا على تعريف امن منظومة القدرة و تأثير انسياب الاحمال و التحليل الافتراضي على امن نظام الطاقة ثم اظهر كيفية تأثر معدات شبكة منظومة القدرة بإنسياب الاحمال و التحليل الافتراضي .

تطرق البحث لأطروحة مفهوم التحليل الافتراضي و بعض النظريات ، ثم درس البحث شبكة الشركة السودانية لنقل الكهرباء المحدودة في فترات الحمل الاقصى و خروج افتراضي لخط مؤثر في الشبكة و عمل محاكاة للشبكة بإستخدام برنامج (Ne plane) الحاسوبي ، ثم حددت الدراسة موقع و بيانات نقاط الضعف و المشاكل في الشبكة ثم اعطت ملخصا لحلول هذه المشاكل و نقاط الضعف لتقليل الفقد و للوصول لكفاءة و موثوقية عالية و تشغيل اقتصادي .

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LIST OF ABBREVIATIONS

Abbreviation	
SETCO	Sudanese electricity transmission line cooperation
SVCs	Static var combenstaors
AC	Alternative current
DMS	Distribution management system
DPF	Dispatcher power flow
EMS	Energy Management system
LFR	load Flow Result
VC	Voltage Control
AGC	Automatic Generation Control
OPF	On_line Optimal Power Flow

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Power system engineering is the central area of activity for power system planning, project engineering, operation and rehabilitation of power systems for electrical power supply. Power system engineering comprises the analysis, calculation and design of electrical systems and equipment, the setup of tender documents, the evaluation of offers and their technical and financial assessment and contract negotiations and award. It is seen as an indispensable and integral part of the engineering activities for feasibility studies, for planning and operating studies, for project engineering, for the development, extension and rehabilitation of existing facilities, for the design of network protection concepts and protective relay settings and also for clearance of disturbances.

The supply of electricity at competitive unit price, in sufficient quantity and quality, and with safe and reliable supply through reliable equipment, system structures and devices is of crucial importance for the economic development of industries, regions and countries. The planning of supply systems must take into account different boundary conditions, which are based on regional and structural consideration that in many cases have a considerable impact on the technical design. Given that, in comparison with all other industries, the degree of capital investment in electric utilities takes the top position , not only from the monetary point of view but also in terms of long term return of assets, it becomes clear that each investment decision requires particularly careful planning and investigation, to which power system engineering and power system planning contribute substantially.

The reliability of the supply is determined not only by the quality of the equipment but also by careful planning and detailed knowledge of power systems, together with a consistent use of relevant standards and norms, in particular IEC standards, national standards and norms as well as internal regulations. Furthermore, the mode of system operation must conform to the conditions specified by standards, including the planning process, manufacturing of equipment and commissioning. Just as faults in equipment cannot be totally excluded because of technical or human failure, likewise the equipment and installations cannot be

1.2 Electrical power system

Modern power systems are designed to operate efficiently to supply power on demand to various load centers with high reliability. The generating stations are often located at distant locations for economic, environmental and safety reasons. For example, it may be cheaper to locate a thermal power station at pithead instead of transporting coal to load centers. Hydropower is generally available in remote areas. A nuclear plant may be located at a place away from urban areas. Thus, a grid of transmission lines operating at high or extra high voltages is required to transmit power from the generating stations to the load centers.

In addition to transmission lines that carry power from the sources to loads, modern power systems are also highly interconnected for economic reasons. The interconnected systems benefit by:

(a) Exploiting load diversity

(b) Sharing of generation reserves

(c) Economy gained from the use of large efficient units without sacrificing reliability.

However, there is also a downside to ac system interconnection – the security can be adversely affected as the disturbances initiated in a particular area can spread and propagate over the entire system resulting in major blackouts caused by cascading outages. [6].

1.3 Problem Statement

The motivation for the study arises from the undergoing project to procure and install nine SVC compensation plants various substations in the national Grid. The sizing and location of the compensation was based on study commissioned by BCP Switzerland. Since the study was undertaken for the existing level of load and system topology of 2012 with a maximum of 1700 MW, the aim of this study is to analyze the impact and performance of the SVC size and location, the level of utilization and general impact on the network performance is to be assessed.

It was originally envisaged to carry out the studies for both 2013 and 2014, but since SVC project has fallen behind schedule and is not expected to be commissioned in 2013, the study concentrates only on the year 2014

1.4 Objectives

1. To carry load follows studies with and without the SVC equipment in place for level of load and system topology of the year 2016 under various system conditions of light and peak load.

2. To assess the system performance in light of the study result and comment on the SVC utilization and adequacy regarding size and location.

3. To comment on general weak points on the system which are not covered by SVC compensation under the present scope of supply of the ongoing project and which may benefit from such compensation in the future.

4. To comment on general weak points on the system this deemed to benefit from transmission and generation reinforcement rather than SVC equipment or any other form of reactive compensation

1.5 Project Layout

Chapter Two describes the structure of power system network in general while

Chapter Three gives the investigates the FACT devices technologies and the modeling of SVC.

Chapter Four presents and discuss the results of the studies on peak with and without SVC equipment , the impact upon increasing generation in Khartoum , the performance under special conditions , such as increase in the loading at Port- Sudan , load project at Port-Sudan , or a general outage of 70% of load in the network under Peak condition .Finally the conclusion and recommendations are presented in chapter 5

CHAPTER TWO

POWER SYSTEM SECURITY CONTINGENCY ANALYSIS

2.1 Introduction

System security was part of reliability assured at the system planning stage by providing a strong system that could ride out any "credible" disturbances without serious disruption. It is no longer economically feasible to design systems to this standard. At that time, power system operators made sure that sufficient spinning reserve was on line to cover unexpected load increases or potential loss of generation and to examine the impact of removing a line or other apparatus for maintenance. Whenever possible, the operator attempted to maintain a desirable voltage profile by balancing VARs in the system. Security monitoring is perceived as that of monitoring, through contingency analysis, the conditional transition of the system into an emergency state.

2. 2 Perspectives of Security Assessment

There is a need to clarify the roles of security assessment in the planning and real-time operation environments. The possible ambiguity is the result of the shift of focus from that of system robustness designed at the planning stage as part of reliability, to that of risk avoidance that is a matter operators must deal with in real time. The planner is removed from the time varying real world environment within which the system will ultimately function. The term "security" within a planning context refers to those aspects of reliability analysis that deal with the ability of the system, as it is expected to be constituted at some future time, to withstand unexpected losses of certain system components. Reliability has frequently been considered to consist of adequacy and security. Adequacy is the ability to supply energy to satisfy load demand. Security is the ability to withstand sudden disturbances. System operations is concerned with security as it is constituted at the moment, with a miscellaneous variety of elements out for maintenance, repair, etc., and exposed to environmental conditions that may be very different from the normal conditions considered in system planning. In operations, systems nearly always have less than their full complement of equipment in service. As a result, an operator must often improvise to improve security in ways that are outside the horizon of planners [2].

2. 3 Security Assessment Defined

Security assessment involves using available data to estimate the relative security level of the system currently or at some near-term future state. Approaches to security assessment are classified as either direct or indirect.

A) The direct approach:

This approach evaluates the likelihood of the system operating point entering the emergency state. It calculates the probability that the power System State will move from normal state to emergency state, conditioned on its current state, projected load variations, and ambient conditions. It is common practice to assess security by analyzing a fixed set of contingencies. The system is declared as insecure if any member of the set would result in transition to the emergency state. This is a limiting form of direct assessment, since it implies a probability of the system being in the emergency state conditioned on the occurrence of any of the defined contingencies.

B) The indirect approach:

Here a number of reserve margins are tracked relative to predetermined levels deemed adequate to maintain system robustness vis-a-vis pre-selected potential disturbances. An indirect method of security assessment defines a set of system “security” variables that should be maintained with predefined limits to provide adequate reserve margins.

Once derived for a given system configuration, they could be applied without further power flow analysis to determine post-contingency line loading even, by superposition, for multiple contingencies. Such a computationally simple method of analysis made on-line contingency assessment practicable for “thermal security,” where reactive flows were not of concern.

More recently, post-contingency voltage behavior has become a prominent element in security assessment. Assessment of “voltage security” is a complex process because the behavior of a system undergoing voltage collapse cannot be completely explained on the basis of static analysis alone. [2].

2.4 Implications of Security

The trend towards reducing the costs associated with robust systems has lead to heightened requirements of active security control. This necessitates an increase in the responsibilities of the system operator.

2.5 Security Analysis

On-line security analysis and control involve the following three ingredients:

- Monitoring
- Assessment
- Control

The following framework relates the three modules:

Step 1. Security Monitoring: Identify whether the system is in the normal state or not using real-time system measurements. If the system is in an emergency state, go to step 4. If load has been lost, go to step 5.

Step2. Security Assessment: If the system is in the normal state, determine whether the system is secure or insecure with respect to a set of next contingencies.

Step 3. Security Enhancement: If insecure, determine what action to take to make the system secure through preventive actions.

Step 4. Emergency Control: Perform proper corrective action to bring the system back to the normal state following a contingency, which causes the system to enter an emergency state.

Step 5. Restorative Control: Restore service to system loads.

Security analysis and control have been implemented in modem energy control centers

The monitoring module starts with real-time measurements of physical quantities such as line power and current flows, power injections, bus voltage magnitudes, and the status of breakers and switches. Measured data are telemeter from various locations to the control center computer. The available data are further processed to obtain an estimate of the system state variables (bus voltage magnitudes and phase angles for normal steady state). State estimation is a mathematical procedure for computing the “best” estimate of the state variables of the system based on the available data, which are in general corrupted with errors.

It needs a set of contingencies to assess whether a normal operating state is secure or not. The contingency selection process employs a scheme to select a set of important and plausible disturbances. Security assessment involves primarily steady-state power flow analysis. Stability constraints are expressed in terms of the limits on line flows and bus voltages. As a result, to assess system response to contingencies, a contingency evaluation is carried out using on-line power flows. The on-line power flow uses the actual power flow model of the system under study (from the state estimation solution) together with a system representation of the unmonitored network and neighboring systems, i.e., an external network model.

Since the contingencies are future events, a bus-load forecast is needed.

Certain implementations of the state estimator render the external model observable by strategic placement of pseudo-measurements. Then the state estimate is performed on the entire model in one step. [4].

2.6 The Energy Control Center

The following criteria govern the operation of any electric power system

- ❖ Safety
- ❖ Quality
- ❖ Reliability
- ❖ Economy

The first criterion is the most important consideration and aims to ensure the safety of personnel, environment, and property in every aspect of system operations. Quality is defined in terms of variables, such as frequency and voltage that must conform to certain standards to accommodate the requirements for proper operation of all loads connected to the system.

Reliability of supply does not have to mean a constant supply of power, but it means that any break in the supply of power is one that is agreed to and tolerated by both supplier and consumer of electric power. Making the generation cost and losses at a minimum motivates the economy criterion while mitigating the adverse impact of power system operation on the environment.

Within an operating power system, the following tasks are performed in order to meet the preceding criteria:

- ❖ Maintain the balance between load and generation.
- ❖ Maintain the reactive power balance in order to control the voltage profile.

❖ Maintain an optimum generation schedule to control the cost and environmental impact of the power generation.

❖ Ensure the security of the network against credible contingencies.

This requires protecting the network against reasonable failure of equipment or outages.

The fact that the state of the power network is ever changing because loads and networks configuration change, makes operating the system difficult.

Heavier loading of tie-lines which were originally built to improve reliability, and were not intended for normal use at heavy loading levels, has increased interdependence among neighboring utilities. With greater emphasis on economy, there has been an increased use of large economic generating units. This has also affected reliability.

These trends allow systems to be operated much closer to security limits (thermal, voltage and stability). On some systems, transmission links are being operated at or near limits 24 hours a day, with the following consequences

The trends have adversely affected system dynamic performance.

A power network stressed by heavy loading has a substantially different response to disturbances from that of a non-stressed system.

The potential size and effect of contingencies has increased dramatically. When a power system is operated closer to the limit, a relatively small disturbance may cause a system upset. The situation is further complicated by the fact that the largest size contingency is increasing. Thus, to support operating functions many more scenarios must be anticipated and analyzed. In addition, bigger areas of the interconnected system may be affected by a disturbance.

Two control centers are normally implemented in an electric utility, one for the operation of the generation-transmission system, and the other for the operation of the distribution system. We refer to the former as the energy management system (EMS), while the latter is referred to as the distribution management system (DMS). The two systems are intended to help the dispatchers in better monitoring and control of the power system. The simplest of such systems perform data acquisition and supervisory control, but many also have sophisticated power application functions available to assist the operator.

An energy control center represents a large investment by the power system ownership. Major benefits flowing from the introduction of this system include more reliable system operation and improved efficiency of usage of generation resources. In addition, power system operators are offered more in-depth information quickly. It has been suggested that at Houston Lighting & Power Co., system dispatchers' use of network application functions (such as Power Flow, Optimal Power Flow, and Security Analysis) has resulted in considerable economic and intangible benefits. [4].

2.7 Overview of EMS Functions

System dispatchers at the EMS are required to make short-term (next day) and long-term (prolonged) decisions on operational and outage scheduling on a daily basis. Moreover, they have to be always alert and prepared to deal with contingencies that may arise. Many software and hardware functions are required as operational support tools for the operator. Broadly speaking, we can classify these functions in the following manner:

- Base functions
- Generation functions
- Network functions
- Each of these functions is discussed briefly in this section.

The required base functions of the EMS include: The ability to acquire real time data from monitoring equipment throughout the power system.

Process the raw data and distribute the processed data within the central control system.

The data acquisition function (DA) acquires data from remote terminal units (RTUs) installed throughout the system using special hardware connected to the real time data servers installed at the control center. Alarms that occur at the substations are processed and distributed by the DA function. In addition, protection and operation of main circuit breakers, some line isolators, transformer tap changers and other miscellaneous substation devices are provided with a sequence of events time resolution.

A) Data Acquisition

The data acquisition function collects, manages, and processes information from the RTUs by periodically scanning the RTUs and presenting the raw analog data and digital status points to a data processing function. This function converts analog values into engineering units and checks the digital status points for change since the previous scan so that an alarm can be raised if status has changed. Computations can be carried out and operating limits can be applied against any analog value such that an alarm message is created if a limit is violated.

B)Supervisory Control

Supervisory control allows the operator to remotely control all circuit breakers on the system together with some line isolators. Control of devices can be performed as single actions or a line circuit can be switched in or out of service.

C) Alarm Processor

The alarm processor software is responsible to notify the operator of changes in the power system or the computer control system. Many classification and detection techniques are used to direct the alarms to the appropriate operator with the appropriate priorities assigned to each alarm.

D) Logical Alarming

This predetermines a typical set of alarm operations, which would result from a single cause. For example, a faulted transmission line would be automatically taken out of service by the operation of protective and tripping relays in the substation at each end of the line and the automatic opening of circuit breakers. The coverage would identify the protection relays involved, the trip relays involved and the circuit breakers that open.

E) Sequence of Events Function

The sequence of events function is extremely useful for post-mortem analysis of protection and circuit breaker operations. Every protection relay, trip relay, and circuit breaker is designated as a sequence of events digital point.

This data is collected, and time stamped accurately so that a specified resolution between points is possible within any substation and across the system.

Sequence of events data is buffered on each RTU until collected by data acquisition automatically or on demand.

F) Historical Database

This function takes any data obtained by the system and stores it in a historical database. It then can be viewed by a tabular or graphical trend display. The data is immediately stored within the on-line system and transferred to a standard relational data base system periodically. Generally, this function allows all features of such database to be used to perform queries and provide reports.

G) Automatic Data Collection

This function is specified to define the process taken when there is a major system disturbance. Any value or status monitored by the system can be defined as a trigger. This will then create a disturbance archive, which will contain a pre-disturbance and a post-disturbance snapshots to be produced.

H) Load Shedding Function

This facility makes it possible to identify that particular load block and instruct the system to automatically open the correct circuit breakers involved.

2.8 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 readjust and remain within acceptable limits, or that 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 readjustment 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.

The motivation to use contingency analysis tools in an EMS is that when forewarned the operator can initiate preventive action before the event to avoid problems should an outage take place. From an economic point of view, The operator strives to avoid overloads that might directly damage equipment, or worse, might cause the system to lose a number of components due to relay action and then cause system-wide outages.

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.

The operator must play an active role in maintaining system security. The first step is to perform contingency analysis studies frequently enough to assure that system conditions have not changed significantly from the last execution. The outcome of contingency analysis is a series of warnings or alarms to the operators alerting them that loss of component A will result in an overload of PA on line T1. To achieve an accurate picture of the system's exposure to outage events several points need to be considered: [4].

A) System Model

Contingency analysis is carried out using a power flow model of the system. Additional information about system dynamics is needed to assess stability as well. Voltage levels and the geographic extent to include in the model are issues to be considered. In practice, all voltage levels that have any possibility of connecting circuits in parallel with the high voltage system are included. This leaves out those that are radial to it such as distribution networks.

B) Contingency Definition

Each modeled contingency has to be specified on its own. The simplest definition is to name a single component. This implies that when the model of the system is set up, this contingency will be modeled by removing the single component specified. Another important consideration is the means of specifying the component outage. The component can be specified by name, such as a transmission line name, or more accurately, a list of circuit breakers can be specified as needing to be operated to correctly model the outage of the component. Contingencies that require more than one component to be taken out together must be defined as well.

C) Double Contingencies

A double contingency is the overlapping occurrence of two independent contingent events. To be specific, one outside event causes an outage and while this outage is still in effect, a second totally independent event causes another component to be taken out. The overlap of the two outages often causes overloads and under-voltages that would not occur if either happened separately.

D) Contingency List

Generally, contingency analysis programs are executed based on a list of valid contingencies. The list might consist of all single component outages including all transmission lines, transformers, substation buses, and all generator units. For a large interconnected power system just this list alone could result in thousands of contingency events being tested.

E) Speed

Generally, operators need to have results from a contingency analysis program in the order of a few minutes up to fifteen minutes. Anything longer means that the analysis is running on a system model that does not reflect current system status and the results may not be meaningful.

2.9 Historical Methods of Contingency Analysis

There is a conflict between the accuracy with which the power system is modeled and the speed required for modeling all the contingencies specified by the operator. If the contingencies can be evaluated fast enough, then all cases specified on the contingency list are run periodically and alarms reported to the operators. This is possible if the computation for each outage case can be performed very fast or else the number of contingencies to be run is very small.

The number of contingency cases to be solved in common energy management systems is usually a few hundred to a few thousand cases. This coupled with the fact that the results are to be as accurate as if run with a full power flow program make the execution of a contingency analysis program within an acceptable time frame extremely difficult.

2.10 Selection of Contingencies to be studied

A full power flow must be used to solve for the resulting flows and voltages in a power system with serious reactive flow or voltage problems when an outage occurs. In this case, the operators of large systems looking at a large number of contingency cases may not be able to get results soon enough. A significant speed increase could be obtained by simply studying only the important cases, since most outages do not cause overloads or under-voltages.

2.10.1 Fixed List

Many operators can identify important outage cases and they can get acceptable performance. The operator chooses the cases based on experience and then builds a list for the contingency analysis program to use. It is possible that one of the cases that were assumed to be safe may present a problem because some assumptions used in making the list are no longer true.

2.10.2 Indirect Methods (Sensitivity-Based Ranking Methods)

An alternative way to produce a reduced contingency list is to perform a computation to indicate the possible bad cases and perform it as often as the contingency analysis itself is run. This builds the list of cases dynamically and the cases that are included in the list may change as conditions on the power system change. This requires a fast approximate evaluation to discover those outage cases that might present a real problem and require further detailed evaluation by a full power flow. Normally, a sensitivity method based on the concept of a network performance index is employed. The idea is to calculate a scalar index that reflects the loading on the entire system.

2.10.3 Comparisons of Direct and Indirect Methods

Direct methods are more accurate and selective than the indirect ones at the expense of increased CPU requirements. The challenge is to improve the efficiency of the direct methods without sacrificing their strengths. Direct methods assemble severity indices using monitored quantities (bus voltages, branch flows, and reactive generation), that have to be calculated first. In contrast, the indirect methods calculate severity indices explicitly without evaluating the individual quantities. Therefore, indirect methods are usually less computationally demanding. Knowing the individual monitored quantities enables one to calculate severity indices of any desired complexity without significantly affecting the numerical performance of direct methods. Therefore, more attention has been paid recently to direct methods for their superior accuracy (selectivity). This has lead to drastic improvements in their efficiency and reliability.

2.10.4 Fast Contingency Screening Methods

To build a reduced list of contingencies one uses a fast solution and ranks the contingencies according to its results. Direct contingency screening methods can be classified by the imbedded modeling assumptions. Two distinct classes of methods can be identified:

a) Linear methods specifically intended to screen contingencies for possible real power (branch MW overload) problems.

b) Nonlinear methods intended to detect both real and reactive power problems (including voltage problems).

Bounding methods offer the best combination of numerical efficiency and adaptability to system topology changes. These methods determine the parts of the network in which branch MW flow limit violations may occur.

The zero mismatches (ZM) method extends the application of localization ideas from contingency screening to full iterative simulation. Advantage is taken of the fact that most contingencies significantly affect only small portions (areas) of the system. Significant mismatches occur in only very few areas of

the system being modeled. There is a definite pattern of very small mismatches throughout the rest of the system model. This is particularly true for localizable contingencies, e.g., branch outages, bus section faults. Consequently, it should be possible to utilize this knowledge and significantly speed up the solution of such contingencies. The following is a framework for the approach:

1) Bound the outage effects for the first iteration using for example a version of the complete boundary.

2) Determine the set of buses with significant mismatches resulting from angle and magnitude increments.

3) Calculate mismatches and solve for new increments.

4) Repeat the last two steps until convergence occurs.

The main difference between the zero mismatch and the concentric relaxation methods is in the network representation. The zero mismatch method uses the complete network model while a small cutoff representation is used in the latter one. The zero mismatch approach is highly reliable and produces results of acceptable accuracy because of the accuracy of the network representation and the ability to expand the solution to any desired bus. [5].

2.11 Optimal preventive and corrective action

For contingencies found to cause overloads, voltage limit violations, or stability problems, preventive actions are required. If a feasible solution exists to a given security control problem, then it is highly likely that other feasible solutions exist as well. In this instance, one solution must be chosen from among the feasible candidates. If a feasible solution does not exist, a solution must be chosen from the infeasible candidates.

Security optimization is a broad term to describe the process of selecting a preferred solution from a set of (feasible or infeasible) candidate solutions. The term Optimal Power Flow (OPF) is used to describe the computer application that performs security optimization within an Energy Management System.

2.12 Optimization in Security Control

To address a given security problem, an operator will have more than one control scheme. Not all schemes will be equally preferred and the operator will thus have to choose the best or "optimal" control scheme. It is desirable to find the control actions that represent the optimal balance between security, economy, and other operational considerations. The need is for an optimal solution that takes all operational aspects into consideration. Security optimization programs may not have the capability to incorporate all operational considerations into the solution, but this limitation does not prevent security optimization programs from being useful.

The solution of the security optimization program is called an "optimal solution" if the control actions achieve the balance between security, economy, and other operational considerations. The main problem of security optimization seeks to distinguish the preferred of two possible solutions. A method that chooses correctly between any given pair of candidate solutions is capable of finding the optimal solution out of the set of all possible solutions.

There are two categories of methods for distinguishing between candidate solutions: one class relies on an objective function, the other class relies on rules.

2.13 Optimization Subject to Security Constraints

The conventional OPF formulation seeks to minimize an objective function subject to security constraints, often presented as "hard constraints," for which even small violations are not acceptable. A purely analytical formulation might not always lead to solutions that are optimal from an operational perspective. Therefore, the OPF formulation should be regarded as a framework in which to understand and discuss security optimization problems, rather than as a fundamental representation of the problem itself.

2.13.1 Security Optimization for the Base Case State

Consider the security optimization problem for the base case state ignoring contingencies. The power system is considered secure if there are no constraint violations in the base case state. Thus any control action required will be corrective action. The aim of the OPF is to find the optimal corrective action.

When the objective function is defined to be the MW production costs, the problem becomes the classical active and reactive power constrained dispatch. When the objective function is defined to be the active power transmission losses, the problem becomes one of active power loss minimization.

2.13.2 Security Optimization for Base Case and Contingency States

Now consider the security optimization problem for the base case and contingency states. The power system is considered secure if there are no constraint violations in the base case state, and all contingencies are manageable with post-contingent control action. In general, this means that base case control action will be a combination of corrective and preventive actions and that post contingent control action will be provided in a set of contingency plans. The aim of the OPF is then to find the set of base case control actions plus contingency plans that is optimal.

When an operator is not willing to take preventive action, then all contingencies must be addressed with post-contingent control action. The absence of base case control action decouples the multiple network problems into a single network problem for each contingency. When an operator is not willing to rely on post-contingency control action, then all contingencies must be addressed with preventive action. In this instance, the cost of the preventive action is preferred over the risk of having to take control action in the post contingency state. The absence of post-contingency control action means that the multiple network problem may be represented as the single network problem for the base case, augmented with post-contingent constraints.

Security optimization for base case and contingency states will involve base case corrective and preventive action, as well as contingency plans for post-contingency action. To facilitate finding the optimal solution, the objective function and rules that reflect operating policy are required. For example, if it is preferred to address contingencies with post-contingency action rather than preventive action, then post-contingent controls may be modeled as having a lower cost in the objective function. Similarly, a preference for preventive action over contingency plans could be modeled by assigning the post contingent controls a higher cost than the base case controls. Some contingencies are best addressed with post-contingent network switching. This can be modeled as a rule that for a given contingency, switching is to be considered before other post-contingency controls.

2.13.3 Soft Constraints

Another form of security optimization involves ‘‘soft” security constraints that may be violated but at the cost of incurring a penalty. This is a more sophisticated method that allows a true security/economy trade-off. Its disadvantage is requiring a modeling of the penalty function consistent with the objective function. When a feasible solution is not possible, this is perhaps the best way to guide the algorithm toward finding an “optimal infeasible” solution.

2.13.4 Security versus Economy

As a general rule, economy must be compromised for security. However, in some cases security can be traded off for economy. If the constraint violations are small enough, it may be preferable to tolerate them in return for not having to make the control moves. Many constraint limits are not truly rigid and can be relaxed. Thus, in general, the security optimization problem seeks to determine the proper balance of security and economy. When security and economy are treated on the same basis, it is necessary to have a measure of the relative value of a secure, expensive state relative to a less secure, but also less expensive state.

2.13.5 In feasibility

If a secure state cannot be achieved, there is still a need for the least insecure operating point. For OPF, this means that when a feasible solution cannot be found, it is still important that OPF reach a solution, and that this solution be “optimal” in some sense, even though it is infeasible. This is especially appropriate for OPF problems that include contingencies in their definition. The OPF program needs to be capable of obtaining the “optimal infeasible” solution. There are several approaches to this problem. Perhaps the best approach is one that allows the user to model the relative importance of specific violations, with this modeling then reflected in the OPF solution. This modeling may involve the objective function (i.e., penalty function) or rules, or both.

2.14 The Time Variable

The preceding discussion assumes that all network states are based on the same (constant) frequency, and all transient effects due to switching and outages are assumed to have died out. While bus voltages and branch flows are, in general, sinusoidal functions of time, only the amplitudes and phase relationships are used to describe network state. Load, generation, and interchange schedules change slowly with time, but are treated as constant in the steady state approximation. There are still some aspects of the time variable that need to be accounted for in the security optimization problem.

2.14.1 Time Restrictions on Violations and Controls

The limited amount of time to correct constraint violations is a security concern. This is because branch flow thermal limits typically have several

levels of rating (normal, emergency, etc.), each with its maximum time of violation. (The higher the rating, the shorter the maximum time of violation.)
Voltage limits have a similar rating structure and there is very little time to recover from a violation of an emergency voltage rating.
Constraint violations need to be corrected within a specific amount of time. This applies to violations in contingency states as well as actual violations in the base case state. Base case violations, however, have the added seriousness of the elapsed time of violation: a constraint that has been violated for a period of time has less time to be corrected than a constraint that has just gone into violation.
Delay times for switching capacitors and reactors and transformer tap changing mechanisms can preclude the immediate correction of serious voltage violations. If the violation is severe enough, slow controls that would otherwise be preferred may be rejected in favor of fast, less preferred controls. When the violation is in the contingency state, the time criticality may require the solution to select preventive action even though a contingency plan for post-contingent corrective action might have been possible for a less severe violation. [2].

2.14.2 Time in the Objective Function

It is common for the MW production costs to dominate the character of the objective function for OPF users. The objective function involves the time variable to the extent that the OPF is minimizing a time rate of change. This is also the case when the OPF is used to minimize the cost of imported power or active power transmission losses. Not all controls in the OPF can be “costs” in terms of dollars per hour. The start-up cost for a combustion turbine, for example, is expressed in dollars, not dollars per hour. The costing of reactive controls is even more difficult, since the unwillingness to move these controls is not easily expressed in either dollars or dollars per hour. OPF technology requires a single objective function, which means that all

Control costs must be expressed in the same units. There are two approaches to this problem:

Simply adjust the objective function empirically so that the OPF provides acceptable solutions. This method can be regarded as an example of either of the first two approaches [5].

2.15 Using an Optimal Power Flow Program

OPF programs are used both in on-line and in off-line (study mode) Studies. The two modes are not the same.

2.15.1 On-line Optimal Power Flow

The solution speed of an on-line OPF should be high enough so that the program converges to a solution before the power system configuration has changed appreciably. Thus the on-line OPF should be fast enough to run several times per hour. The values of the algorithm's input parameters should be valid over a wide range of operating states, such that the program continues to function as the state of the system changes. Moreover, the application needs to address the correct security optimization problem and that the solutions conform to current operating policy.

2.15.2 Advisory Mode versus Closed Loop Control

On-line OPF programs are implemented in either advisory or closed loop mode. In advisory mode, the control actions that constitute the OPF solution are presented as recommendations to the operator. For closed loop

OPF, the control actions are actually implemented in the power system, typically via the SCADA subsystem of the Energy Management System. The advisory mode is appropriate when the control actions need review by the dispatcher before their implementation. Closed loop control for security optimization is appropriate for problems that are so well defined that dispatcher review of the control actions is not necessary. An example of closed loop on-line OPF is the Constrained Economic Dispatch (CED) function. Here, the constraints are the active power flows on transmission lines, and the controls are the MW output of generators on automatic generation control (AGC). When the conventional

2.15.3 Defining the Real-time Security Optimization Problem

As the power system state changes through time, the various aspects of the security optimization problem definition can change their relative importance. For example, concern for security against contingencies may be a function of how secure the base case is. If the base case state has serious constraint violations, one may prefer to concentrate on corrective action alone, ignoring the risk of contingencies. In addition, the optimal balance of security and economy may depend on the current security state of the power system.

During times of emergency, cost may play little or no role in determining the optimal control action. Thus the security optimization problem definition itself can be dynamic and sometimes not well defined.

2.16 Dynamic Security Analyses

The definition of security is “the prevention of cascading outages when the bulk power supply is subjected to severe disturbances.” To assure that cascading outages will not take place, the power system is planned and operated such that the following conditions are met at all times in the bulk power supply:

A) No equipment or transmission circuits are overloaded;

B) No buses are outside the permissible voltage limits (usually within +5 percent of nominal);

Generally, security analysis is concerned with the system's response to disturbances. In steady-state analysis the transition to a new operating

Condition is assumed to have taken place, and the analysis ascertains that operating constraints are met in this condition (thermal, voltage, etc.). In dynamic security analysis the transition itself is of interest, i.e., the analysis checks that the transition will lead to an acceptable operating condition. Examples of possible concern include loss of synchronism by some generators, transient voltage at a key bus (e g , a sensitive load) falling below a certain level, and operation of an out-of-step relay resulting in the opening of a heavily loaded tie-line.

Normally, any loss of synchronism will cause additional outages thus making the present steady-state analysis of the post-contingency condition inadequate for unstable cases. It is clear that dynamic analysis is needed.

For dynamic security analysis, contingencies are considered in terms of the total disturbance. All faults can be represented as three phase faults, with or without impedances, and the list of contingencies is a list of locations where this can take place. This is a different way of looking at contingencies where the post-contingency outages are determined by the dynamics of the system including the protection system. Obviously, if all possible locations are considered, this list can be very large [2].

The stability mechanism that causes the outages is referred to as the “mode of disturbance.” A number of modes exist. A single generating unit may go out of synchronism on the first swing (cycle). A single unit may lose synchronism after several cycles, up to a few seconds. Relays may operate to cause transmission line outages. Finally, periodic oscillations may occur between large areas of load and/or generation. These oscillations may continue undammed to a point of loss of synchronism. All of these types of events are called modes of disturbances

CHAPTER THREE

POWER FLOW AND VOLTAGE CONTROL

3.1 Introduction

Modern power system is design to operate efficiently to supply power on demand to various load centers with high reliability. The generating stations are often located at distant locations for economic, environmental and safety reasons. Nuclear plants may be located at a place away from urban areas[3]

Transmission line that carry power from the sources to load, modern power systems are also highly interconnected for economic reasons. The interconnected system benefit by:

a- Exploiting load diversity.

b- Sharing of generation reserves.

c- Economy gained from the use of large efficient units without sacrificing reliability.

3.2 Power Flow Control

The power system operator has the following means to control system power flows:

1- Prime mover and excitation control of generations.

2- Switching of shunt capacitor banks, shunt reactors

3- FACTS based technology.

4- Control of tap-changing and regulating transformers.

3.3 Reactive power and voltage control

For efficient and reliable operation of power system, the control of voltage and reactive power should satisfy the following objective:

a- Voltage at terminal of all equipment in the system is within acceptable limits.

b- Systems stability is enhanced to maximize utilization of the transmission system.

3.3.1 Production and absorption of reactive power

Underground cables, owing to their high capacitance, have high natural loads they are always loaded below their natural load, and hence generate power under all operating condition.

Loads normally absorb reactive power, a typical load bus supplied buy a power system is composed of a large number of devices. The composition change depending on the day, season, and weather conditions. The composite characteristics are normally such that a load bus absorbs reactive power. Both active power and reactive power of the composite loads vary as a function of the voltage magnitude. Loads at low-lagging power factors cause excessive voltage drops in the transmission network and are uneconomical to supply. Industrial consumers are normally charge for a reactive as well as active power; this gives them an incentive to improve the load power factor by using shunt capacitors. Compensating devices are usually added to supply or absorb reactive power and thereby control the reactive power balance in the desired manner. In what fallows, we will discuss the characteristics of these devices and the principle of applications[3].

3.4 Methods of Voltage Control

The control voltage level is accomplished by controlling the production, absorbing, and flow of reactive power at all levels in the system. The generating units provide the basic of voltage control; the automatic voltage regulators control field excitation to maintain a scheduled voltage at the terminal of the generators. Additional means are usually required to control voltage throughout the system. The devices used for this purpose may be classified as follows:

a- Source or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs).

b- Line reactance compensators, such as series capacitors.

c- Regulating transformers, such as tap-changing transformers and boosters

Shunt capacitors and reactors, and series capacitors provide passive compensation. They are either permanently connected to the transmission and distribution system, or switched; they contribute to voltage control by modifying the network characteristics. Synchronous condensers and SVCs provide active compensation; the reactive power absorb/supplied by them is automatically adjusted so as to maintain voltages of the buses to which they are connected. Together with the generating units, they establish voltage at specific point in the system. Voltage at other locations in the system is determined by active and reactive power flows through various circuit elements, including the passive compensating devices.

The following is a description of the basic characteristics and forms of application of deices commonly used for voltage and reactive power control[3].

3.5 flexible AC transmission system controllers general description

The large interconnected transmission networks are susceptible to faults caused by lighting discharges and decrease in insulation clearances by undergrowth. The power flow in a transmission line is determined by Kirchhoff's laws for specified power injections at a various nodes. The generation pattern in a deregulated environment also tends to be variable. Thus, the power in a transmission line can vary under normal, steady state conditions.

The increase in the loading of the transmission lines sometimes can lead to voltage collapse due to the shortage of a reactive power delivered at the load centers. This is due to the increased consumption of the reactive power in the transmission network and the characteristics of the load. The factors mentioned in the previous paragraphs point to the problems faced in maintaining economic and secure operation of large interconnected systems. The problems are eased if sufficient margins can be maintained. This is not feasible due to the difficulties in the expansion of the transmission network caused by economic and environmental reasons. The required safe operating margin can be substantially reduced by the introduction of fast dynamic control over reactive and active power by high power electronic controllers.

This can make the AC transmission network flexible to adapt to the changing conditions caused by contingencies and load various[3].

Flexible AC transmission system (FACTS) is defined as alternating current transmission systems incorporating power electronics _based and other static controllers to enhance controllability and increased power transfer capability.

3.5.1 Classification of the FACT controllers:-

The FACT controllers can be classified **(**depending on the power electronic devices used in the control).as:-

1. shunt connected controllers.
2. series connected controllers
3. combined series series controllers
4. combined shunt series controllers

3.5.2 The VSC based FACTS controllers

1- Static synchronous compensator (STATCOM) (shunt connected)

2- Static synchronous series compensator (SSSC). (series connected)

3- Interline power flow controller (IPFC) (combined series _ series)

4- Unified power flow controller (UPFC) (combined shunt series.

3.5.3 The special purpose of FACTS controllers

Some of the special purpose of FACTS controllers are

a- thyrister controller Braking Resistor

b- Thyrister controller voltage limiter

c- thyrister controller voltage regulator

d- interphase power controller

e- NGH-SSR damping

The facts controllers based on VSC have several advantage over the variable impedance type[3].

3.5.4 The benefits due to FACTS controllers

The benefits due to FACTS controllers are listed below:-

1- They contribute to optimal system operation by reducing power losses.

2- The power in critical lines can be enhanced as the operating margins can be reduced due to fast controllability.

3- The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by outages.

4- The steady state or small signal stability region can be increased by providing auxiliary stability controllers to damp low frequency oscillation.

5- FACTs controllers such as TCSC can counter the problem of synchronous Resonance (SSR)

6- The problem of voltage actuations' and in particular, dynamic over voltages can be overcome by FACTS controllers.

3.5.5 FACTS controllers Benefit

Primarily, the FACTS controllers provide voltage support at critical buses in the system (with shunt connected controllers) and regulate power flow in critical lines (with series connected controllers). Both voltage and power flow are controlled by the combined series and shunt controller (UPFC). The power electronic control is quite fast and this enables regulation both.

Under steady state and dynamic conditions (when the system is subjected to disturbances). The benefits dude to FATCTS controllers are listed below.

1- They contribute to optimal system operation by reducing power losses and improving voltage profile.

2- The power flow in critical lines can be enhanced as the operating margins can be reduced due to fast controllability. In general, the power carrying capacity of lines can be increased to values up to the thermal limits (imposed by current carrying capacity of the conductors).

3- The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.

4- The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp frequency oscillations.

5- FACTS controllers such as TCSC can counter the problem of Sub-synchronous Resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal stations (with turbo generators).

6- The problem of voltage fluctuation and in particular, dynamic over voltages can be overcome by FACTS controllers.

The capital investment and the operating costs (essentially the cost of power losses and maintenance) are offset against the benefits provided by the FACTS controllers and the 'payback period' is generally used as an index in the planning. The major issue in the deployment of FACTS controllers are

(a) the location

(b) ratings (conditional and short term)

(c) control strategies required for the optimal utilization. Here, both steady-state and dynamic operating conditions have to be considered.

Server systems studies involving power flow, stability, short circuit analysis are required to prepare the specifications. The design and testing of the control and protection equipment is based on Real Digital Simulator (RTDS) or physical simulators.

The Static Var Compensator (SVC), a first generation FACTS controller is taken up for study. It is a variable impedance device where the current through a reactor is controlled using back to back connected thyristor values.

The application of thyristor value technology to SVC is an offshoot of the developments in HVDC technology. The major difference is that thyristor values used in SVC are rated for lower voltage as the SVC is conducted to an EHV line through a step down transformer or connected to the tertiary winding of a power transformer.

The application of SVC was initially for load compensation of fast changing loads such as steel mills and are furnaces. Here the objective is to provide dynamic power factor improvement and also balance the currents on the source side whenever required. The application for transmission line compensators commenced in the late seventies. Here the objectives are:

1- Increase power transfer in long lines

2- Improve stability with fast acting voltage regulation

3- Damp low frequency oscillations due to swing (rotor) modes

4- Damp sub-synchronous frequency oscillations due to torsional modes.

5- Control dynamic over-voltages

A SVC has no inertia compared to synchronous condensers and can be extremely fast in response (2-3) cycles). This enables the fast control of reactive power in the control range

3.6 Analysis of SVC

The location of SVC is important in determine its effectiveness. I deadly, it should be located at the electrical center of the system or midpoint of a transmission line. For example, consider a symmetric losses transmission

Line with SVC connected as the midpoint sees Fig 3.1. Without SVC, the voltage at the midpoint is given by,

$$V^{mo} = \frac{V \cos\delta/2}{\cos\theta/2} \tag{3.1}$$

Where $\theta = \beta 1$ is the electrical length of the line, 1 is the length of the line and β is the phase constant given by

$$\beta = \omega\sqrt{Ic} = 2\pi f \sqrt{Ic} \tag{3.2}$$

Where I and c are positive sequence inductance and capacitance of the line per unit length, f is the operating frequency

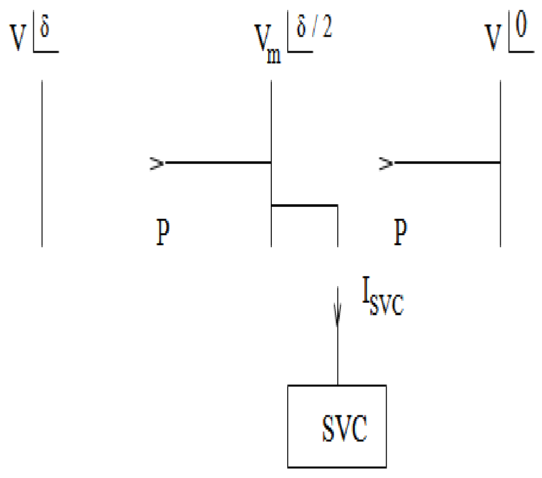

Figure 3.1: A transmission line with SVC connected at midpoint

It can be shown that the voltage variation in the line (due to variation in δ) is maximum at the midpoint. SVC helps to limit the variation by suitable control. The steady state control characteristics of SVC are shown in fig 3.2 where ADB is the control range. OA represents the characteristics where the SVC hits the capacitor limit, BC represents the SVC at its inductor limit. Note that SVC current is considered positive when SVC susceptible is inductive. Thus

$$ISVC = -BSVC\, VSVC \tag{3.3}$$

The slope of 0 A is BC (susceptance of the capacitor) and the slope of OBC is BL (susceptance of the reactor). A positive slope (in the range of 1-5%) is given in the control range to:

a- Enable parallel operation of more than one SVC connected at the same or neighboring buses and.

b- Prevent SVC hitting the limits frequently

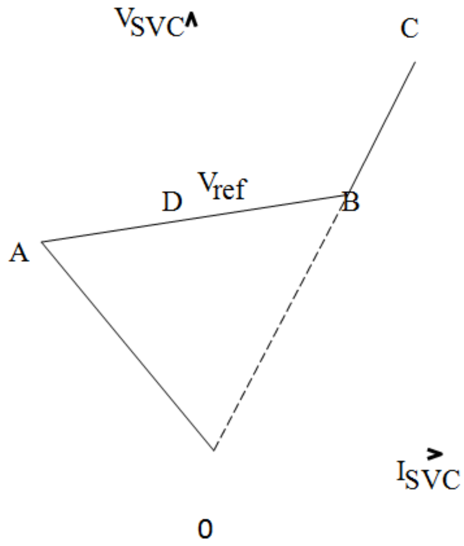

Figure 3.2: control characteristic of SVC

The steady state value of the SVC bus voltage is determined from the intersection of the system characteristic and the control characteristic (as showing in Fig.3.3. The system characteristic is a straight line with negative slope and is defined by

$$VSVC = V_{TH} - X_{TH}\, ISVC \tag{3.4}$$

Where V_{TH} and X_{TH} are the The venin voltage and reactance viewed from the SVC bus. For the system shown in Fig 3.1, we have

$$V_{TH} = V_{mo} = \frac{V\cos(\delta/2)}{\cos(\theta/2)} \tag{3.5}$$

$$X_{TH} = \frac{Z_n}{2}\tan(\theta/2) \tag{3.6}$$

Where Z_n is the surge impedance defined by

$$Z_n = \frac{s-1}{c} \tag{3.7}$$

3.6.1Expression for voltage and power

(a) Control Range: the SVC control range is described by

$$VSVC = V_{ref} + XsISVC \tag{3.8}$$

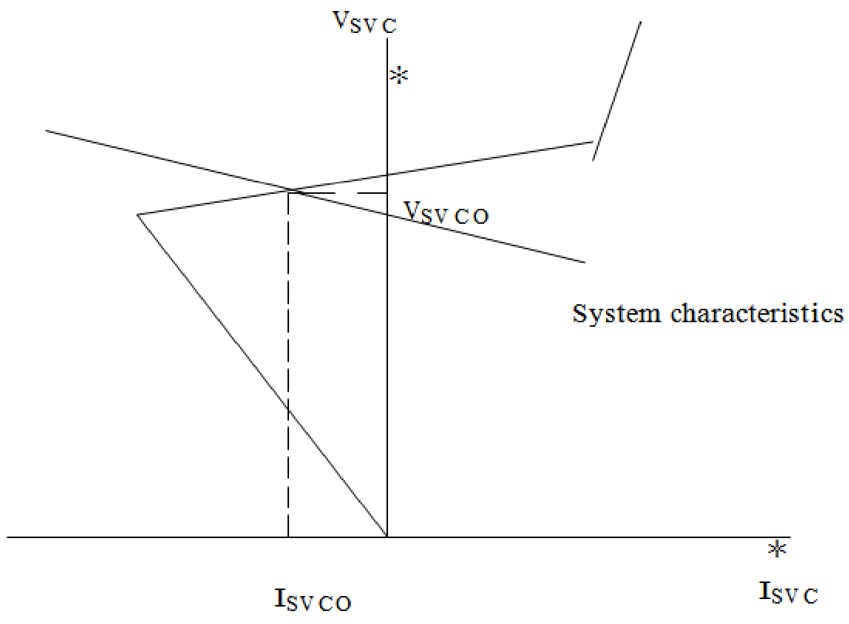

Figure 3.3: Determination of operating point of

Where Xs is the slope of the control characteristics. Verf is the SVC voltage (corresponding to point D) when ISVC = 0

Combining eqs (3.4) and (3.8), we get

$$V_{sv\,c} = V_m = x\frac{Vth\ Xs}{s+Xth} + \frac{Vref\ X\ th}{Xs+Xth} \tag{3.9}$$

The expressions for power flow in the line is given by

Where Xs is the slope of the control characteristics. Vref is the SVC voltage (corresponding to point D) when Isvc = 0

Combining eqs (3.4) and (3.8), we get

$$V_{sv\ c} = V_m = \text{x} \frac{Vth\ Xs}{s+Xth} + \frac{Vref\ X\ th}{Xs+Xth} \tag{3.10}$$

The expressions for power flow in the line is given by

$$p = \frac{Vm\ V \sin(\delta/2)}{Zn \sin(\theta/2)} \tag{3.11}$$

With Vref = V, it can be shown that P is given by,

$$p = KP_0 + (I - k)\ P_I \tag{3.12}$$

$$\text{where } p_0 \frac{V2 \sin \text{ı}\ \delta}{Zn \sin \theta'}\ P_I = \frac{V2 \sin(\delta/2)}{Zn \sin(\theta/2)} \tag{3.13}$$

and

$$k = \frac{Xs}{Xs+X\ th} \tag{3.14}$$

3.6.2 Remarks

1- P0 is the power in the line without SVC PI is the power flow in the line when SVC maintain a constant voltage V at the midpoint (Xs = 0)

2- $k \rightarrow 1\ as\ Xs \longrightarrow \infty$

3- for small values of θ, it can be assumed that

$$\sin \theta = \theta,\ sin_2^0 = \frac{0}{2},\ \cos \frac{0}{2} = 1.$$

$$\text{In this case, } P_0 = \frac{v^2}{x_l} sin\ \delta,\ p_1 = p_1 = \frac{V^2}{2\ X_L} sin\delta/2 \tag{3-15}$$

Where $X_L = (\omega 1)d$ is the total reactance of the line (d is the length of the line).

(B) At SVC limits: When the SVC hits the limit it can be represented as a fixed susceptance (BSVC) where BSVC = BC at capacitive limit. At the inductive limit, BSVC = BL

Substituting 1SV C form eq. (3.3) in eq. (3.4), we get

$$Vsv\ c = \frac{v_{th}}{(1 - X_{TH} B_{SVC})} = \quad (3.16)$$

The power flow in the line is given by

$$P = \frac{P_0}{(1 - X_{TH} B_{SVC})} = \frac{V^2 \ sin\delta}{Z_n \left(1 - X_{TH} \ B_{CVC}\right) sin\theta} \quad (3.17)$$

3.6.3 Power angle curve For SVC

The power angle curve for SVC is made up of 3 segments corresponding to:

(i) BSVC = - BL,

(ii) Control range

(iii)BSVC = BC.

For typical value of parameters, the power (expressed in per unit of Pn = Surge Impedance Load) as function of δ is shown in Fig 3.4. The power angle curve for the line without SVC is also shown in Fig 3.4 (curve b).

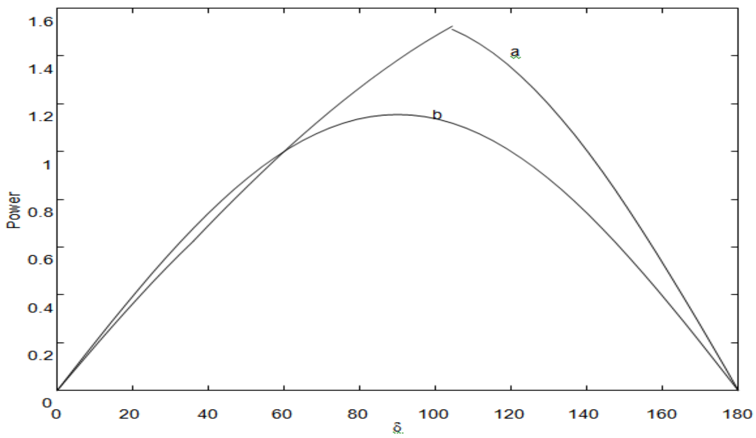

Figure 3:4: plot of power

3.6.4 Configuration of SVC

There are two types of SVC:

1- Fixed Capacitor – Thyristor Controlled Reactor (FC-TCR)

2- Thyristor Switched Capacitor – Thyristor Controller Reactor (TSC-TCR).

The second type is more flexible than first one and requires smaller rating of the reactor and consequently generates less harmonics.

This shows that the TCR and TSC are connected on the secondary side of a step-down transformer. Tuned and high pass filters are also connected in parallel which provide capacitive reactive power at fundamental frequency. The voltage signal is taken from the high voltage SVC bus using a potential transformer.

The TSC is switched in using two thyristor switches (connected back to back) at the instant in a cycle when the voltage across valve is minimum and positive. This results in minimum switching transients. In steady state pulses are blocked and the thyristors turns off when the current through them fall below the holding currents. It is to be noted that several pairs of thyristors are connected in series as the voltage rating of a thyristor is not adequate for the voltage level required. However the voltage ratings of valves for a SVC are much less than the voltage ratings of a HVDC valve as step down transformer is used in the case of SVC. To limit di in a TSC it is necessary to provide a small reactor in series with the capacitor.

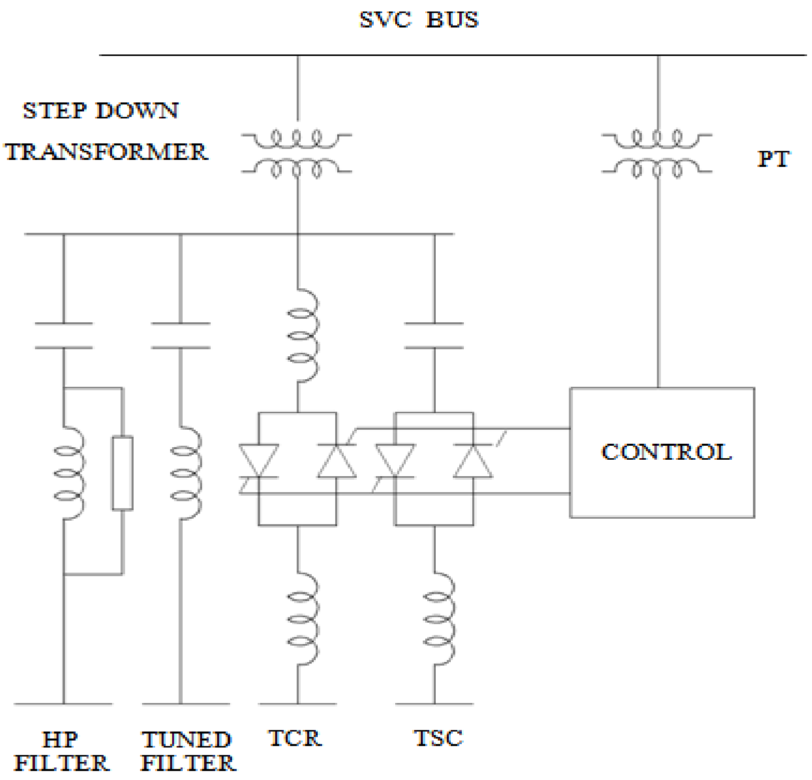

Figure 3.5: A typical SVC (TSC-TCR) configuration

3.6.5 Modeling of SVC

For a detailed study of SVC control interactions, it is necessary to perform transient simulation for which SVC is modeled in detail including the switching of the thyristor valves in TCR and TSC.

However, for stability study it is not necessary to consider the switchling of valves and assume that SVC generates only fundamental current. In addition, the network transient s are neglected and represented by algebraic equations of the type:

$$[Y]\ V = 1 \qquad (3.18)$$

With these simplifications, SVC can be modeled as a variable susceptance which is the output of the control system as shown in fig.3.13. if SMC is a part of the SVC controller, it should be included in the model. However, suseptance regulator, gain supervisor and the protective functions can be neglected in the model.

For the preliminary studies, it is adequate to ignore the dynamics of SVC control (without SMC) and assume the SVC is described by its steady state control characteristics. [3]

3.7 Steady State Model of SVC

The steady state control characteristics are modeled by an equivalent circuit in fig. 3.32. This shows a complex voltage sources ESV C in series with a reactance XSV C. The losses in the SVC are neglected. The values of ESV and XSV C are given below the SVC operating in

(i) The control range

(ii) Capacitive limit and

(iii)Inductive limit

$$E_{SV\ C} = V_{ref} - \varphi svc \qquad (3.19)$$

$$X_{SV\ C} = X_s \qquad (3.20)$$

Where φsvc is the angle of the SVC bus voltage. The control range applies when the SVC bus voltage lies in the range.

$$\frac{V_{ref}}{1+X_s\ B_{max}} < V_{SVC} < \frac{V_{ref}}{1+X_s\ B_{min}} \qquad (3.21)$$

Where Bmin and Bmax are the limits of BSV C. Note that Bmin is , in general, negative (corresponding to the inductive limit) and Bmax = Bc, where BC is the total capacitive susceptance. (neglecting the transformer leakage reactance)

(ii) At Capacitive Limit

$$E_{SVC} = 0.0 + j0.0 \quad XSV\ C = -_B \qquad (3.22)$$

(iii) At Inductive Limit:

$$E_{SVC=}\ 0.0 + j0.0\ \ XSV\ C =\ -_{B} \tag{3.23}$$

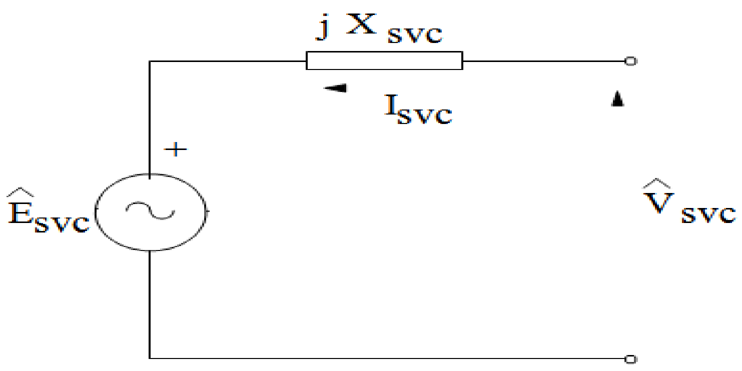

Figure 3.6: Equivalent circuit of SVC

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Introduction

Figure (appendix (A)) shows single line diagram of Sudan electric network, with voltages of 500 Kv, 220 Kv and 110 Kv.

The generation in **(SETCO)** consists of hydro generation which is far away from the load center and Thermal generation which is concentrated in the center of load. The transmission line network consists of 110 Kv Khartoum ring which supplies the load center and 220 Kv ring which surrounds the 110 Kv ring. The Blue Nile transmission line links Risers power station with the center load throw 220 Kv and 110 kv transmission line. The 500 kv transmission line links Marawe power station which is regarded as the biggest one in the network with the center load. Few radial transmission lines are also included in the network. The busbars data and transmission lines data showed in appendix (A and B)

4. 2 Limit Violations

Most of equipments in the network as (generators, transmission line, transformer, current transformer, voltage transformer and customers) may be affected by the voltage and current when they exceed the limit of operation. The protection should then protect the equipments from damage. The types of protection used in the scheme are over-voltage, under-voltage and over-current. As the result of operating protection scheme, the stability may be lost..

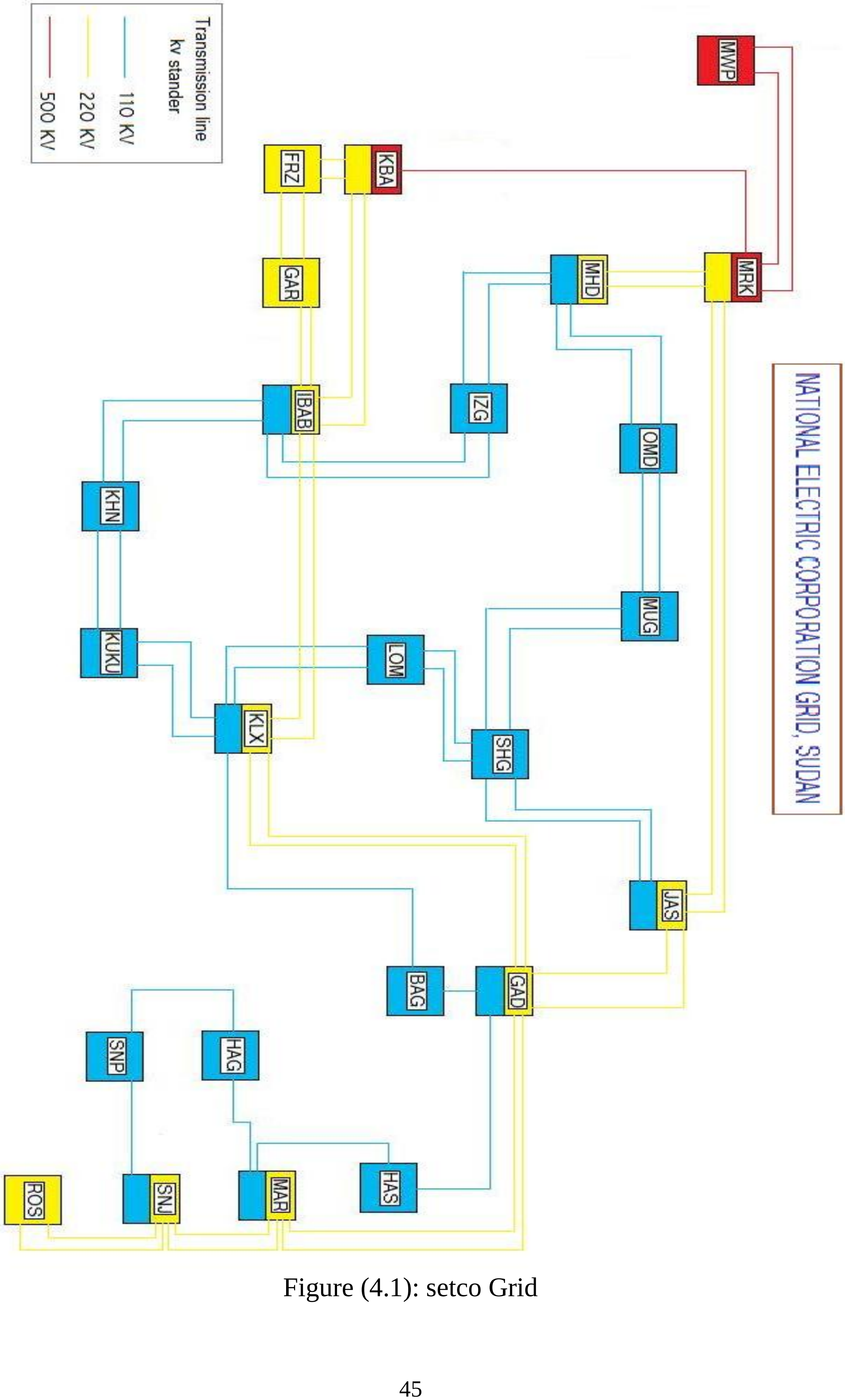

Figure (4.1): setco Grid

4.2.1 Solution of Nonlinear Algebraic Equations:-

The most common methods for solving nonlinear algebraic equations are Gauss- Seidel .Newtow-Rahpson, and quasi-Newton-Raphson methods. We start with dimensional equations and then generalize to n-dimensional equations [1].

4.2.2 Newton-Raphson Power Flow Solution

Due to its quadratic convergence, the N-R method has rapid convergence indent from system size. Thus, the method usually converges in less than 10 iterations regardless of system size! ! However, as the system size (number of equations) increase [1].

4.3 load flow and Contingency Analysis:-

We use a(Neplan) program version (554) to give load flow and contingency analysis result and give suggestion to return a system back to be stable.

Program applications: we have three applications; the first one is load flow result which is giving the limit violation of the system.

The second one is load flow result with svc which is given the limit violation of the system after

The third one is contingency analysis, it is able you to choose power system equipments (Generator, Transmission line, Transformer and load) and applying contingency analysis, the result of that a short list of limit violation shown, if the system is not healthy we can use OPFS. The last one is Optimal Power Flow Solution, which is give suggestions to do correction action in the system to prevent it from the limit violations as a possible as.

4.3.1 Data required

To apply this program we must include data of the power system, the Generation data required are amount of power, mode of generation, is it slack or control, the per unit voltage value and voltage stander. The transmission line parameters, tap changer position, the circuit number, the circuit status and the over load current setting must be including in the data. The data of reactor and condenser must be including the Var value and equipment status, is it in service or not. After we prepare the data, we drown the (setco) network and inter the data for(element and nodes and gen………)

neplane program version **(55.4)** is used to give load flow and contingency analysis results , and gives week point of elements which help in giving optimum solution that return a system back to stability neplane program version **(55.4)** calculation depends on Newton-Raphson Power Flow Solution.

4.4 load flow

Neplane load flow is applied to (setco) grid during the peak load period. The following steps show the procedures

Step 1: Select load flow results from tool bar menu as shown in table (4.3) and then select continue to tool bar by (99≥vrea ≥121) as flow

Over voltage list = 1

Under voltage list =9

Over load list = 0

Step 2: From tool bar select result by zone and then select over and under voltage in (110kva)nodes as shown in table (4.4) and from tool bar menu select summary Transmission loss as shown in table (4.5)

Table (4.1): result of (110bus) without (svc)by applied load flow

area	NAME	U(KV)	%U
Blue Nile	SNG1	108.045	98.22
	SNJ 1	108.76	98.87
	SNP1	108.201	98.36
East	BSH1	110.586	100.53
	HWT1	113.758	103.42
	POR1	95.57	87
Gezera	GND1	104.569	95.06
	HAG1	98.1	98.2
	MAN1	99.851	90.77
	MAR1 B1	103.849	94.41
	MAR1 B2	103.849	94.41
	NHAS1	105.268	95.7
	OHAS1	97.39	88.5
Khar. North	KUK1	98.157	89.2
	KHN1	109.244	99.31
	IZG1	107.365	97.6
	IZB1	108.702	98.82
	IBA1	109.499	99.54
Khartoum	AFR1	97.57	88.7
	BAG1	97.25	88.4
	FAR1	98.01	89.1
	GAD B2	104.744	95.22
	GAD1 B1	104.744	95.22
	JAS1	104.999	95.45
	KLX1	103.911	94.46
	SHG1	103.962	94.51
	LOM1	97.84	88.9
	SOB1 B2	103.95	94.5
Omduman	MUG`	104.612	95.1
	OMD1	105.141	95.58
	GAM1	98	89.9
	BNT1	104.69	95.17
	MHD1	95.89	87.1
White Nile	ORBK1	105.837	96.22
	NRBK1	121.502	110.46
	MSH1	109.898	99.91
	MIN1	103.944	94.49
	FAO1	100.934	91.76
Zone 1	SOB1 B1	103.95	94.5

Table (4.2): - Summary Transmission Losses (without svc)

Un		P Loss Line	Q Loss Line	P Loss Transformer	Q Loss Transformer
kV		MW	MVar	MW	MVar
33		0	-0.014	0	0
66		0.338	-3.084	0.015	0.644
110		14.733	13.005	0.731	48.013
220		48.577	-930.35	1.692	230.41
500		21.984	-402.17	4.348	221.79
TOTAL LOSSES		85.63	1322.613	6.8	501

From the table we see 8 node under voltage & one of them over voltage .this this problem saluted by one of method below:-

1. Prime mover and excitation control of generators
2. Switching of shunt capacitor banks, shunt reactors, and static var systems.
3. FACTS based technology.
4. Control of tap-changing and regulating transformers.

We can choice number (3) FACTS based technology (static var compensators)

4.5 SVC Modeling

In our simulation we use same arrangement for the SVC connection i.e. one TR (110/33 K.V) at each S/S, then the TCR, Fifth and seventh filter all are connected to the 33k.v side. In substation like Kuku, Local market and Hashish were capacitor until is exist, it is also connected in the 33k.v side .
TCR represents only the inductive part and control the (33k.v) voltage in the range of (30-36 k.v).

Table (4.3): SVC Modeling

	Substation	TCR MVar	Capacitor Unit 1 MVar	Capacitor Unit 2 MVar	5^{th} Filter MVar	7^{th} Filter MVar
1	Local Market	30	35.4	22.3	32.4	10.6
2	Mahadiya	55			10.7	5.2
3	Port Sudan	55			10.7	5.2
4	Gamouia	60			5.3	5.2
5	Kuku	45	13.8		16	10.4
6	Hasahisa	30	17.5	16.5	16	10
7	Bageir	45			5.3	5.2
8	Hag Abdalla	20			10.7	5.2
9	Farouk	60			5.3	5.2

Step 3: SVCs are added to setco grid , in order to correct actions shown in table (4.7) to keep system stable. And the summary of Transmission losses are shown as flow

Over voltage list = 0

Under voltage list =0

Over load list = 0

Table (4.4): - Summary Transmission Losses (with svc)

Un		P Loss Line	Q Loss Line	P Loss Transformer	Q Loss Transformer
kV		MW	MVar	MW	MVar
33		0.001	-0.016	0	0
66		0.353	-3.083	0.017	0.715
110		9.026	-15.955	0.55	56.937
220		38.021	-962.151	1.764	229.304
500		10.168	-910.16	3.742	175.172
TOTAL LOSSES		57.569	-1891.335	6.073	462.1

Table (4.5): result of (110bus)with (svc)by applied load flow

	NAME	U(KV)	%U
Blue Nile	SNG1	111.028	100.93
	SNJ 1	112.601	102.36
	SNP1	112.173	101.98
East	BSH1	110.617	100.56
	HWT1	116.201	105.64
	POR1	110.579	100.53
Gezera	GND1	110.52	100.47
	HAG1	109.065	99.15
	MAN1	104.945	95.4
	MAR1 B1	108.684	98.8
	MAR1 B2	108.684	98.8
	NHAS1	111.015	100.92
	OHAS1	110.946	100.86
Khar. North	KUK1	110.956	100.87
	KHN1	111.456	101.32
	IZG1	109.857	99.87
	IZB1	111.213	101.1
	IBA1	111.974	101.79
Khartoum	AFR1	107.768	97.97
	BAG1	109.487	99.53
	FAR1	106.763	97.06
	GAD B2	110.125	100.11
	GAD1 B1	110.125	100.11
	JAS1	109.456	99.51
	KLX1	108.882	98.98
	SHG1	108.978	99.07
	LOM1	108.928	99.03
	SOB1 B2	109.108	99.19
	MUG`	110.662	100.6
Omdurman	MUG`	109.353	99.41
	OMD1	107.869	98.06
	GAM1	111.86	101.69
	BNT1	107.439	97.67
	MHD1	109.822	99.84
White Nile	ORBK1	109.834	99.85
	NRBK1	120	101
	MSH1	112.821	102.56
	MIN1	108.111	98.28
	FAO1	105.135	95.58
Zone 1	SOB1 B1	109.108	99.19

Step 4: compare the result above as shown in table (4.6)

Table (4.6): compare result of (110bus) with out and with (svc)

AREA	NAME	without svc U(KV)	U(KV)
Blue Nile	SNG1	108.045	111.028
	SNJ 1	108.76	112.601
	SNP1	108.201	112.173
East	BSH1	110.586	110.617
	HWT1	113.758	116.201
	POR1	95.57	110.579
Gezera	GND1	104.569	110.52
	HAG1	98.1	109.065
	MAN1	99.851	104.945
	MAR1 B1	103.849	108.684
	MAR1 B2	103.849	108.684
	NHAS1	105.268	111.015
	OHAS1	97.39	110.946
Khar. North	KUK1	98.157	110.956
	KHN1	109.244	111.456
	IZG1	107.365	109.857
	IZB1	108.702	111.213
	IBA1	109.499	111.974
Khartoum	AFR1	97.57	107.768
	BAG1	97.25	109.487
	FAR1	99.01	106.763
	GAD B2	104.744	110.125
	GAD1 B1	104.744	110.125
	JAS1	104.999	109.456
	KLX1	103.911	108.882
	SHG1	103.962	108.978
	LOM1	97.84	108.928
	SOB1 B2	103.95	109.108
	MUG`	104.612	110.662
Omdurman	MUG`	104.612	109.353
	OMD1	105.141	107.869
	GAM1	98	111.86
	BNT1	104.69	107.439
	MHD1	95.89	109.822
White Nile	ORBK1	121.502	109.834
	NRBK1	121.501	120
	MSH1	103.944	112.821
	MIN1	100.934	108.111
	FAO1	103.95	105.135
Zone 1	SOB1 B1	103.95	109.108

4.6 contingency mode

Apply **(**NEPLANE contingency analysis)to the (setco)grid during the load period. In the beginning we apply load flow result to make over view, and then apply contingency analysis application, select line (GER22-IBA220kv) from the list to make contingency and show the effect of that by limit violation list

contingency analysis is applied to the (setco) grid during the load period. The follow steps shows the procedures

Step 1: Select contingency analysis results from tool bar menu as shown as flow and then select continue to tool bar (by $99 \geq vrea \geq 121$)

Over voltage list = 4

Under voltage list =8

Over load list = 7

Step 2: From tool bar select result by zone and then select over and under voltage in the (line& element &nodes) as shown in table (4.12)

Step 3: SVCs are added to setco grid , in order to correct actions shown in table (4.13)&table(4.14) to keep system stable

Over voltage list = 4

Under voltage list =8

Over load list = 1

Table (4.7): result of(LINE& element&node) without (svc) by applied contingency

contingency	violated element	element type	zone of violation	violation %	base value
GER22_IBA22	NRBK11N7	Node	White Nile	115.34	115.72
GER22_IBA22	NRBK11 N5	Node	White Nile	115.34	115.72
GER22_IBA22	RBK2	Node	White Nile	110.66	111.06
GER22_IBA22	NRBK11N6	Node	White Nile	110.38	110.78
GER22_IBA22	FAR3	Node	Khartoum	91.29	91.99
GER22_IBA22	ZBD11 N1	Node	Kord	89.1	89.24
GER22_IBA22	ZBD11 N2	Node	Kord	89.1	89.24
GER22_IBA22	FAO3	Node	White Nile	88.8	89.23
GER22_IBA22	HMD11N2	Node	North	87.59	87.68
GER22_IBA22	HMD11N1	Node	North	87.59	87.68
GER22_IBA22	FAO 11 N2	Node	Zone 1	86.54	86.98
GER22_IBA22	FAO11 N1	Node	White Nile	86.54	86.98
GER22_IBA22	KUK11-KHN11	Line	Khar. North	125.56	124.2
GER22_IBA22	IBA21_KLX21	Line	Khar. North	119.32	111.1
GER22_IBA22	IBA22_KLX22	Line	Khar. North	119.32	111.1
GER22_IBA22	KLX TR1	3W Transformer	Khartoum	108.43	109.35
GER22_IBA22	KLX TR2	3W Transformer	Khartoum	108.43	109.35
GER22_IBA22	KLX TR3	3W Transformer	Khartoum	108.43	109.35
GER22_IBA22	GER21_IBA21	Line	Khar. North	105.48	77.19

Table (4.8): result of element with (svc)by applied contingency

contingency	violated element	element type	zone of violation	violation %	base value
GER22_IBA22					
GER22_IBA22	NRBK11N7	Node	White Nile	115.39	115.75
GER22_IBA22	NRBK11 N5	Node	White Nile	115.39	115.75
GER22_IBA22	RBK2	Node	White Nile	110.71	111.09
GER22_IBA22	NRBK11N6	Node	White Nile	110.43	110.82
GER22_IBA22	FAR3	Node	Khartoum	91.44	91.29
GER22_IBA22	ZBD11 N2	Node	Kord	89.12	89.25
GER22_IBA22	ZBD11 N1	Node	Kord	89.12	89.25
GER22_IBA22	FAO3	Node	White Nile	88.84	89.25
GER22_IBA22	HMD11N2	Node	Kord	87.61	87.69
GER22_IBA22	HMD11N1	Node	Kord	87.61	87.69
GER22_IBA22	FAO 11 N2	Node	Kord	86.58	87.01
GER22_IBA22	FAO11 N1	Node	White Nile	86.58	87.01
GER22_IBA22	KLX TR1	3W Transformer	Khartoum	147.31	148.56

4. 7 Modeling Results Discussion

4.7.1 load flow discussion without and with SVC :-

The total load for this case is 2129 MWs and the transmission losses are 75 MW (3.5%). The voltage in the hydro machines at Merowi is regulated up to 102%. All ten units are assumed available for generation.

A number of points on the network suffer from under-voltages (more than 5% drop) on the 220 and 110 kV networks ; these are Afraa, Bageir , Farouk, Giad, Guneid, Local Market, Managil, Hasahisa, Shagara. Most notably the voltage at Port-Sudan and Basahir drops by 17% on the 110 kV level .

With the SVC the voltage problems are corrected to about 100% at Guneid, Hasahisa, Managil, Port-Sudan and Basahir. The voltage at Khartoum Substations, on the other hand, improve but do not reach 100%, generally increasing from 94% to 97% for most substations. The transmission losses drop to about 68 MW – a saving of 7 MWs

SVC utilization can be detailed as follows

At Bageir, Farouk, Gamoia, Local market, Mahdiya, and Port-Sudan the TCR is fully off; maximum substation capacitive compensation is needed. At Hag-Abdalla, and Hasahisa a margin of 7-13% remains for capacitive compensation

4.7.2. contingency discussion without &with SVC :-

As shown in the table, 19 problems start to appear in the grid once taking out the line (GARR-IBAB). The affect of the problem can be reduced to 13 elements after adding SVC into the grid. These elements are:

A. 6 node in white nile region .

B. 5 node in kurdofan region.

C. 1 node in farouk substation.

D. 1 trans in kilox (TR01)

This in dicates that all the problems are located in the western region of the grid for these reasons:

1-The long distance from generation plants.

2-Weakness of load consumption at this region

3-The long distance of the transmission lines

Subsequently, it's recommended to

- Set up power plants there

-Maximizing the size of TR01 in kilox

- Maximizing the size of the SVC in farouk substation

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

During investigation of the load flow analysis for power systems, is necessary to know more if the power flows and voltages will readjust and remain within acceptable limits or otherwise severe overloads and under/over voltages will occur when applied load flow application by using (NEPLANE prrograme) We connect an svc on setco grid to control voltage and reactive power Load flow analysis gives this estimate about The week node in the net work and over/under voltage node . and what is optimal power flow solution. a list of corrector action appears to baking system stable

During investigation of contingency analysis there is 19 problems start to appear in the grid once taking out the line (GARR-IBAB). The affect of the problem can be reduced to 13 elements after adding SVC into the grid. These elements are :

A. 6 node in White Nile region.

B. 5 nodes in kurdofan region.

C. 1 node in farouk substation.

D. 1 trans in kilox (TR01)

This in dicates that all the problems are located in the western region of the grid for these reasons :

1-The long distance from generation plants.

2-Weakness of load consumption at this region

3-The long distance of the transmission lines

Subsequently, it's recommended to

- Set up power plants there

-Maximizing the size of TR01 in kilox

- Maximizing the size of the SVC in farouk substation

5.2 Recommendations

Based on the results produced from this application, the following was recommended:

1. Use this program to

- Analyze the effect of reducing generation in center load.
- Analyze the effect of interconnection between Sudan & Ethiopia
- Plan new substation or power station

3. Improve system security

- find the weak points in the power system and prepare solutions if it happens.
- A quick solution ready to use in case of forced outage.
- build new substation or power station in the (whitenile&kor)zone
-add new transformer (220/110/33)to KLX substation

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Appendix (A) LINES DATA

	ID	Name	Type	Length	R(1)	X(1)	C(1)	B(1)	R(0)	X(0)	C(0)	B(0)	Units	Irmax (low)	Irmax (high)	Temp	SC	Temp	OperTemp	Q1(1)	Q2(1)	Q1(0)	Q2(0)	Shunt 1 active	Shunt 2 active	From	On	To	On	Area	Zone
				km	Ohm/...	Ohm/...	uF/...	uS/...	Ohm/...	Ohm/...	uF/...	uS/...		A	A	*	*	*	*	Mvar	Mvar	Mvar	Mvar	%	%						
1	1229801972	AFRAA-FAROUG 1	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	AFRAA	1	FAR1	1	Area 1	KHARTOUM
2	1229801977	AFRAA-FAROUG 2	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	AFRAA	1	FAR1	1	Area 1	KHARTOUM
3	440	Atbara-Merowe Dam	ACSR 4 x 325 mm²	236.7	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	125	0	125	0	100	100	ATB5	1	MRWS_S1	1	Area 1	NORTHERN
4	436	Atbara-Port Sudan	ACSR 1 x 480 mm²	448.92	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	30	0	30	100	100	POR2	1	ATB2	1	Area 1	Red Sea
5	324	Atbara (NEC)-Shendi 1	ACSR 2 x 240 mm²	140	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	ATB2	1	SHN2	1	Area 1	River Nile
6	328	Atbara (NEC)-Shendi 2	ACSR 2 x 240 mm²	140	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	ATB2	1	SHN2	1	Area 1	River Nile
7	307	Bagair-Glad	ACSR 1 x 95 mm²	3	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	BAG1	1	GAD1	1	Area 1	JAZEERA
8	159	BANAT-Mugran 1	ACSR 2 x 240 mm²	3.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	MUG1_1	1	BNT1	1	Area 1	OMDURMAN
9	155	BANAT-Mugran 2	ACSR 2 x 240 mm²	3.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	MUG1_1	1	BNT1	1	Area 1	OMDURMAN
10	1229802026	BANAT-OMD 1	ACSR 2 x 240 mm²	5.9	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	BNT1	1	OMD1	1	Area 1	OMDURMAN
11	1229802021	BANAT-OMD 2	ACSR 2 x 240 mm²	5.9	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	BNT1	1	OMD1	1	Area 1	OMDURMAN
12	300	Debba-Dongola 1	ACSR 1 x 480 mm²	139.38	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	DEB2S2	1	DON2S2	1	Area 1	NORTHERN
13	304	Debba-Dongola 2	ACSR 1 x 480 mm²	139.38	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	DON2S1	0	DEB2S1	1	Area 1	NORTHERN
14	1229802733	DON-WWA-1	ACSR 2 x 240 mm² - 220 kV	166	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	DON2S2	1	WWA2	1	Area 1	NORTHERN
15	1229802738	DON-WWA-2	ACSR 2 x 240 mm²	166	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	DON2S1	0	WWA2	0	Area 1	NORTHERN
16	268	Eid Babiker-Garri 1	ACSR 2 x 240 mm² - 220 kV	60	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	IBA2	1	GAR2S1	1	Area 1	KHARTOUM NORD
17	334	Eid Babiker-Garri 2	ACSR 2 x 240 mm² - 220 kV	60	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	IBA2	1	GAR2S1	1	Area 1	KHARTOUM NORD
18	20	Eid Babiker-Izba 1	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	IZBA	1	Area 1	KHARTOUM NORD
19	15	Eid Babiker-Izba 2	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	IZBA	1	Area 1	KHARTOUM NORD
20	429	El Fau-NGedaref	ACSR 1 x 95 mm²	153	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	FAO1	1	NGDF1	1	Area 1	EASTERN
21	1229791515	El Girba-Halfa1	ACSR 2 x 240 mm² - 220 kV	58	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GBA2	1	NHLF2	1	Area 1	kassla
22	1229801818	El Girba-Halfa2	ACSR 2 x 240 mm² - 220 kV	58	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GBA2	1	NHLF2	1	Area 1	kassla
23	231	El Girba-Kassala	ACSR 1 x 120 mm²	85	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	460	460	20	80	40	80	0	0	0	0	100	100	GBA66	1	KSL66	1	Area 1	kassla
24	1229791500	El Girba-Kassala220_1	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	KSL2	1	GBA2	1	Area 1	kassla
25	1229791505	El Girba-Kassala220_2	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	KSL2	1	GBA2	1	Area 1	kassla
26	236	El Girba-Kilo 3	ACSR 1 x 120 mm²	3	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	GBA66	1	KL366	1	Area 1	kassla
27	417	El Girba-Showak	ACSR 1x 95 mm² - 66 kV	70	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	287	287	20	80	40	80	0	0	0	0	100	100	GBA66	1	SHK66	1	Area 1	EASTERN
28	1229791529	El Girba-Showak220_1	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.105	0.262	1.2	0.00575	1.806	km	572	1250	20	80	40	80	0	0	0	15	100	100	SHK2	1	GBA2	1	Area 1	EASTERN
29	1229791532	El Girba-Showak220_2	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	SHK2	1	GBA2	1	Area 1	EASTERN
30	145	El Kabashi-Eid	ACSR 2 x 240 mm²	30	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	k	125	125	20	80	40	80	0	0	0	0	100	100	KAB2	1	IBA2	1	Area 1	KHARTOUM

		Babiker 1											m	0	0																NORD
31	142	El Kabashi-Eid Babiker 2	ACSR 2 x 240 mm^2	30	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	IBA2	1	Area 1	KHARTOUM NORD
32	139	El Kabashi-Free Zone 1	ACSR 2 x 240 mm^2 - 220 kV	34	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	FRZ2	1	Area 1	KHARTOUM NORD
33	134	El Kabashi-Free Zone 2	ACSR 2 x 240 mm^2 - 220 kV	34	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	FRZ2	1	Area 1	KHARTOUM NORD
34	5859	Gamoeia-Banat 1	ACSR 2 x 240 mm^2	16.5	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM1	1	BNT1	1	Area 1	OMDURMAN
35	5864	Gamoeia-Banat 2	ACSR 2 x 240 mm^2	16.5	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM1	1	BNT1	1	Area 1	OMDURMAN
36	148	Gamoeia-Jebel Aulia 1	ACSR 2 x 240 mm^2 - 220 kV	37	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	JAS2	1	Area 1	OMDURMAN
37	152	Gamoeia-Jebel Aulia 2	ACSR 2 x 240 mm^2 - 220 kV	37	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	JAS2	1	Area 1	OMDURMAN
38	343	Garri-Free Zone 1	ACSR 2 x 240 mm^2 - 220 kV	5	0.067	0.302	0.01306	4.103	0.262	1.2	0.00574868	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAR2S1	1	FRZ2	1	Area 1	KHARTOUM NORD
39	348	Garri-Free Zone 2	ACSR 2 x 240 mm^2 - 220 kV	5	0.067	0.302	0.01306	4.103	0.262	1.2	0.00574868	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAR2S1	1	FRZ2	1	Area 1	KHARTOUM NORD
40	425	Gedarif-Raweshda	ACSR 1x 95 mm^2 - 66 kV	38	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	0	370	20	80	40	80	0	0	0	0	100	100	GDF66	1	RW566	1	Area 1	EASTERN
41	7193	Gedarif-Shehedi 1	ACSR 2 x 240 mm^2 - 220 kV	192	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	15	0	100	100	GDF2	1	SHEH	1	Area 1	EASTERN
42	7198	Gedarif-Shehedi 2	ACSR 2 x 240 mm^2 - 220 kV	192	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	15	0	100	100	GDF2	1	SHEH	1	Area 1	EASTERN
43	1229791526	Gedarif-Showak220_1	ACSR 2 x 240 mm^2 - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GDF2	1	SHK2	1	Area 1	EASTERN
44	1229791522	Gedarif-Showak220_2	ACSR 2 x 240 mm^2 - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GDF2	1	SHK2	1	Area 1	EASTERN
45	311	Glad-NHAS	ACSR 1 x 95 mm^2	80.7	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	GAD1	1	NHAS-110	1	Area 1	JAZEERA
46	99	Hassa Heisa-Meringan	ACSR 1 x 95 mm^2	55	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	HAS1	1	01-مارس	1	Area 1	JAZEERA
47	374	Hawata-Gedarif 1	ACSR 2 x 240 mm^2 - 220 kV	100	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	HWT2	1	GDF2	1	Area 1	EASTERN
48	364	Hawata-Gedarif 2	ACSR 2 x 240 mm^2 - 220 kV	100	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	HWT2	1	GDF2	1	Area 1	EASTERN
49	84	Jebel Aulia-Glad 1	ACSR 2 x 240 mm^2 - 220 kV	36	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAD2	1	JAS2	1	Area 1	KHARTOUM
50	89	Jebel Aulia-Glad 2	ACSR 2 x 240 mm^2 - 220 kV	36	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAD2	1	JAS2	1	Area 1	KHARTOUM
51	6690	JEBEL Aulia 33 SS-PS 2	ACSR 1 x 185 mm^2	5	0.15	0.28	0.008913	2.8	0.45	0.9	0.003947	1.24	km	350	350	20	160	40	80	0	0	0	0	100	100	JAS33	1	JAP33	1	Area 1	KHARTOUM
52	1229791508	Kassala-Aroma1	ACSR 2 x 240 mm^2 - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	ARO2	1	KSL2	1	Area 1	kassla
53	1229791512	Kassala-Aroma2	ACSR 2 x 240 mm^2 - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	ARO2	1	KSL2	1	Area 1	kassla
54	117	Khartoum Nord-Eid Babiker 1	ACSR 2 x 240 mm^2	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IBA1	1	Area 1	KHARTOUM NORD
55	114	Khartoum Nord-Eid Babiker 2	ACSR 2 x 240 mm^2	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	KHN1	1	Area 1	KHARTOUM NORD
56	46	Khartoum Nord-Kuku 1	ACSR 2 x 350 mm^2	4.5	0.0384	0.302	0.0095	2.985	0.3995	1.206	0.00653	2.051	km	1200	1200	20	80	40	80	0	0	0	0	100	100	KHN1	1	KUK1	1	Area 1	KHARTOUM NORD
57	50	Khartoum Nord-Kuku 2	ACSR 2 x 350 mm^2	4.5	0.0384	0.302	0.0095	2.985	0.3995	1.206	0.00653	2.051	km	1200	1200	20	80	40	80	0	0	0	0	100	100	KHN1	1	KUK1	1	Area 1	KHARTOUM NORD
58	1229801985	KHN-IZERGAB 1	ACSR 2 x 240 mm^2	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IZG1-2	1	Area 1	KHARTOUM NORD
59	1229801990	KHN-IZERGAB 2	ACSR 2 x 240 mm^2	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IZG1-2	1	Area 1	KHARTOUM NORD
60	223	Kilo X-AFRAA 1	ACSR 2 x 240 mm^2	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	AFRAA	1	Area 1	KHARTOUM
61	1229801967	Kilo X-AFRAA 2	ACSR 2 x 240 mm^2	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	AFRAA	1	Area 1	KHARTOUM
62	123	Kilo X-Bagair	ACSR 1 x 95 mm^2	28	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	KLX1	1	BAG1	1	Area 1	KHARTOUM
63	210	Kilo X-Eid Babiker 1	ACSR 2 x 240 mm^2 - 220 kV	14	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KLX2	1	IBA2	1	Area 1	KHARTOUM NORD
64	61	Kilo X-Eid Babiker 2	ACSR 2 x 240 mm^2 - 220 kV	14	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KLX2	1	IBA2	1	Area 1	KHARTOUM NORD

65	274	Kilo X-Glad 1	ACSR 1 x 400 mm²	43	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	KLK2	0	GAD2	1	Area 1	KHARTOUM
66	213	Kilo X-Glad 2	ACSR 1 x 400 mm²	43	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	KLK2	0	GAD2	1	Area 1	KHARTOUM
67	38	Kilo X-Kuku 1	ACSR 1 x 350 mm²	14.6	0.087	0.379	0.0095	2.985	0.502	1.93	0.0043	1.351	km	780	780	20	80	40	80	0	0	0	0	100	100	KUK1	1	KLK1	1	Area 1	KHARTOUM
68	43	Kilo X-Kuku 2	ACSR 1 x 350 mm²	14.6	0.087	0.379	0.0095	2.985	0.502	1.93	0.0043	1.351	km	780	780	20	80	40	80	0	0	0	0	100	100	KUK1	1	KLK1	1	Area 1	KHARTOUM
69	351	Kilo X - Local Market 1	ACSR 2 x 240 mm²	3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLK1	1	LOM1	1	Area 1	KHARTOUM
70	354	Kilo X - Local Market 2	ACSR 2 x 240 mm²	3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLK1	1	LOM1	1	Area 1	KHARTOUM
71	361	Kuku-Karthum East 1	ACSR 2 x 240 mm²	3.2	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KUK1	1	KHE1	1	Area 1	KHARTOUM NORD
72	357	Kuku-Karthum East 2	ACSR 2 x 240 mm²	3.2	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KUK1	1	KHE1	1	Area 1	KHARTOUM NORD
73	1229816522	LOM SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	LOMS VC3	1	LOM SVC 33	1	Area 1	Zone 1
74	1229816700	Has SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	HAS-TCR 33	1	HAS SVC 33	1	Area 1	Zone 1
75	1229817392	KuKu SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	TCR KUK 33	1	KUK SVC 33	1	Area 1	Zone 1
76	30	Magirus-Local Market 1	ACSR 2 x 240 mm²	7.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-1	1	LOM1	1	Area 1	KHARTOUM
77	35	Magirus-Local Market 2	ACSR 2 x 240 mm²	7.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	LOM1	1	Area 1	KHARTOUM
78	23	Mahadia-Izergab 1	ACSR 2 x 240 mm²	8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IZG1-1	1	MHD1-2	1	Area 1	KHARTOUM NORD
79	27	Mahadia-Izergab 2	ACSR 2 x 240 mm²	8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IZG1-1	1	MHD1-2	1	Area 1	KHARTOUM NORD
80	177	Mahadia-Omdurman 1	ACSR 2 x 240 mm²	9.3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	OMD1	1	MHD1-1	1	Area 1	OMDURMAN
81	180	Mahadia-Omdurman 2	ACSR 2 x 240 mm²	9.3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	OMD1	1	MHD1-1	1	Area 1	OMDURMAN
82	190	Makhiyat-El Kabashi	ACSR 4 x 325 mm²	36.8	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	0	0	0	100	100	KAB5	1	MRK5	1	Area 1	NORTHERN
83	170	Makhiyat-Gamoeia 1	ACSR 2 x 240 mm²	37	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	MRK2	1	Area 1	OMDURMAN
84	174	Makhiyat-Gamoeia 2	ACSR 2 x 240 mm²	37	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM1	1	MRK2	1	Area 1	OMDURMAN
85	183	Makhiyat-Mahadia 1	ACSR 2 x 240 mm² - 220 kV	21	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MRK2	1	MHD2	1	Area 1	OMDURMAN
86	187	Makhiyat-Mahadia 2	ACSR 2 x 240 mm² - 220 kV	21	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MRK2	1	MHD2	1	Area 1	OMDURMAN
87	96	Mashkur-Jebel Aulia 1	ACSR 2 x 240 mm² - 220 kV	147.7	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MSH2	1	JAS2	1	Area 1	White Nile
88	386	Mashkur-Jebel Aulia 2	ACSR 2 x 240 mm² - 220 kV	147.7	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MSH2	1	JAS2	1	Area 1	White Nile
89	219	Meringan-Alfau	ACSR 1 x 95 mm²	71	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	01-مارس	0	FAO1	1	Area 1	JAZEERA
90	271	Meringan-Hag Abdallah	ACSR 1 x 95 mm²	35	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	01-مارس	1	HAG1	1	Area 1	JAZEERA
91	198	Meringan-Managil	ACSR 1 x 150 mm²	75.6	0.105	0.289	0.00965	3.032	0.315	0.867	0.0054	1.696	km	500	500	20	80	40	80	0	0	0	0	100	100	01-مارس	1	MAN1	1	Area 1	JAZEERA
92	66	Meringan-Sennar 1	ACSR 1 x 400 mm²	84	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	SEN2	1	Area 1	JAZEERA
93	71	Meringan-Sennar 2	ACSR 1 x 400 mm²	84	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	SEN2	1	Area 1	JAZEERA
94	167	Merowe Dam-Makhiyat 1	ACSR 4 x 325 mm²	346	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	125	0	125	100	100	MRW5_S1	1	MRK5	1	Area 1	NORTHERN
95	162	Merowe Dam-Makhiyat 2	ACSR 4 x 325 mm²	346	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	125	0	125	100	100	MRW5_S1	1	MRK5	1	Area 1	NORTHERN
95	283	Merowe Dam-Merowe Town 1	ACSR 1 x 480 mm²	34.55	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWAI S1	1	MWT2S 2	1	Area 1	NORTHERN
97	288	Merowe Dam-Merowe Town 2	ACSR 1 x 480 mm²	34.55	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWAI S2	0	MWT2S 1	1	Area 1	NORTHERN
98	292	Merowe Town-	ACSR 1 x 480 mm²	139.3	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	k	850	850	20	80	40	80	0	0	0	0	100	100	MWT	1	DEB292	1	Area 1	NORTHERN

		Debba 1											m													252					
99	296	Merowe Town-Debba 2	ACSR 1 x 480 mm^2	139.3	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWT 251	1	DEB251	1	Area 1	NORTHERN
100	131	Mugran-Magirus 1	ACSR 2 x 240 mm^2	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-1	1	MUG1	1	Area 1	KHARTOUM
101	127	Mugran-Magirus 2	ACSR 2 x 240 mm^2	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-1	1	MUG1	1	Area 1	KHARTOUM
102	1229801401	New Hasahesa-Giad 1	ACSR 1 x 400 mm^2	87.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	GAD2	1	Area 1	JAZEERA
103	1229801396	New Hasahesa-Giad 2	ACSR 1 x 400 mm^2	87.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	GAD2	1	Area 1	JAZEERA
104	277	New Hasahesa-Meringan 1	ACSR 1 x 400 mm^2	53.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	NHAS-220	1	Area 1	JAZEERA
105	120	New Hasahesa-Meringan 2	ACSR 1 x 400 mm^2	53.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	02-مارس	1	Area 1	JAZEERA
106	1229802823	NGDF-GDF	ACSR 1 x 95 mm^2	3	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	NGDF 1	1	GDF1	1	Area 1	EASTERN
107	109	NGER-Halfa	ACSR 1 x 120 mm^2	52	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	NGBA 66	1	NHLF66	1	Area 1	kasala
108	1229802831	NGER-KL3	ACSR 1 x 120 mm^2	3	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	NGBA 66	1	KL366	1	Area 1	kasala
109	414	NHAS-Genaid 1	ACSR 2 x 240 mm^2-110kv	15	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	GND1	1	Area 1	JAZEERA
110	410	NHAS-Genaid 2	ACSR 2 x 240 mm^2-110kv	15	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	GND1	1	Area 1	JAZEERA
111	1229801593	NHAS-HAS	ACSR 1 x 95 mm^2	4.6	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	HAS1	1	Area 1	JAZEERA
112	1229818415	POR-BSH 1	ACSR 2 x 240 mm^2-110kv	20	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	POR1	1	BSH	1	Area 1	Red Sea
113	1229818420	POR-BSH 2	ACSR 2 x 240 mm^2-110kv	20	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	POR1	1	BSH	1	Area 1	Red Sea
114	92	Rabak-Mashkur 1	ACSR 2 x 240 mm^2 - 220 kV	107.2	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	MSH2	1	Area 1	White Nile
115	383	Rabak-Mashkur 2	ACSR 2 x 240 mm^2 - 220 kV	107.2	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	MSH2	1	Area 1	White Nile
116	227	Rabak-Tandalti 1	ACSR 2 x 240 mm^2 - 220 kV	111	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	TAN2	1	Area 1	White Nile
117	380	Rabak-Tandalti 2	ACSR 2 x 240 mm^2 - 220 kV	111	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	TAN2	1	Area 1	White Nile
118	79	Rank-Rabak 1	ACSR 2 x 240 mm^2 - 220 kV	163.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	RBK2	1	Area 1	White Nile
119	337	Rank-Rabak 2	ACSR 2 x 240 mm^2 - 220 kV	163.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	RNK2	1	Area 1	White Nile
120	421	Rawesda-Showak	ACSR 1x 95 mm^2 - 66 kV	32	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	287	287	20	80	40	80	0	0	0	0	100	100	SHK66	1	RWS66	1	Area 1	EASTERN
121	216	Roseires-Rank 1	ACSR 2 x 240 mm^2 - 220 kV	172.8	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	ROS2	1	Area 1	Blue nile
122	340	Roseires-Rank 2	ACSR 2 x 240 mm^2	172.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	ROS2	1	Area 1	Blue nile
123	194	Sennar-Rabak	ACSR 1 x 95 mm^2	96	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	RBK11	1	SENJ1	1	Area 1	Sennar
124	104	Sennar-Sennar Hydro	ACSR 1 x 95 mm^2	10	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENJ1	1	SENP1	1	Area 1	Sennar
125	371	Sennar-Singa 1	ACSR 1 x 400 mm^2	50	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SENJ2	1	SNG2	1	Area 1	Sennar
126	368	Sennar-Singa 2	ACSR 1 x 400 mm^2	50	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SENJ2	1	SNG2	1	Area 1	Sennar
127	202	Sennar Hydro-Hag Abdallah	ACSR 1 x 95 mm^2	60	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENP1	1	HAG1	1	Area 1	Sennar
128	206	Sennar Hydro-Mina Sharif	ACSR 1 x 95 mm^2	69	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENP1	1	MNA1	1	Area 1	Sennar
129	403	Shagar-Jebel Aulia 1	ACSR 2 x 240 mm^2	39	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	JAS1	1	Area 1	KHARTOUM
130	407	Shagar-Jebel Aulia 2	ACSR 2 x 240 mm^2	39	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	JAS1	1	Area 1	KHARTOUM
131	445	Shendi-Free Zone 1	ACSR 2 x 240 mm^2 - 220 kV	115	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SHN2	1	FRZ2	1	Area 1	KHARTOUM NORD
132	448	Shendi-Free Zone 2	ACSR 2 x 240 mm^2 - 220 kV	115	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SHN2	1	FRZ2	1	Area 1	KHARTOUM NORD

133	433	Singa-Hawata 1	ACSR 2 x 240 mm² - 220 kV	90	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SNG1	1	HWT1	1	Area 1	Sennar
134	377	Singa-Hawata 2	ACSR 2 x 240 mm² - 220 kV	90	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SNG1	1	HWT2	1	Area 1	Sennar
135	331	Singa-Roseires 1	ACSR 1 x 400 mm²	178	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SNG1	1	ROS1	1	Area 1	Blue nile
136	74	Singa-Roseires 2	ACSR 1 x 400 mm²	178	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SNG2	1	ROS2	1	Area 1	Blue nile
137	393	Tandalti-Umrawaba 1	ACSR 2 x 240 mm² - 220 kV	78.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	TAN1	1	UMR2	1	Area 1	White Nile
138	389	Tandalti-Umrawaba 2	ACSR 2 x 240 mm² - 220 kV	78.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	TAN2	1	UMR2	1	Area 1	White Nile
139	400	Umrawaba-Obeid 1	ACSR 2 x 240 mm² - 220 kV	126	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	UMR2	1	OBE2	1	Area 1	North Kurdofan
140	396	Umrawaba-Obeid 2	ACSR 2 x 240 mm² - 220 kV	126	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	UMR2	1	OBE2	1	Area 1	North Kurdofan
141	12298602743	WWIA-WLF 1	ACSR 2 x 240 mm² - 220 kV	204	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	WWIA 1	1	WLF	1	Area 1	NORTHERN
142	12298602748	WWIA-WLF 2	ACSR 2 x 240 mm² - 220 kV	204	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	WWIA 2	0	WLF	0	Area 1	NORTHERN

Appendix (B) : Shunt Data

	Name	Type	Ur	Q(1)	Q(0)	Active	U set	Connection	Regulation	Cosphi mi n capac.	Cosphi max capac.	Cosphi capac.	P-Scaling Factor	Q-Scaling Factor	Phases	From	On	Area	Zone
			kV	MVar	MVar	%	%												
1	ARO Rea1		220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	ARO2	1	Area 1	kassla
2	Bagair 11 Cap		110	-5	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	BAG1	1	Area 1	JAZEERA
3	Debba 22 Rea		220	20	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	DEB2S2	1	Area 1	NORTHERN
4	Eid Babiker 11 Rea		11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	IBA3_1	0	Area 1	KHARTOUM NORD
5	GDF 33-1 SHUNT		33	5	5	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	GDF 33-1	0	Area 1	EASTERN
6	GDF 33-2 SHUNT		33	5	5	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	GDF 33-2	0	Area 1	EASTERN
7	Gedaref 33 2 Rea		33	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	GDF 33-2	1	Area 1	EASTERN
8	Gedaref 33 4 Rea		33	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	GDF 33-1	1	Area 1	EASTERN
9	Izergab 11 Cap		110	-5	-5	100	100	Wye Gnd	switched-continuous	1	1	1	1	1	L1L2L3N	IZG1-1	1	Area 1	KHARTOUM NORD
10	Kassala 11 Cap		11	-7	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	KSL11	1	Area 1	kassla
11	KSL Rea1		220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	KSL2	1	Area 1	kassla
12	KSL Rea2		220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	KSL2	1	Area 1	kassla
13	MAR-11Rea1	15 MVar	11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	11-Mar	0	Area 1	JAZEERA
14	MAR-11Rea2	15 MVar	11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	MAR11 1	0	Area 1	JAZEERA
15	Mashkur 22 Rea	2x15 MVar	220	30	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	MSH2	0	Area 1	White Nile
16	MRW Rea 1		500	125	125	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	MRW5_S1	1	Area 1	NORTHERN
17	MRW Rea 2		500	125	125	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	MRW5_S1	1	Area 1	NORTHERN
18	NHAS Rea1		11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	NHAS-11-2	0	Area 1	JAZEERA
19	NHAS Rea2		11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	NHAS-11-1	0	Area 1	JAZEERA
20	NHLF REACTOR1		220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	NHLF2	1	Area 1	kassla
21	NHLF REACTOR2		220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	NHLF2	1	Area 1	kassla
22	Obeid 22	15	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	OBE2	0	Area 1	North Kurdofan

	Rea1	MVar																	
23	Obeid 22 Rea2	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	OBE2	1	Area 1	North Kurdofan
24	Omdurman 11 Cap		110	-3	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	OMD1	1	Area 1	OMDURMAN
25	Port Sudan 22 Rea1	15 MVar	110	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	POR1	0	Area 1	Red Sea
26	Port Sudan 22 Rea2	15 MVar	110	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	POR1	0	Area 1	Red Sea
27	Rabak 22 Rea	2x15 MVar	220	30	30	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	RBK2	0	Area 1	White Nile
28	Rank 22 Rea1	2x15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	RNK2	1	Area 1	Southern
29	RNK Rea 2	2x15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	RNK2	1	Area 1	Southern
30	Roseires 11 1 Rea		11	15	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	ROS11_1	0	Area 1	Blue nile
31	Roseires 11 8 Rea		11	15	0	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	ROS11_8	0	Area 1	Blue nile
32	SENJ REACTOR	15 MVar	33	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SENJ-11	0	Area 1	Sennar
33	SHK		220	30	30	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SHK2	0	Area 1	EASTERN
34	SHUNT-1229802540	15 MVar	11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SNJ0	0	Area 1	Sennar
35	SHUNT-KLX1	15 MVar	11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	KLX11-1	0	Area 1	KHARTOUM
36	SHUNT-KLX2	15 MVar	11	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	KLX11-2	0	Area 1	KHARTOUM
37	SHUNT-SHD	15*2	220	30	30	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SHEH	0	Area 1	Zone 1
38	SHUNT-SNJ		33	5	5	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SENJ-11	0	Area 1	Sennar
39	SHUNT-WLF	15	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	WLF	0	Area 1	NORTHERN
40	SHUNT-WLF2	15	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	WLF	1	Area 1	NORTHERN
41	Singa 22 Rea1	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SNG2	0	Area 1	Sennar
42	Singa 22 Rea2	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	SNG2	0	Area 1	Sennar
43	Tandalti 22 Rea1	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	TAN2	1	Area 1	White Nile
44	Tandalti 22 Rea2	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	TAN2	1	Area 1	White Nile
45	Umrawaba 22 Rea1	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	UMR2	1	Area 1	North Kurdofan
46	Umrawaba 22 Rea2	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	UMR2	0	Area 1	North Kurdofan
47	WAW Rea2	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	WWA2	1	Area 1	NORTHERN
48	WWA Rea1	15 MVar	220	15	15	100	100	Wye Gnd	fixed	1	1	1	1	1	L1L2L3N	WWA2	1	Area 1	NORTHERN