قال تعالى: ﴿وَأَنزَلَ ٱللَّهُ عَلَيْكَ ٱلْكِتَٰبَ وَٱلْحِكْمَةَ وَعَلَّمَكَ مَا لَمْ تَكُن تَعْلَمُ ۚ وَكَانَ فَضْلُ ٱللَّهِ عَلَيْكَ عَظِيمًا﴾

(النساء:113)

DEDICATION

This Research is Dedicated with Love and Affection

To Our Parents

And to Abdualsalam Omer,Alsadig Jallab,Abdelmonim Idress and to Every One

Who,

Throughout the long past ages,

Have Contributed to the Joys of Life through their Embroideries.

ACKNOWLEDGEMENT

We would like to express our Special thanks of Gratitude to our Teacher Associated Professor .Khamis Arbeesh,Who gave us The golden opportunity to do this project of Electrical Interconnection between Sudan and Egypt ,Who also helped us in Completing this project. Also We would like to Thanks the Engineer in Sudan Electricity Holding Company LTD especially Engineers Abdelkhalig and Hamad nalla, to their effort for helping us in collecting data.We came to know about so many things we really thankful to them.

ABSTRACT

In many countries or electrical utilities , studies for cross-border interconnections and import and export of electric power are parts of the transmission expansion planning to meet energy demand and improve stability (ability to keep generating units operating in a synchronized manner after occurrence Disturbances in the system), quality (possibility of maintaining voltage and frequency within acceptable ranges), reliability (reduction of the expected risk of energy supply impossibility due to possible defects of the system elements) and economy (reduction of the electric systems operation cost), the research discusses how interconnection between Sudan and Egypt will have benefit effect on Sudan electric grid .

المستخلص

في اي دولة تعتبر دراسة وربط شبكتها الداخلية مع شبكات دول الجوار، لشراء او تصدير الكهرباء جزء من التخطيط السليم لتوسيع شبكتها الكهربائية لمقابلة الزيادة في مستوى معين من الطلب وتحسين استقرارية الشبكة (وهي قدرة النظام على البقاء متزنا عند حدوث اضطرابات في الشبكة) ، الجودة(وهي المحافظة على قيم الجهد والتردد ضمن القيم المقبولة)الإعتمادية و الإ قتصادية(وهي تقليل التكلفة التشغيلية لمنظومة القوى الكهربية). البحث يناقش فوائد ربط الشبكة السودانية بالشبكة المصرية وتأثير عملية الربط على الشبكة السودانية.

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LIST OF ABBREVIATION

AC	Alternating Current
HVDC	High Voltage Direct Current
TWh	Tera Watt Hour
DC	Direct Current
ACSR	Aluminum Conductor Steel Reinforced
SF6	Sulfur Hexafluoride
VT	Voltage Transformer
CT	Current Transformer
ISO	Independent System Operator
SCADA	Supervisory Control and Data Acquisition
ATC	Available Transmission Capacity
TTC	Transmission Transfer Capability
AGC	Automatic Generator Control
FACTS	Flexible Alternative Current Transmission Systems
ACE	Area Control Error
WAMS	Wide Area Monitoring Systems
NPP	Nuclear Power Plants
MED	Ministry of Electricity and Dams
EETC	Egyption Electricity Transmission Company
SMP	System Marginal Price

LIST OF SYMBOLS

P	**Power**
VR	**Voltage at the Receiving side**
VS	**Voltage at the Sending side**
X	**Reactance**

CHAPTER ONE

LITRUATURE REVIEW

1.1. Overview

Electricity grid interconnections have played a key role in the history of electric power systems. Most national and regional power systems that exist today began many decades ago as isolated systems, often as a single generator in a large city. As power systems expanded out from their urban cores, interconnections among neighboring systems became increasingly common [1]. Groups of utilities began to form power pools, allowing them to trade electricity and share capacity reserves. The first power pool in the United States was formed in the Connecticut Valley in 1925 [2]. As transmission technologies improved, long distance interconnections developed, sometimes crossing national borders. The first international interconnections in Europe came in 1906, when Switzerland built transmission links to France and Italy.

One of the great engineering achievements of the last century has been the evolution of large synchronous alternating current (AC) power grids, in which all the interconnected systems maintain the same precise electrical frequency. Today, the North American power system is composed of four giant synchronous systems, namely the Eastern, Western, Texas, and Quebec interconnections [3].

At the same time that synchronous AC networks have reached the continental scale, the use of high voltage direct current (HVDC) interconnections is also rapidly expanding as a result of technical progress over the last two decades. HVDC permits the asynchronous interconnection of networks that operate at different frequencies, or are otherwise incompatible, allowing them to exchange power with-out requiring the tight coordination of a synchronous network. HVDC has other advantages as

Well, especially for transmitting large amounts of power over very long distances.

The process of generating, transporting and distributing electric power is characterized by long-term strategic planning and requires a tremendous amount of funding and it must be recognized that economic and social development throughout the world has been associated today with the availability of stable electricity services for all economic, industrial and residential sectors consumed by them, and the world-renowned wisdom in energy security is to diversify energy sources.

Sudan has some of the lowest levels of electricity in the world ,Only 30 per cent of the population in the country has access to electricity .the country has turned to the electricity interconnection in a step aimed at facing the acute shortage of supplies , continuous power cuts that extend to several hours a day and complete black out in some periods , which worsens the living of citizens and impedes the economic and commercial process .

The industrial sector is the most affected , due to its dependence of electricity on production , so any interruption negatively , affects leads to the payment of worker's wages without actual production .

Most of the generation stations in Sudan are thermal stations depend on fuel , the lack of fuel made most of these stations out of service , all these reasons let Sudan interconnected its network with Egypt especially the cost of thermal generation in Egypt is low because it is produced from gas compared to its production in Sudan which depends on fuel .

The interconnection is an important to the two countries in terms of technical , and economic terms , it makes the both grid more stable and protecting Sudan from black out , also reduces the percentage of losses inside of Sudan grid .

1.2. Previous Studies

The U.S. and Canadian electric power grids are connected through 37 major transmission lines from New England to the Pacific Northwest. The interconnected North American power grid provides numerous benefits for Canada and the United States, including enhanced electric reliability, security, affordability and resilience as well as increased economic benefits. The two countries have worked together to improve service through markets, international regulatory bodies and various bilateral engagements. Increasing actions by provinces, states, cities and businesses are growing demand for clean energy. Due to the comparatively clean mix of Canadian electricity, increased exports could assist the United States as well as individual states and cities in achieving their clean energy goals. Furthermore, the inherent storage capability of Canadian hydropower can help states integrate greater quantities of intermittent renewable power'1.Since 1990, Canada and the United States have been trading electricity. In 2008, Canada exported 55.7 TWh to the United States at an average rate of $0.065 per kWh while the United States exported 23.5 TWh to Canada at an average rate of $0.057 per kWh.17 While Canada's export of 55.7 TWh of electricity may seem miniscule compared to the United States' 4,119TWh of electricity generated, this energy export greatly benefits the importing area.18 For example, in 2008, New York consumed approximately 144 TWh of electricity. Canada exported approximately 16.8 TWh of electricity, accounting for 11.7% of New York's electricity requirements[4].

The interconnectors between Lithuania and Belarusare used for system services within the synchronous area(frequency control, power balancing and loop flows) as well as for electricity transfer. In both countries, Russia and Belarus, electricity is mainly generated from thermal and nuclear capacities. The conventional fuel prices are subsidised for internal Russian and Belarusian producers and less stringent environmental requirements apply, such as those related to (CO2)emissions and market transparency rules. Considering the substantial differences of market and environmental rules, a level playing field for electricity trade between those countries and the EU in the framework of the EU energy and climate objectives does not exist[5].

The contract of the electric energy exchange between the Jordanian and the Egyptian sides was renewed for the year 2012. Jordan is electrically interconnected with the Egyptian electrical network from the south via a 13km, 400 kV submarine cable across the Gulf of Aqaba with an exchange capabilities of 550 MW.

- Jordan is electrically interconnected with the Syrian electrical network from the north through a 400 kV overhead single circuit transmission line of 58km with exchange capabilities of 1000 MW.

- During the year 2011 NEPCO imported 1457.6 GWh from Egypt and 280.5 GWh from Syria for the purpose of meeting the electricity needs of the Jordanian network, while the exported energy from Jordan to Egypt during the year 2011 was 4.2 GWh and 75.7 GWH to Jerusalem Co (Jericho).and 5.7 GWh to Border Trabeel. This energy exchange determined mutual technical and economical benefits for all the parties.

- During the year 2011, 235.1 & 30.4 GWh was transmitted from the Egyptian network to the Lebanese network and Syrian network respectively, and 8.9 GWh from Syrian network to the Egyptian network through the

Jordanian network. This energy exchange determined benefits to Jordan resulted from electric energy transmission fees Wheeling Charges.

• Electric energy exchange between the Egyptian and Libyan sides continued since operating the interconnection line in the year 1998 in accordance with the agreement signed between the two countries.

• The electric energy exchange during the year 2011 was 129 GWh from Egypt to Libya and 113 GWh from Libya to Egypt[15].

The interconnectors with Russia enable import of electricity to Finland; in this case, trade takes place purely on a bilateral basis and is not governed by any rules related to the EU market frame work. In case of Estonia and Latvia, there are no commercially scheduled flows at the border. The lines are used only for physical flows as the countries are still synchronized with Russia,being part of the Integrated/Unified Power System (IPS/UPS).

Interconnectors with Lithuania are used for commercial import from Kaliningrad Region but also enable electricity transit between mainland Russia and its Kaliningrad Region exclave[5].

The highest capacity HVDC interconnection in the world at present is a bipolar +/- 600 kV line transmitting6300 MW of power from the Itaipu dam on the Brazilian-Paraguayan border into Brazil over a distance of 800 km. HVDC was selected at the technology for this transmission project for two reason (1)the great distance between the dam and demand centers, and (2) because the dam generates power at 50 Hz, while Brazil has a 60 Hz power system[6].

Electric Power Transmission Lines from Ethiopia to Sudan The project involves the construction of a high voltage transmission line from Ethiopia to Sudan. The immediate objective is to facilitate cross-border trade between the two countries and thus optimize utilization of existing and planned generation capacity. The long-term objective is to promote regional power trade through coordinated planning and development of power generation and transmission interconnections in the context of multipurpose water resources development in the Eastern Nile Basin. The line is to generate 500 kV-AC through an interconnection of 2 lines ,2circuits and 544 Km.

Ethiopia and Sudan derive several benefits from the power interconnection project at the national level. Ethiopia will benefit from generating revenue from exporting power to Sudan and the latter will benefit by replacing its current thermal power generation with surplus hydropower from Ethiopia thereby reducing Sudan’s greenhouse gas emissions. The project improves the availability and reliability of power supply to both countries since it provides benefits in terms of meeting the variability in peak demands (where Sudan can be provided with power during the day time when demand is higher and Ethiopia can use the power during the night time when demand is high). Meanwhile, the project may generally have potential socio-economic benefits for the two countries in terms of stimulating national and local economies through providing more employment opportunities and access to improved health care and education etc. Moreover, the project may provide additional incentives for both countries to embark on additional cooperative activities including cross-border trade and cultural exchanges furthering improved relations between the participating countries[7].

1.3.Problem Statement

Sudan has been suffering from a lack of electrical supply and Insufficient to meet demand due to the lack of generations.

1.4. Objectives

It is expected that the project would assist the two partners to obtain the following specific benefits:

1. To promote energy connectivity among the countries by assisting them to integrate their respective networks and thereby develop ability for building larger power projects to meet larger regional markets.

2. To reduce the cost of power in both countries.

3. To create productive employment and economic development across the borders.

1.5.Methodology

The purpose of the research is to study the effect of interconnection between Sudan and Egypt ,so it uses Neplanv557 to enter the technical component of the two countries and receive the result witch shown the effect to the Sudan grid.

1.6. Project Layout

Chapter 2: Addresses the Interconnection , Including general types and benefit of Electricity interconnection also advantages and disadvantages of each type Of the interconnection and technical complexities and risks of interconnection.

Chapter 3: Describes the interconnection between Sudan and Egypt ,The agreement of the two countries and parameters of lines and level Voltage then put the results in tables to discuss in the next chapter.

Chapter 4: Discusses the results and the impact of the interconnection on Sudan grid.

Chapter 5: Provides key conclusions from the materials presented in this Report, and offers recommendations for follow-up activities associated with the analysis of the multi-disciplinaryaspects electricity grid interconnections.

CHAPTER TWO

INTERCONNECTION

2.1. General Introduction

International power grid interconnections provide links between the electricity transmission systems of two or more adjoining countries, and thus allow those countries to share power generation resources. As different countries are differently endowed with natural resources, energy trade among countries, as it has for centuries (perhaps millennia) helps to reduce energy prices and increase energy supply in importing countries, while providing a means of income for exporting countries. Most fuels can be transported by land or sea, by cart, freighter, truck, train, or tanker. Electricity, however, is generally not (yet) easily “storable” in bulk quantities, and must therefore be transferred by power lines .

International grid interconnections can be as modest as the one-way transfer of a small amount of electricity from one country to another, or as ambitious as the full integration of the power systems and markets of all of the countries in a region. Whatever the scale, international power grid interconnections can help to contribute toward the process of sustainable development. Grid interconnections can help to increase the supply and/or reliability of electricity for use in education, employment generation, health care, and many other development related activities, and can contribute toward the formation of competitive markets for electricity on national and regional scales, helping to potentially reduce the cost of electricity to developing economies.

2.2.Issues Associated with Power Grid Interconnection

International power grid interconnections are often, however, extremely complex undertakings, with technical, economic, legal, political, social, and environmental issues (costs, benefits , and considerations) that must be taken carefully into account before and as arrangements for power sharing are made. A small sampling of the many issues associated with international power grid interconnections includes:

2.2.1.Technical issues

Technical issues, such as grid stability benefits, potential costs in the form of impacts on thenational grid of technical problems in an interconnected network, and considerations in transferring power between grids with different technical standards of power quality and reliability.

2.2.2. Economic issues

Economic issues, such as benefits in the form of avoided fuel, capacity, and operating requirements for one or both countries (for example, through taking advantage of economies of scale), costs in the form of required payments for transmission infrastructure, and considerations such as deciding on electricity pricing, national contributions toward interconnection costs, and the impact of power from interconnections on local economies.

2.2.3. legal issues

Legal issues, including benefits in the form of model legal standards for cooperative activities of all types, costs such as the need to adapt National laws and practices to international standards, and complications such as determining jurisdictions for settling disputes, deciding on protocols for selecting contractors, and determining liability for third-party injuries due to activities related to the power line.

2.2.4. Political issues

Political issues, for example, benefits such as increasing cooperation and understanding between governments linked by the interconnections, liabilities such as additional exposure to potential political instabilities in a neighboring country, and considerations such as existing political rivalries between would-be electricity trading partners.

2.2.5. Social issues

Social issues, with benefits in the form of improved access to electricity for development-related activities, but potential costs in the form, for example, of intrusion of power lines into traditional areas used by indigenous peoples, and considerations such as providing opportunities for all affected social groups to provide input into the interconnection planning process.

2.2.6. Environmental issues

Environmental issues, including potential benefits such as avoided greenhouse gas, regional ,local, and indoor air pollution, possible costs such as the impacts of power lines on animal populations, and considerations such as compliance with local and international regulations and protocols, and coordination in operation of grid interconnections so as to maximize environmental benefits.

As such, any development of international electricity grid interconnections requires thorough analysis that crosses a number of disciplines, from engineering and economics/finance though sociology and environmental science . A thorough treatment of all of the issues noted above is well beyond the scope of this Research. What this document seeks to provide, rather, is a survey of the costs, benefits, and other considerations that would require analysis in the evaluation and implementation of international grid interconnection between Sudan and Egypt , with some guidance as to tools and resources that can be used in grid interconnection planning.

2.3. Classification of Interconnections

The argument most widely used in justifying an international grid interconnection (also valid for national interconnections) is to overcome difficulties in sitting new facilities (generation and transmission) in order to meet a growing demand for electric energy, and for mutual support and reliability.

Electrical interconnections can be broadly classified as [8] :

1. Synchronous
2. Asynchronous

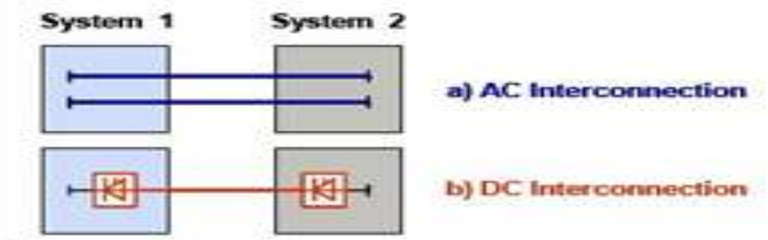

Figure2.1: Classification of electrical interconnections.

A synchronous operation means that all units will generate at the same frequency and operate exactly at the same speed, and that rotor angular positions are linked by a synchronous electric torque.

The natural development of power systems has been through alternating current (AC) synchronous interconnections. The advantages of these diminish with an increasing size of the system. Recent blackouts in America and Europe [9], [10], have shown that a favorable close electrical coupling with AC might also include a risk of uncontrollable cascading effects during disturbances.

In an asynchronous connection, as the name implies, the two electric grids involved do not operate in a synchronous way. An asynchronous connection is typically achieved with direct current (DC), usually at a high voltage (HVDC).

One of the advantages of using DC (in back-to-back or long distance transmission) is the total control of the active power flowing between the two grids, both in magnitude and schedule.

Aback-to-back solution is suitable for exchange of moderate amounts of power (<2 000 MW); but if a large amount of power is exchanged over long distance, HVDC transmission offers more advantages.

In the event of a serious disturbance in one of the electric systems, DC technology will prevent cascading to the other grid of such disturbance. An HVDC solution provides often, a more economical solution. A further solution is the hybrid interconnection, consisting of an AC connection, supported by and additional HVDC link. In case the synchronous interconnection is technically close to its limits, HVDC additionally can support the operation of interconnected systems.

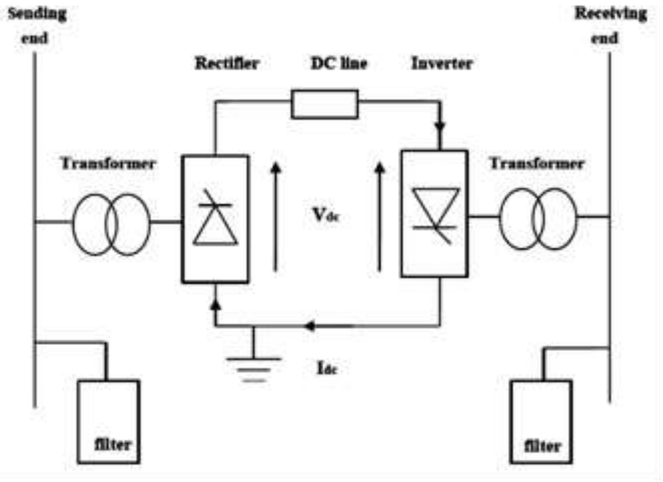

Figure 2.2:The basic HVDC system

In this day and age of limited investments in the transmission grid, application of new technologies to improve grid performance (including cross-border interconnections) is of great relevance [11],[12] .

Proven technologies are now available which have significantly less environmental impact, smaller footprints and are flexible in their operation. From time to time, efforts have been made to determine the optimum type and size for a cross-border interconnection, derived from the interest of countries to share energy flows with its neighbor.

An optimum type and size interconnection should consider the adequacy of the firm transmission capacity, emergency support, transmission system design, economical energy interchange, enhanced security and voltage control [13].

2.4. Benefits of Interconnection

Reasons given for an international grid interconnection vary for each particular situation, although the importance and the benefits of the electrical connection frequently cited are:

1. Reduce or differ the necessary investment for establishing new generating stations.
2. Efficient operation of generation.
3. Exchange of reserve(generation)capacity among national power utilities, that may involve three type of services:
    - Emergency supply at cost for a limited period.
    - Scheduled outages to be covered by supply from the interconnection.

A proportion of spinning (immediately available) reserve capacity.

In general, such reserve capacity exchanges enable each of the participating national power utilities to achieve acceptable levels of system reliability with lower reserve capacity margins than with independent operation of each system in isolated mode.

4. Allow the retirement of old and contaminating generating plants.
5. Extend the use of renewable sources.
6. Provide energy sources to developing countries.
7. Take advantage of load diversity and disparity in fuel prices in different regions.
8. Fuel availability to meet load demand with the required reliability.
9. Provision for transmission reserve in parallel paths.
10. Enhancement of stability and quality of supply.
11. Increase in capacity, energy interchange, and sale opportunities.
12. Provision for back-up transmission in a particular area or country.

2.5. Technical Complexities and Risks of Grid Interconnections

The fact that interconnections between power systems are increasingly common does not imply that they are as simple as connecting a few wires. Interconnections obviously entail the expense of constructing and operating transmission lines and substations, or in the case of HVDC, converter stations. Interconnections also entail other costs, technical complexities, and risks. For AC interconnections especially, a power system interconnection is a kind of marriage, because two systems become one in an important way when they operate in synchronism. To do this requires a high degree of technical compatibility and operational coordination, which grows in cost and complexity with the scale and inherent differences of the systems involved. To give just one example, when systems are interconnected, even if they are otherwise fully compatible, fault currents (the current that flows during a short circuit) generally increase, requiring the installation of higher capacity circuit breakers to maintain safety and reliability. To properly specify these and many other technical changes required by interconnection requires extensive planning studies, computer modeling, and exchange of data between the interconnected systems.

The difficulties of joint planning and operation of interconnected systems vary widely. As with marriages, from the institutional and administrative standpoint, coupled systems may become a single entity, or they may keep entirely separate accounts.

The greatest benefits of interconnection are usually derived from synchronous AC operation, but this can also entail greater reliability risks. In any synchronous network, disturbances in one location are quickly felt in other locations. After interconnecting, a system that used to be isolated from disturbances in a neighboring system is now weak to those disturbances. As major blackouts in North America and Europe in 2003 demonstrated, large-scale disturbances can propagate through interconnections and result in cascading outages, bringing down systems that had previously been functioning normally. In addition, long-distance interconnections with long transmission lines have potentially greater stability problems than is the case for shorter lines. Finally, many systems that have undergone electricity liberalization in recent years have experienced large increases in transmission capacity utilization, reducing reserve margins. Minimizing the likelihood that an interconnection will lead to such problems as voltage collapse, dynamic and transient instability, or cascading outages due to propagated disturbances requires careful planning and well-coordinated operation.

2.6.Interconnection Elements

A listing of the basic elements of an interconnection is provided below:

2.6.1. Technical Objectives

The ultimate objective of an interconnection, like the power systems it is part of, is to provide power to customers economically, safely, reliably, efficiently, and with minimal environmental impact. Each of these aspects has one or more quantitative measure, such as price per kilowatt-hour, number and lethality of accidents, frequency and duration of service interruptions, generating plant heat rate, transmission and distribution losses, and emissions factors. Interconnections are designed, and their individual components selected, with all of these objectives in mind, though they may be optimized differently in different systems.

2.6.2.Transmission Lines

Transmission lines come in two basic varieties: overhead lines and underground (or undersea) cables. Overhead lines are more common and generally less expensive than cables. The main design consideration for overhead lines is the choice of conductor type and size, which must balance the need to minimize impedance (and the associated losses), minimize cost, and minimize the weight that must be carried by support structures. Although copper is a better conductor, it has been overtaken in recent years by aluminum, which is lighter, cheaper, and in abundant supply. The most common variety of overhead conductors for high-capacity, long-distance transmission is stranded aluminum wire reinforced with steel (known as ACSR, for “aluminum conductor steel reinforced”). Other design considerations for overhead lines are the type of support structures (such as transmission towers and insulators) used, and the con-figuration of conductors on the support structures, which affects the reactance of the conductors and the strength of

Electromagnetic fields (EMFs) around the lines.

Underground cables are used where overhead conductors are inappropriate due to environmental or land use considerations, such as in high-density urban areas or ecologically sensitive areas. Cables are insulated and are typically routed through underground conduits, and often require cooling systems to dissipate heat. Cables may use copper instead of aluminum, balancing the greater cost of copper against its superior conductivity and lower resistive heating. Undersea cables are usually made of copper, and may be surrounded by oil or an oil-soaked medium, then encased in insulating material to protect from corrosion. Undersea cables often have a coaxial structure, which has an inherently high capacitive reactance; therefore undersea cables are usually DC, which is not affected by reactance. Conductor cross sections are typically measured in square centimeters (cm2) in the metric system, or thousands of circular mils (kmil) in the American system12. The capacity of a conductor to carry current without exceeding thermal limits is called its capacity, measured in kA for large conductors.

2.6.3. Support Structures

There are many possible types of support structures for overhead transmission lines. In developed countries, transmission lines are supported on structures made out of steel lattice, tubular steel, wood, and concrete. Of these, steel lattice has the highest strength to weight ratio, and is the easiest to assemble in areas that are difficult to access. Where aesthetics are an important factor, however, other materials are often used. The main function of support structures is to keep the conductors from contacting trees or other objects, including people and animals; thus the structures must be tall enough to do so even when the conductors sag due to high temperatures caused by resistive heating. All things being equal, taller structures also minimize ground-level EMFs. Because overhead transmission lines are not insulated, they are typically suspended from towers on strings of ceramic insulators, which are designed to prevent flashover, or the leakage of current from the conductor to the tower , which would present a lethal prospect to anyone touching the tower. AC transmission towers are usually designed to carry three conductors: the three phases of AC power systems. Towers that hold these in an equilateral triangle shape (called a "delta") keep the mutual reactance of the three phases balanced; non-delta configurations often require that conductors be transposed, or switch places, at regular intervals along the transmission path. Some towers carry more than one circuit, with three phases per circuit; for example, a double-circuit tower will have six conductors. (The conductor for each phase may also be subdivided into "bundles" of two or more conductors, which are physically close together.) DC transmission towers carry two conductors per circuit. On the following page shows various options for transmission tower design.

2.6.4. Transformers and Substations

Transformers are used to change voltage levels in AC circuits, allowing transmission at high voltages to minimize resistive losses, and low voltages at the customer end for safety. This ability, following the development of transformers by William Stanley in 1885, led to the rapid adoption of AC systems over DC systems. The essential element of a transformer consists of two coils of wire wrapped around an iron core. An alternating current in one coil produces a changing electromagnetic field that induces a current in the other. The voltages on either side are in the same ratio as the number of turns on each coil. For example, a transformer with a 10:1 "turns ratio" that is connected to a 15 kV supply on its *primary* side, will have a voltage of 150 kV on its secondary side. Transformers step up the voltage from generator to transmission system, and other transformers step it down, often in several stages, from transmission to sub-transmission to primary distribution to secondary distribution, and finally to the end-user voltage, such as 120 V. At the distribution level, transformers often have taps that can be used to change the turns ratio; this allows operators to maintain customer voltage levels when system voltages change. Modern transformers are extremely efficient, typically greater than 99%, but even small losses can produce a great deal of heat, which must be dissipated to prevent damage to the equipment. Large transformers are cooled by circulating oil, which also functions as an electrical insulator.

Large transformers are housed in substations, where sections of a transmission and distribution system operating at different voltages are joined. Larger substations have a manned control room, while smaller substations often operate automatically. In addition to transformers, important substation equipment includes switch-gear, circuit breakers and other protective equipment (see next section), and capacitor banks used to provide reactive power support.

2.6.5. Protection Systems

Protection systems are an extremely important part of any power system. Their primary function is to detect and clear *faults*, which are inadvertent electrical connections – that is, short circuits – between system components at different voltages. When faults occur, very high currents can result, typically 2-10 times as high as normal load currents. Since power is proportional to I2, a great deal of energy can be delivered to unintended recipients in a very short time. The goal of protection systems is to isolate and de-energize faults before they can harm personnel or cause serious damage to equipment. Note that protection systems are designed to protect the power system itself, rather than end-user equipment.

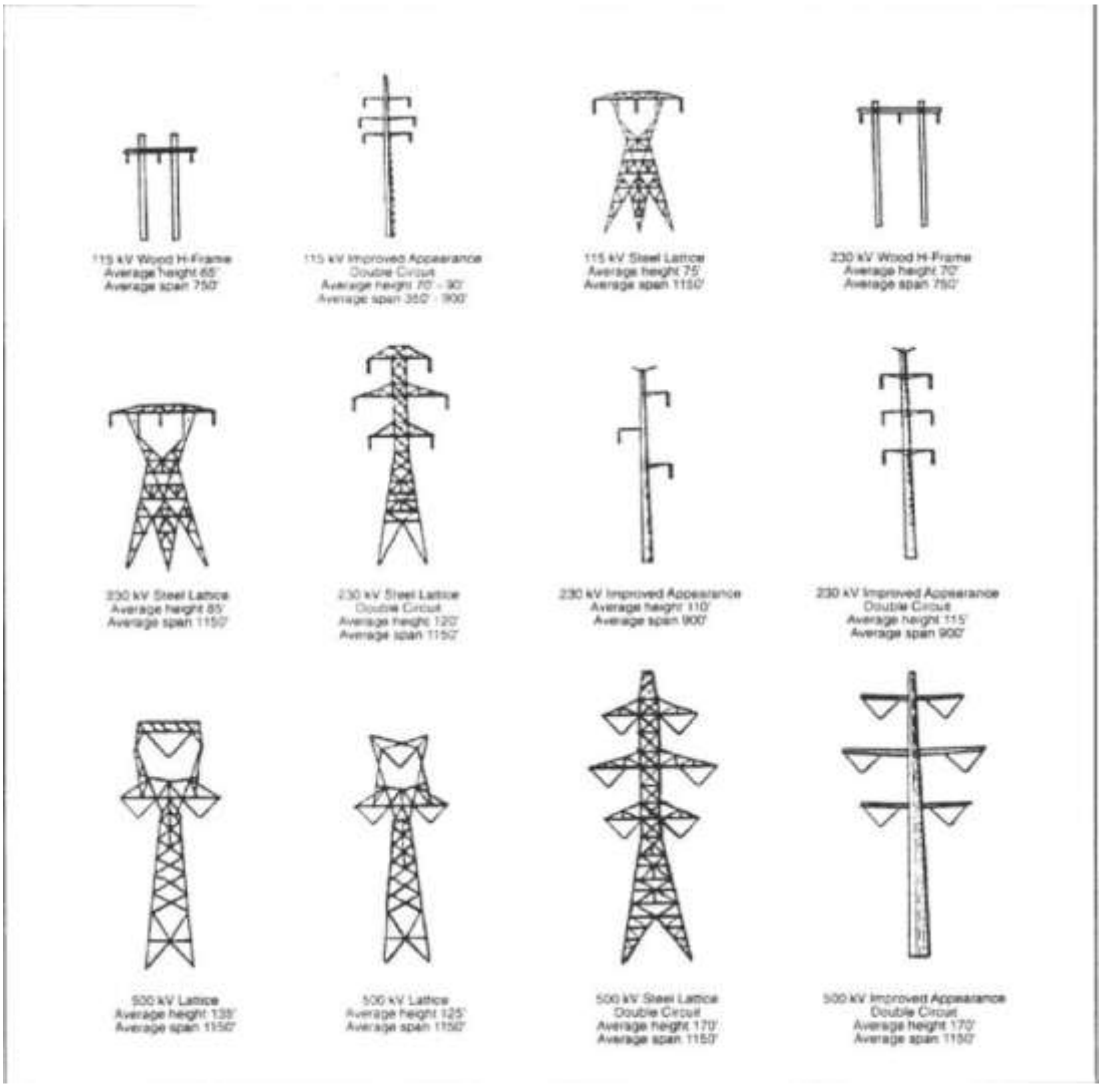

Figure 2.3: Common configurations for transmission towers. source: oak ridge national laboratory

The key components of protection systems are circuit breakers, instrument transformers, and relays. Circuit breakers are designed to interrupt a circuit in which high levels of current are flowing, typically within three voltage cycles (about 50 milliseconds in a 60 Hz system). To do this they must quench the electric arc that appears when the breaker contacts are opened; this is usually accomplished by blowing a gas, such as compressed air or sulfur hexafluoride (SF_6) across the contacts. Since human operators generally could not respond to a fault in time to prevent damage, circuit breakers are operated by automatic relays that sense faults or other undesirable system conditions.

To distinguish between normal operations and fault conditions, relays are connected to instrument transformers – voltage transformers (VT) and current transformers (CT) – that reflect the voltages and currents of the equipment they are connected to. Relays themselves can be either electromechanical or solid state devices.

Essential aspects of protection system design include determining the Specifications and placement of protection equipment, and also the correct timing and sequence of relay operations. Protection engineers must determine how long an undesirable condition should be allowed to persist before opening a circuit breaker, and the order in which circuit breakers must open to correctly isolate faults in different zones.

2.6.6.Communications, Monitoring, and Control Systems

Power system operations take place within geographically well-defined control areas, which traditionally corresponded to a utility’s service territory. With market liberalization, individual utility control area shave sometimes been combined into larger control areas under the jurisdiction of an independent system operator (ISO). In either case, system operations are coordinated by a central control center, the responsibility of which it is to keep the entire system running safely and reliably. This entails continuously monitoring system conditions and deploying system resources as the situation requires.

Traditionally, monitoring and control have been conducted semi-manually, with a heavy relianceon telephone communications with plant operators and field personnel. Increasingly, these activities are automated. Supervisory control and data acquisition (SCADA) systems combine remote sensing of system conditions with remote control over operations. For example, control center SCADA systems control key generators through automatic generator control (AGC), and can change the topology of the transmission and distribution network by remotely opening or closing circuit breakers. This monitoring and control is enabled by dedicated phone systems (often fiber optic based), microwave radio, and/or power line carrier signals.

2.7. Technical Issues Associated with AC Grid Interconnection

2.7.1.General requirements for AC interconnection

AC interconnection usually provides the greatest interconnection benefits, except in certain cases for which DC is the preferred option .Synchronous interconnection of different systems is, however, technically demanding. At a general level, the first requirement is that the systems share the same nominal frequency, either 50 Hz or 60 Hz. Then, they must regulate frequency so that they achieve and remain in synchronism (see Section 2.7.4, below). They must also interconnect at a common voltage level.

This is easier if the countries involved have agreed to a common standard for transmission voltage, such as the 380 kV standard in Europe. It is still possible for countries with different voltage schemes to interconnect by using transformers (if voltages are not very different, *autotransformers* are often used, which have only a single winding and are less expensive than ordinary transformers). Having to use an excessive number of transformers is, however, undesirable, since transformers are costly, add impedance to the line, and may require lengthy repair after a fault, keeping the transmission intertie out of operation for an extended period.

Good engineering must be complemented by good cooperation among the interconnected systems. In both planning and operation phases, this requires extensive data sharing, joint modeling, and clear communication.

2.7.2. Technical issues for AC interconnection

One way of thinking about the technical issues of AC interconnections is to group them into those associated with the transmission interconnection itself, and those associated with operating the larger interconnected sys-tem. Transmission issues are discussed in 2.7.3. Key issues include thermal limits, stability limits, and voltage regulation, which are the main constraints on transmission line operation. Other transmission issues include loop and parallel path flows, available transfer capacity, and FACTS technologies. System-wide issues are discussed in 2.7.4, including frequency regulation, power quality and the coordination of planning and operations.

2.7.3. Transmission issues

Thermal limits

The capacity of transmission lines, transformers, and other equipment is determined by temperature limits. If these limits are exceeded, the equipment can be damaged or destroyed. Equipment ratings have traditionally been conservative, and operators have stayed well below the rated limits, but increased power trading in liberalized markets has created pressure for higher utilization. Instead of a single thermal limit, dynamic ratings are now often used. For example, transmission lines can carry more current when heat is effectively dissipated, and thus will have a higher rating on cold, windy days without direct sunlight.

When transmission lines heat up, the metal expands and the line sags. If the sag becomes too great, lines can come into contact with surrounding objects, causing a fault. Excess sag can also cause the metal to lose tensile strength due to annealing, after which it will not shrink back to its original length. Important transmission lines are often monitored by a device called a “sagometer”, which measures the amount of sag, making system operators aware of dangerous sag conditions.

Stability limits

The stability limit of a transmission line is the maximum amount of power that can be transmitted for which the system will remain synchronized if a disturbance occurs. The power flow through a transmission line is governed by the difference in power angle between the sending and receiving sides:

$$P = V_R * V_S * \sin(\delta) / X$$

All other factors being equal, the power transmitted from the sending side to the receiving side increases as the difference in power angle between the two points, called δ (delta), approaches 90°, and decreases as it approaches 0°. However, the feedback mechanism that keeps generators in synchronism and returns them to synchronous operation if they are disturbed becomes more tenuous as δ approaches 90°. The stability limit rep-resents the value of the power angle that allows the highest power transfer while maintaining stability; a typical maximum value of δ is around 45°.

In general, stability limits are more important than thermal limits for long transmission lines, while thermal limits are more important for shorter lines. In the United States, for example, thermal limits are more important in the Eastern interconnection, while stability limits play a larger role in the Western interconnection.

Voltage Regulation

Utilities generally maintain system voltages within 5-10 percent of nominal values in order to avoid the risk of voltage collapse, which can lead to a major interruption of service. Power system voltages are primarily governed by reactive power flows. Voltages along a transmission link are a function of the physical length of the circuit, the impedance per unit length, and the flow of real power: the higher the current and the greater the reactance, the larger the voltage-drop (if the reactance is predominantly inductive) or gain (if capacitive). Voltage collapse can be triggered when reactive demand is high and systems are operating near their stability limits, then undergo a disturbance that triggers a quick downward spiral. To maintain voltages along long AC trans-mission lines, reactive compensation of various kinds can be employed, such as series and shunt capacitors, and shunt reactors.

System operators also maintain voltage levels in order to protect end-use equipment (for example, low voltages cause motor currents to increase, and higher currents can cause thermal damage). Utilities are usually obliged to provide power to customers within prescribed voltage tolerances. Devices called tap-changing transformers in the local distribution system are used to ensure that customer voltages are maintained even when system voltages change substantially. Note, however, that the power quality experienced by the customer is generally more affected by local conditions in the distribution system, such as switching, lightning strikes, and the loads of other customers, than by conditions in the transmission system. Protecting sensitive electronic end-use equipment is the responsibility of the customer rather than the utility.

Loop and parallel path flows

In power systems, power flows do not necessarily follow a specified transmission path – for example, from seller in system A to buyer in system B - but divide themselves among various connected transmission paths according to the voltage levels and impedances of the path. To put it another way, power flows con-form to physical laws rather than economic agreements. In some cases, a power transaction can take quite unwanted paths, resulting in line losses and possibly overloading lines of neighbors having nothing to do economically with the transaction. In general, these phenomena are referred to as circulating power, loop flows, and parallel path flows. A well-known example of these flows is that in a power transfer from the U.S. Pacific Northwest to the state of Utah, one-third of the power flows through Southern California, and another one-third flows through Arizona. What is important for the reliability of an interconnected system is that operators know the sources and destinations of all transactions and where the power will flow, and are able to calculate the resulting reliability risks.

Available Transmission Capacity (ATC)

An important measure of transmission capacity is transmission transfer capability (TTC), which is the maximum power flow that a line can accommodate at any given time and still be able to survive the loss of a major generator or transmission link elsewhere in the system. Available transmission capacity (ATC) is the TTC of a line minus the amount of capacity already committed to other uses on that line. ATC is thus the measure of how much power can be safely transmitted over a transmission line at a given time while ensuring overall system reliability.

Flexible AC Transmission System (FACTS)

Flexible AC Transmission System (FACTS) refers to a number of different technologies based on power electronics and advanced control technologies, which are used to optimize power flows and increase grid stability18. FACTS equipment is expensive, but it can pay for itself by directing power flows with precision, eliminating loop flows, and relieving transmission bottlenecks without requiring that new lines be built. It can also improve frequency and voltage stability, decrease transmission losses and voltage drops, and improve power quality. FACTS equipment includes static compensators, static VAR compensators, thyristor controlled series capacitors, phase-shifting transformers, inter phase power controllers, universal power flow controllers, and dynamic voltage restorers. With FACTS, AC transmission over distances that were not previously possible due to stability limits has become possible . FACTS devices have been used extensively in the North American and European interconnections, and increasingly in developing regions, including the South Africa-Zimbabwe interconnection, the Brazil north-south interconnection, and other inter-connections in Latin America, Africa, and South Asia.

Transmission upgrades

If existing transmission facilities are to be used in the interconnection but are not adequate to transmit the expected volume of power, they can be upgraded either by adding additional lines in parallel or increasing the transmission voltage. If these options are not available, FACTS or HVDC solutions can be explored.

2.7.4. Systems issues

Key technical systems issues that must be addressed in planning and implementing a grid interconnection include frequency regulation, coordination of operations, interconnections of power systems with weak grids, and aspects of interconnection that are associated with electricity market liberalization.

Frequency Regulation

Controlling frequency in a synchronous network is ultimately an issue of precisely matching generation to load. This load-matching occurs on several time scales. System planners and operators plan generation from hours to months in advance, coordinating the dispatch of generating units and power exchanges with other systems based on factors such as historical load patterns, weather predictions, maintenance schedules, and unplanned outages. At the scale of minutes to seconds, frequency is maintained by Automatic Generator Control (AGC), which precisely controls the real and reactive power output of certain generators that are able to respond rapidly to changes in load. Hydroelectric and gas turbine units are generally used for regulation and load following; nuclear plants and large coal-fired plants can be damaged by rapid changes of output and are not used in this function.

At the instantaneous time scale, frequency synchronization is a self-regulating phenomenon. When loads suddenly increase, generators slow down slightly, giving up some of their mechanical energy of rotation to supply the additional electrical energy required; when loads suddenly decrease, generators speed up. Through feedback among the different generators in the system, synchronism is maintained, at a frequency slightly higher or lower than nominal. When the control center computers sense these frequency movements, AGCs are notified to increase or decrease generator output to the amount necessary to balance load and return frequency to nominal levels. System operators also have a variety of off-line reserves or “ancillary services” available upon need to assist in frequency regulation and other aspects of reliable system operation. The theory of parallel operation of generators in large networks, once a daunting engineering problem, was established in the 1930s. Modern networks seldom deviate from nominal frequency by more than 0.1 Hz, and generally operate within 0.01 Hz of nominal.

In an interconnected system, except where DC links are used, frequency synchronization must be accomplished through the means above, jointly administered across the interconnected systems.

Interconnection of power systems with weak grids

Not all interconnections take place between power systems in top technical condition. In the developing world, many power systems bear the marks of age, poor repair, and insufficient investment, ranging from corroded conductors and deteriorating insulation to leaking transformers, worn out switchgear, and a variety of inoperable equipment. Equipment is often obsolete, and operations that are automated elsewhere may be carried out manually. Systems in poor repair generally perform poorly, have serious reliability problems, and often fail to comply with safety or environmental standards. As one scholar described the difficulties of interconnection among sparse, poorly maintained systems:

“The vastness of the area and the low power consumption density in most African countries makes the operation of the interconnection difficult from an operational point. Many of the loads are connected to spurs off a grid that has a low level of interconnectivity. In addition, most of the networks have suffered from a lack of maintenance due to a shortage of funds. This has dramatically reduced the reliability of the system and outages frequently occur in many places. The combination of these factors has forced industries to provide their own generating facilities in the form of diesel power. These plants then operate in island mode and will often also provide power to towns and villages in the immediate vicinity of the plant. Some utilities are discouraging this practice, but need to convince these clients to connect to a grid that may not be that reliable in the first place, particularly in areas connected to spurs.”

Interconnection can improve such systems, by providing emergency reserves and more reliable sup-plies. However, careful planning must ensure that the interconnection doesn’t lead to additional stresses elsewhere in the interconnected system.

Countries with weak or isolated grids are usually poor candidates for siting nuclear power plants (NPP). NPPs have much more stringent requirements regarding grid stability than do fossil fuel thermal plants, for two reasons. First, the auxiliary systems in a NPP are much more sensitive to power conditions than such systems at other plants because of the potential consequences – namely, that a major failure could lead to a nuclear accident. Second, NPPs have large amounts of decay heat to remove long after the chain reaction is shut down, and require power to operate cooling water pumps during this extended period. With weak grids, large variations in voltage and frequency will trip a NPP off-line; worse, the sudden loss of a large power plant start a cascading failure that collapses the grid altogether. With interconnection to other grids, however, siting a NPP in a country with a weak or isolated grid becomes a plausible option. The interconnection can help to stabilize the weak grid, and it can also provide access to an independent back-up grid connection, which is a safety requirement for NPPs.

2.8. Planning and Modeling of Interconnection Technical Parameters

2.8.1. Modeling requirements for transmission interconnections

During the project planning process, the design of the technical and operating parameters of an interconnection requires extensive computer modeling to assure that the interconnection and the systems it connects provide reliable and economical service. The types of modeling required include the following:

Power Flow Modeling

The most important single class of tools in power system engineering is that of power flow models, also called load flow models. These models are used to compute voltage magnitudes, phase angles, and flows of real and reactive power through all branches of a synchronous network under steady-state conditions. Power flow models account for loop flows, and make it possible to understand how much power will actually flow on trans-mission lines under a given set of circumstances. Modelers vary the initial conditions – for instance, adding a proposed new generator to the network – and determine the impact on power flows throughout the system.

A standard reliability requirement is that utilities meet the “n-1” criterion, meaning that the system is able to continue to supply all loads despite the loss of a large generator or the outage of large transmission line. These “contingencies” are modeled with a power flow model, and if the model results indicate a problem, planners and operators must address it, typically by adding new generation and/or transmission capacity, or by changing operational procedures.

To run power flow models requires that each bus and line in the system be thoroughly described, requiring a great deal of input data. The real and reactive power consumption at each load bus, the impedance of each line and transformer, and the generating capacity of all generators must be known.

Power flow models are used by the North American Electric Reliability Council (NERC) to calculate a power transfer distribution factor (PTDF) for individual power transfers. The PTDF shows the incremental impact of a power transfer from a seller to a buyer on all transmission lines, as a percentage of their transfer capacity. If a line is overloaded, transactions that have PTDF values greater than 5 percent on the overloaded line can be curtailed.

Optimal Power Flow (OPF) Modeling

Optimal power flow models take the outputs of power flow models and analyze them according to user-defined objective functions, such as least cost or minimization of transmission loading. Where the ordinary power flow model provides only engineering information – voltage, power, and phase angle, for example – OPF models assist operators in ranking alternatives according to economic and other criteria.

Short Circuit Modeling

Short-circuit models are used to compute fault currents for various kinds of short circuits (phase-to-phase and line-to-ground). The results of short-circuit models are used to determine the required specifications for protection equipment such as circuit breakers and relays, and to determine the proper settings for relays to clear faults.

Dynamic Stability Modeling

Dynamic stability models are used to determine whether the synchronous machines in a power system – namely the generators and motors - will remain in synchronism in the case of a disturbance, for example the loss of a generator or transmission line, a fault, or a sudden increase in demand. The models work by calculating the angular swings of synchronous machines during a disturbance, and determining whether they will remain within an envelope of stable operation.

Transient Modeling

Transient models are used to compute the magnitude of transient voltages and current spikes due to sources such as lightning and circuit switching. The model results are used to specify the insulation requirements for lines and transformers, to determine grounding schemes, and to determine surge arrester specifications.

3.4.2.Data Requirements for Planning

Exchange of data between the owners/operators of the systems to be interconnected regarding the technical characteristics and requirements of their respective systems is essential from the outset of an interconnection project. The need for transparency and for the development of mutual under-standing cannot be overemphasized. An example of the kinds of technical data that are typically exchanged in an interconnection project can be seen in Table 2.1.

Table 2.1: Sample of technical data requirements for interconnection

Overhead	Nominal Voltage (kV)
Transmission Line	Length (km)
	Route Map (including transposition locations)
	Plan and profile drawings
	Electrical single line diagram showing transmission line and any other associated devices
	required for switching, reactive compensation, protection and control and communication
	and the interface to the generator or end-user facility
	Nominal power transfer rating
	Emergency power transfer rating
	Conductor type and size
	Overhead ground wire type and size
	Configuration of condactors and overhead ground wires on tower (include diagram
	showing phase spacing and clearances to ground)
	Positive Sequence R_1 , X_1 and B_1 (ohms/km)
	Zero sequence R_o and X_o (ohms/km)
	Description of protections provided
	Description of communication systems

Reactive	Connection Location
Compensation	Type, make, model
device	Configuration
(if applicable)	
	Rated Voltage (kV)
	Size (MVAr)
	Switching device: type, make, model, interrupting capability, continuous current
	rating, tripping and closing times and any switching restrictions
	Criteria for automatic switching
	Description of protections provided
Intermediate	Electrical single line diagram
or terminal	Circuit Breakers: type, model, interrupting capability, continuous current rating,
substation	tripping and closing times
(if applicable)	Description of protections

CHAPTER THREE

Interconnection between Sudan and Egypt

3.1. Introduction

The Ministry of Electricity and Dams (MED) - the Republic of Sudan - and the Egyptian Electricity Transmission Company (EETC) - Arab Republic of Egypt (Egypt) - have agreed to jointly conduct and finance a feasibility study into the interconnection of their electrical networks.
The objective of the study is to conduct a techno-economic feasibility study for the Sudan-Egypt Bilateral Electrical Interconnection Project up to the year 2030 and investigate and determine the economic viability of the proposed electrical interconnection between Sudan and Egypt.

The study will determine the preferred scheme for interconnection of the two countries based on technical and economic analysis and will include functional specifications, cost estimates, implementation schedules and social and environmental scoping studies for the preferred schemes.

Both EETC and MED have noted that there is a high level commitment to the study within their organizations. More generally, it was noted also that there is strong commitment from the League of Arab States for interconnection of Arab countries.

Following the submission and acceptance of the Inception Report, this Interim Report identifies potential trade flows that could occur between Egypt and Sudan between 2011 and 2030. This Interim Report also includes initial technical studies to assess a number of potential electrical interconnection options. The two preferred options emerging from this initial analysis will be taken forward, following agreement with EETC and MED.

3.2. Rules of Trading

For any power trading between EETC and MED, the following simple rules must apply:

•A utility can export power only if it has capacity in excess of that required to meet its own demand, all export commitments at that time and maintain the required spinning reserve.

•Utility‘A’canexportpowertoUtility‘B’aslongastheSMPislowerthanthatofUtility‘B’.

•The maximum export level is reached when any additional exports from ‘A’ to ‘B’ results in an SMP for ‘A’ that is equal to or higher than the SMP for ‘B’.

3.3. Study Options

The interconnection options considered here are as identified in the Inception Report and include four 220 kV options as listed in Table 3-1. The approximate route lengths are identified as are the assumed commissioning dates.

Table 3.1: Interconnectionoptions

Option	EgyptTerminal	SudanTermial	ApproximateLength(km)	Assumedcommissioningdate
220 kVoptions				
1	Toshka 1 or2	WadiHalfa	120	2015
2	HighDam	WadiHalfa	330	2015
3	Shalatein	PortSudan	450	2015
4	HighDam	PortSudan	650	2015

Typical conductor types, sizes and bundling arrangements for 220 kV transmission lines in use in Egypt and Sudan are summarized in Table 3.2, which also shows the assumed electrical parameters for these lines. For the purpose of the interim studies they have assumed the following for the interconnectors

- Double circuit 220 kV - 2*400 mm^2 ACSR conduct

Table 3.2: Conductor details

Voltage	Country	Conductor	R(Ohm/k)	X(Ohm/k)	B (Mho/km*106)	Thermalrating(MVA)
220Kv	Egypt	2*400 mm2ACSR	0.0412	0.302	3.72	461
220kV	Sudan	2*240 mm2ACSR	0.0669	0.302	2.05	366

5.4. Sudan study model

In Sudan the main grid developments up to 2015 comprise the addition of a single 500 kV Atbara – Kabashi line and various extensions of the 220 kV systems as indicated in Figure 3.1. A number of the 220 kV developments are not shown as they are radial developments which will not significantly affect the study.

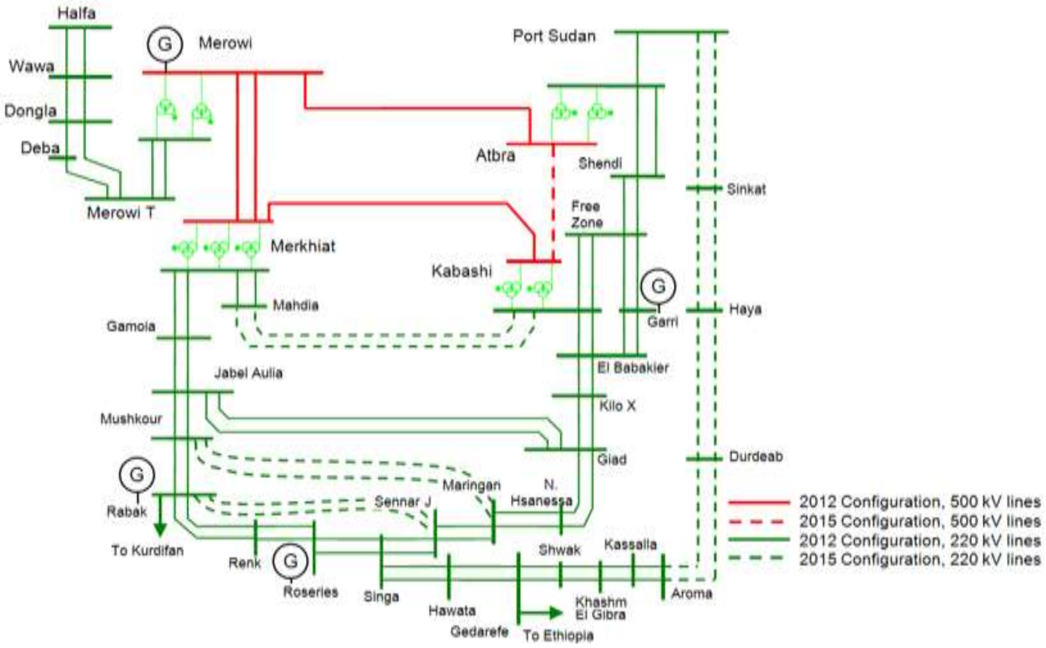

Figure 3.1: Structure of the main grid in Sudan between 2012 up to2015

5.5.220kV options

Table 3.3.shows indicative power transfer limits for each 220 kV option in each direction. Options 1 and 2 indicate similar transfer limits. This is expected as the effective transmission distance is the same in both cases.

Option 1, Toshka 2 – WadiHalfa has clear benefits as it is a much shorter interconnection than any of the other 220 kV options and could therefore be realized at significantly lower cost. Apart from the economic benefits that may be realized from energy trade, Option 1 would also provide the mutual benefit of increased security of supply for the areas near to the border in both countries.

Table 3.3: Indicative transfer limits for 220 kVoptions

Option	Description	Approximate length(km)	Transfer limits(MW)	
			Egypt to Sudan	Sudan to Egypt
1	Toshka 2 - WadiHalfa	120	220	160

2	High Dam - WadiHalfa	330	220	160
3	Shalatein - PortSudan	450	160	100
4	High Dam - PortSudan	650	180	100

3.6. Effect of Interconnection to Sudan Grid

Table 3.4:220KV Voltage change before and after interconnection

Case 220KV				
Before Interconnection			After interconnection	
Station	voltage	Voltage%	Voltage	Voltage%
WadiHalfa	228.271	103.76	220.534	100.24
Wawa	231.941	105.43	221.78	100.81
Dongla	232.705	105.78	223.185	101.45
Aldeba	231.094	105.04	223.799	101.73
Merowi Town	231.769	105.35	226.159	102.8
MerowiGeneration	232.206	105.55	227.584	103.45
Atbara	217.912	99.05	217.331	98.79
Almarkhiat	212.589	96.59	212.075	96.4

Table 3.5:500KV Voltage change before and after interconnection

Case 500KV				
Before Interconnection			After Interconnection	
Station	Voltage	Voltage%	Voltage	Voltage%
Merowi	524.067	104.81	522.216	104.44

Almarkhiat	497.567	99.51	496.285	99.26
Atbara	497.437	99.49	495.845	99.17
AlkabaShi	494.108	98.82	492.889	98.58

Table3.6:Transmission lines befor interconnection

Before Interconnection				
Line	Active Power	Reactive Power	Loading%	Power Losses
Merowi-Atbara(500KV)	325.731	278.051	17.2	3.5078
Merowi-Almarkhiat(500KV)	279.878	65.202	10.95	3.36
Egypt-WadiHalfa	0	0	0	0
WadiHalfa-Wawa	5.047	9.992	2.23	0.0472
Wawa-Dongla	5.03	15.705	3.27	0.0067
Aldeba-Dongla	27.556	8.718	4.22	0.1629
Aldeba-Merowi Town	53.91	13.792	8.15	0.2913
Merowi Generation-MerowiTown	75.187	8.762	22.14	0.2771
Merowi Generation-Dongla	26.643	14.151	8.82	0.1741

Table3.7:Transmission lines after interconnections

After Interconnection				
Line	Active Power	Reactive Power	Loading%	Power Losses
Merowi-Atbara(500KV)	325.633	274.594	17.16	3.5059

Merowi-Almarkhiat(500KV)	280.067	67.33	11.02	3.3557
Egypt-WadiHalfa	75	32.344	17.15	1.3578
WadiHalfa-Wawa	136.428	27.879	29	5.8561
Wawa-Dongla	64.637	8.433	13.49	1.0769
Aldaba-Dongla	61.89	21.938	9.99	0.4078
Aldeba-Merowi Town	35.291	19.433	6.05	0.2907
Merowi Generation-Merowi Town	14.246	23.504	8.2	0.0447
Merowi Generation-Dongla	23.245	4.404	7.06	0.213

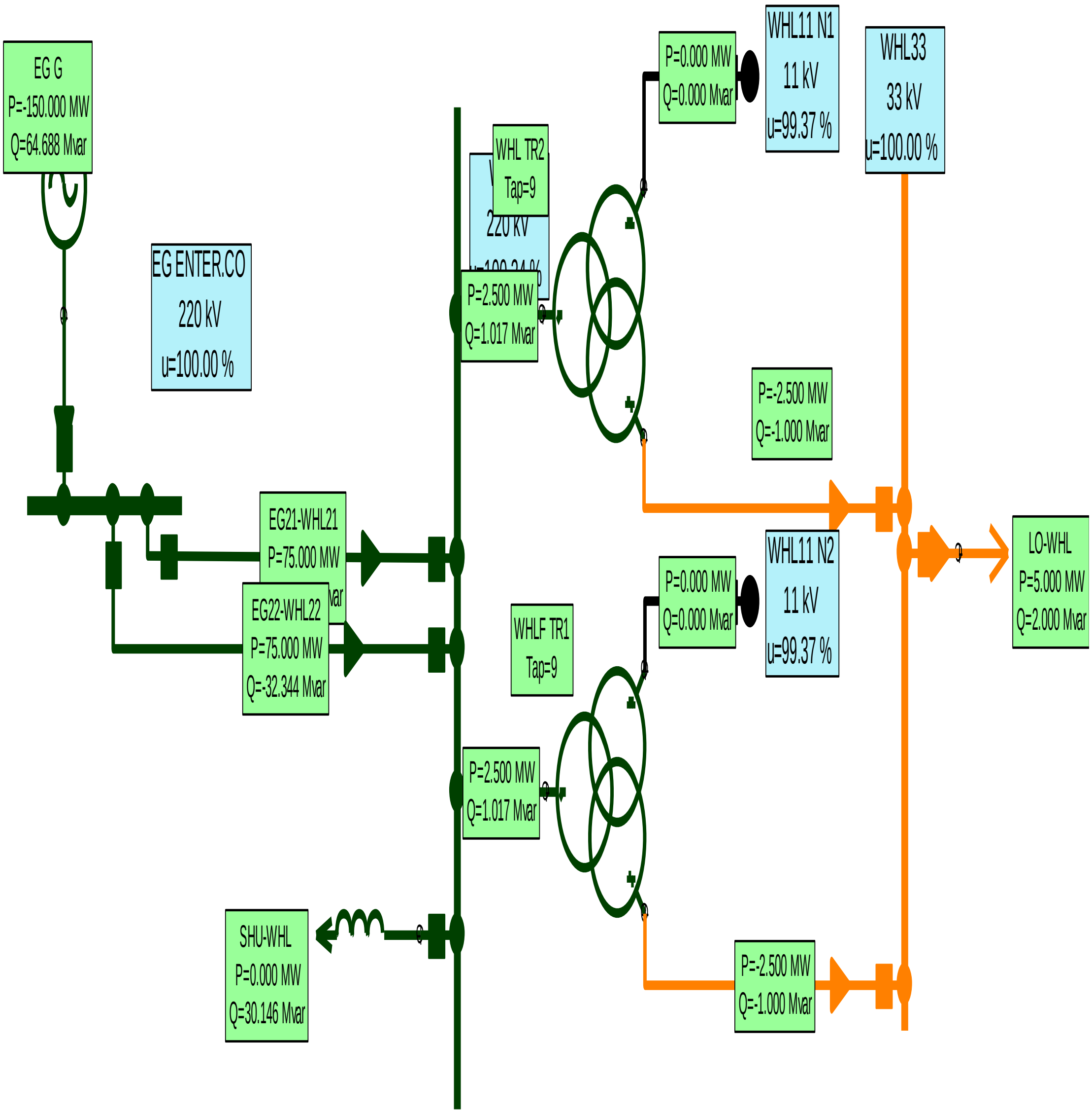

Figure 3.2:Sudan grid after interconnection

CHAPTER FOUR

DISCUSSION OF RESULTS

4.1. Introduction

The impact of interconnection between Sudan and Egypt included six areas ,they are Wadi Halfa,Wawa,Dongla,Aldeba , Merowi town and Merowi generation,which contains transmission lines connecting wadi Halfa with wawa ,wawa with dongla,dongla with aldeba,aldeba with merowi town,merowi town with merowi generation and merowi town with dongla.In this unit it studied the impact of interconnection to those areas and extract the benefits achieved from the Interconnection.

4.2. Results Achieved from the Interconnection

From the load flow we find that the interconnection with Egypt let to improving the level voltage side 220KV (Wadi Halfa,Wawa,Dongla)and most of 220KV stations in North Sudan state .

Also the interconnection decreased the over loading in Merowi Transformers 33/220/500KV.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The last 15 years have seen a spurt in the implementation of projects Electrical interconnection between states, in terms of the number of projects or capabilities Exchange between systems. Completed interconnection projects have contributed to varying degrees In improving the reliability of electricity grids and in reducing the investment costs of countries indicated, however, the volume of energy exchange did not live up to the expectations used in Feasibility studies for these projects. This is mainly due to the delay of some states in Sign trade agreements governing energy cost and mutual capacity, and to sometimes limited font capacity. The next 15 years are expected to see a big spurt in interconnection systems, in terms of the number of states associated with and the ability to exchange between those States, as a result of the completion of a number of projects under way or planned Create it.

After met the supervisor more than 3 times to discuss how to collect data about the research he gave us a letter to the competent authorities to gave us the studies of included the research.

The journey of collecting data about the studies of interconnection between Sudan and Egypt has been began firstly, by visiting the Sudanese Electricity Company LTD ,then they send us to the Sudan Holding Company LTD where there we met the engineers of the company more than 8 times, at first they gave us the feasibility study of the interconnection between Sudan and Egypt and after read the report of the study and extract important elements to puted them in the research ,then we met them another time to do the simulation using Neplanv557 program for design interconnection grid between Sudan and Egypt and simulated it, then wrote the results and discuss them to extract the benefits from the interconnection. We preferred HVAC to HVDC because it acheived the minimum cost if we compared to HVDC ,also the frequency and the voltage of the two countries as the same .In some station we require reactive power to keep the voltage at the normal level especially those stations which has under voltage.

5.2. RECOMMENDATIONS

- Study the option of HVDC Interconnection and Its effect on stability and quality on the grid of Sudan and compare it result with HVAC interconnection.
- Study the effect of HVAC and/or HVDC interconnection with 500KV level.
- The effect of STATCOM to increase the limit of power transferred from Egypt .
- Study the effect of interconnection from political and/or Environmental and/or Social Issues side.

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