Palestine Polytechnic University

College of Engineering

Title

Design of High Voltage Transmission system between Al-Eizariya and Huwara

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جامعة بوليتكنك فلسطين

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كلية الهندسة

دائرة الهندسة الكهربائية

#######

فريق المشروع

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بناء على نظام كلية الهندسة وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة المناقشة , تم تقديم هذا العمل إلى دائرة الهندسة الكهربائية وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة تكنولوجيا الطاقة الكهربائية.

توقيع المشرف

توقيع اللجنة المناقشة

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توقيع رئيس الدائرة

الاهداء

الى معلمنا الاول ومعلم الناس الخير نبينا محمد "صلى الله عليه وسلم"

الى من زرعوا في نفوسنا الطموح والمثابره .... آبائنا الاعزاء

الى ينابيع المحبه والعطاء .... امهاتنا الاحبه

الى من يحملون في نفوسهم ذكريات الطفولة والشباب .... إخوتنا وأخواتنا

الى من مهّدوا لنا طريق العلم والمعرفة .... أساتذتنا الأفاضل

الى من هم احياء في قلوبنا رغم انهم غادرونا

الى من قدموا الغالي ونفيس لهذا الوطن .... اسرانا البوسل وشهدائنا الابرار

الى كافه الاصدقاء والاهل والاحبه

"ان استطعت فكن عالما .. فإن لم تستطع فكن متعلما ، فإن لم تستطع فأحب العلماء ،فإن لم تستطع فلا تبغضهم"

بعد رحلة بحث و جهد تكللت بإنجاز هذا البحث ، نحمد الله عز وجل على نعمه التي منَ بها علينا فهو العلي القدير ، كما لا يسعنا إلا أن نتقدم بأسمى عبارات الشكر و التقدير

للدكتور مــاهر المغــالسة

وله نقول بشراك قول رسلنا صلى الله عليه وسلم:

" ألا أخبركم عن الأجود الأجود ؟. الله الأجود الأجود ، وأنا أجود ولد آدم ، وأجودكم من بعدي رجل علم علما فنشر علمه ؛ يبعث يوم القيامة أمة وحده "

ان كان هناك اهل للشكر فانت اهله

فريق العمل

Abstract

This project aims to design an electrical transmission system that connects the two regions of Al-Ezariya and Hawara. The system consists of many parts such as transmission substations, transmission line, towers, protection systems, in addition to the monitoring system.

Before starting the design of the transmission system, it is necessary to study the load growth in the region in order to ensure that the system can feed the area between Al-Ezariya and Hawara until 2040 without any problems. In addition, studying the load growth is very important in the process of determining the rated power of the transformers and also identifies the appropriate protection devices that required to protecting the system. In addition, to selecting the appropriate type and cross section area for the transmission line and underground cables that required for the transmitting of electric energy.

In this project we have used the simulation programs ETAP and Matlab, where these programs allows us to study the network we designed and find the problems in this system and also find appropriate solutions to improve system performance.

يهدف هذا المشروع إلى تصميم نظام نقل كهربائي يربط بين منطقتي العيزرية وحواره. ويتكون النظام من مجموعه الأجزاء مثل محطات التحويل، وخط النقل، والأبراج، وأنظمة الحماية، بالإضافة إلى نظام المراقبة.

قبل البدء في تصميم نظام النقل، من الضروري دراسة نمو الاحمال في المنطقة لضمان قدره النظام على تغذيه المنطقة بين العيزرية وحواره حتى عام 2040 دون أي مشاكل. وبالإضافة إلى ذلك، دراسة نمو الاحمال مهم جدا في عملية تحديد قدره كل محول من المحولات المستخدمه في محطات التحويل بالاضافه أيضا تحديد أجهزة الحماية المناسبة اللازمه لحماية النظام. وبالإضافة إلى ذلك، اختيار نوع وسماكه خط النقل المناسب الطاقه في هذا النظام.

في هذا المشروع قمنا باستخدام برامج المحاكاة Matlab-Simulink & ETAP، حيث تسمح لنا هذه البرامج بدراسة الشبكة التي قمنا بتصميمها والعثور على المشاكل في هذا النظام وأيضا إيجاد الحلول المناسبة لتحسين أداء النظام.

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1.1. Overview

The electric power industry has evolved over many decades, from a low power generator, serving a limited area, to highly interconnected networks, serving a large number of countries, or even continents. In 1878, Thomas A. Edison began work on the electric light and formulated the concept of a power station where it was the opening of the station in New York City in 1879. But there are problems in the transfer of electrical energy to the long distances that were solved this problem in 1885 by William Stanley.

In 1888 Nikola Tesla explained the advantages of polyphase versus single-phase systems, who invented by Edison. In 1893, the first three phase line in Germany became operational in 1891, transmitting power 179 km at 12 kV. The first three-phase line in the United States (in California) became operational in 1893, transmitting power 12 km at 2.3 kV. The three-phase induction motor conceived by Tesla went on to become the workhorse of the industry.

Then continued evolution of the electrical power systems, where it was set up many power stations, such as thermal power plant and nuclear power plant, where it was set up the first plant in Russia in 1954 and was producing 5 MW in addition to renewable energy power plants. All of this development that took place in the field of power systems, making them the greatest and 2نmost complex network built by man, it includes a very broad areas and it became possible for any individual is indispensable even for one day.

1.2. The objectives of the project

1. Evaluate the load growth at the network then, study the load effect for 30 years.
2. Designed protection system for the transmission system.
3. Design transmission line connect Al-Eizariya and Huwara.

1.3. Methodology

1. Collect the need and appropriate data
2. Analyze the data by using Microsoft Excel
3. Conduct load forecasting
4. Design the component of the transmission system
5. Using Matlab-Simulink and ETAP to simulate the transmission system

1.4. Challenges

1. Difficulties in collection data
2. The lack of a universal standard for the voltage level (161 kV)
3. Lack of case studies about the voltage level (161 kV)

1.5. Time schedule

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Task 1	■	■																																		
Task 2			■	■	■	■																														
Task 3						■	■																													
Task 4								■	■	■																										
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Task 9																								■	■	■	■	■	■	■	■	■				
Task 10																																■	■	■	■	■

Task 1: Selection project

Task 2: Data collection

Task 3: Study the load growth

Task 4: Design the protection system and the substation

Task 5: Design the transmission line for the system

Task 6: Finishing the introduction to graduation project book

Task 7: Make the necessary adjustments to the content of introduction to the graduation project.

Task 8: Study the monitoring system

Task 9: Simulate the transmission system by using ETAP and Matlab

Task 10: Finishing the graduation project book and prepare the presentation

Chapter 2 Literature and Overview

2.1. Electrical Supply

2.2. Load growth

2.3. Symmetrical components and fault analysis

2.3.1. Faults

2.3.2. Symmetrical Components

2.4. Reliability of transmission system

2.5. Summary

2.1. Electrical Supply

Power systems consist of generation system, transmission system, substations and distribution system. Electrical energy is transported through several stages where the step up and step down the voltage to several levels in order to reduce the loss of power.

The region that we want to design transmission system for it is extend from Al-Eizariya and Huwara and the distance between them 42.5 kilometers. This region gets the power needed form JDECO.

Jerusalem district electricity company (JDECO) is a company that is providing power for the region. This region includes several cities are Ramallah, Jerusalem, Bethlehem and Jericho. Get electric energy by 37 electrical connection points (in appendix B) with the Israeli side and the Jordanian side. The value of power that can be provided to anchor points 556.5 MW.

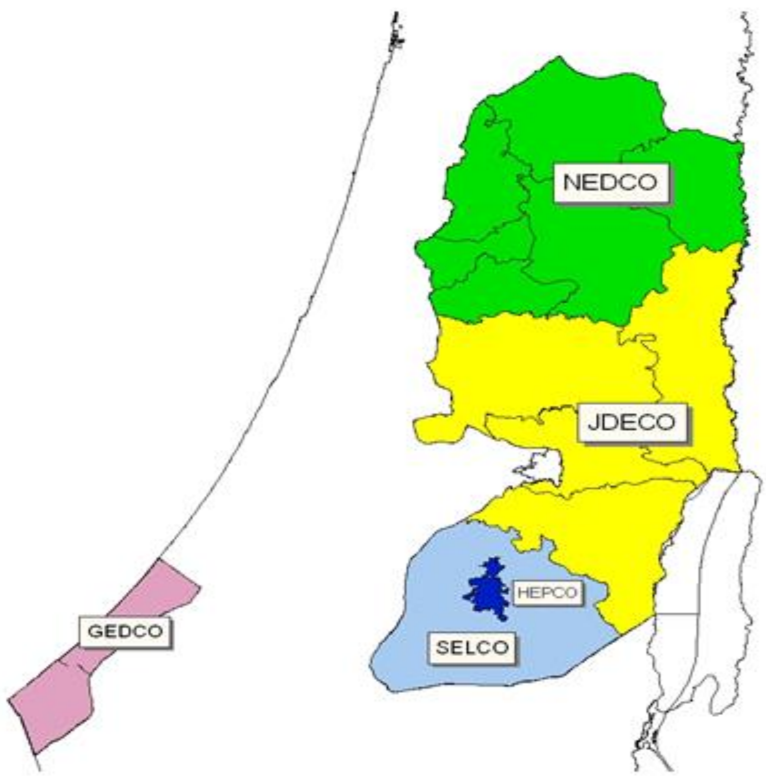


Figure 2.1: West Bank

2.2. Load growth

Load forecasting and load growth:

Load forecast study is a very important step in the improving and designing the power system, where this study refer to the prediction of the load behavior for the future and it aims mainly to predict to quantity of energy needed to meet the needs of customers.

There are two types of forecast:

1. Demand forecast
   To determine capacity of generation, transmission and distribution required.
2. Energy forecast
   To determine the type of generation facilities required.

Now we do this study to design the transmission system for the region between Al-Eizariya and Huwara.

By considering the annual growth as shown in Fig.2.2. The load growth is shown below.

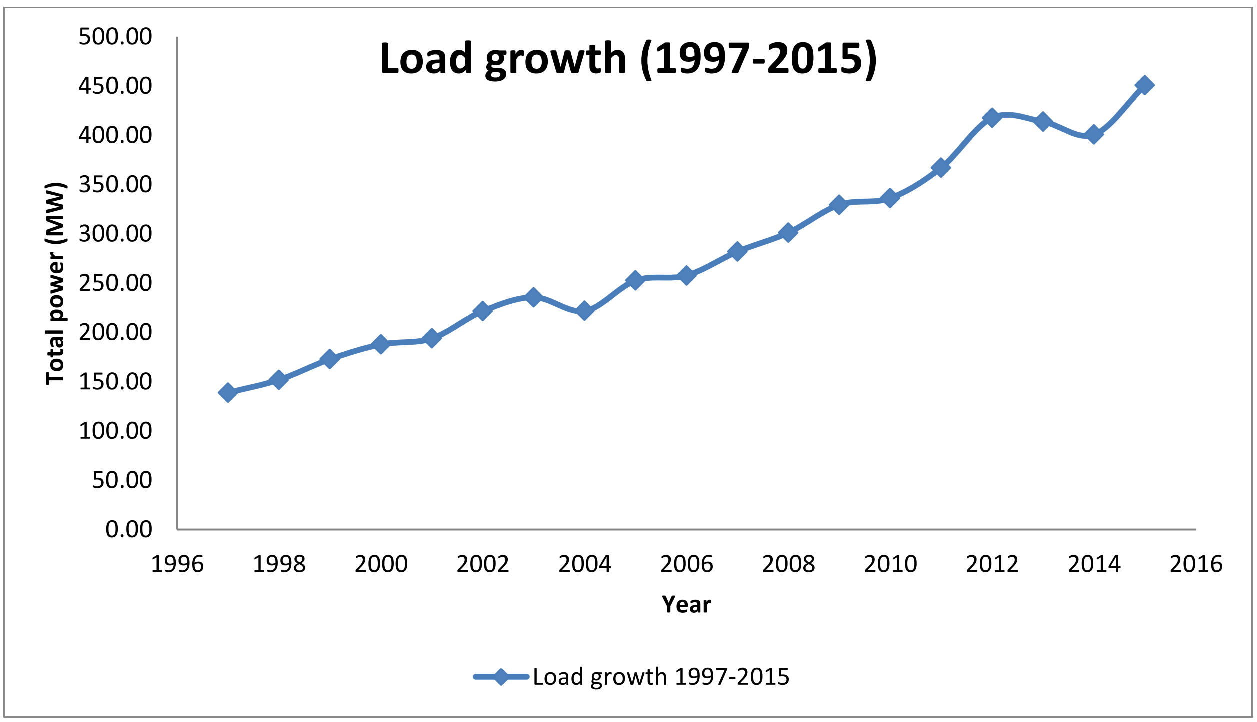


Figure 2.2: Load growth from 1997-2015(JEDCO Distribution area)

After a study load growth from 1997 to 2015 shown in the Fig 2.2, the rate of increase in load is almost 11.5% per year. Consequently, we expect the future loads for the year 2040 based on the equation 2.1 and the growth is shown in Fig 2.3.

This carves have this equation:

$$P= 16.945x - 33710 \quad \textbf{(2.1)}$$

The maximum demand (In 2040) = 16.945*2040-33710 = 857 MW

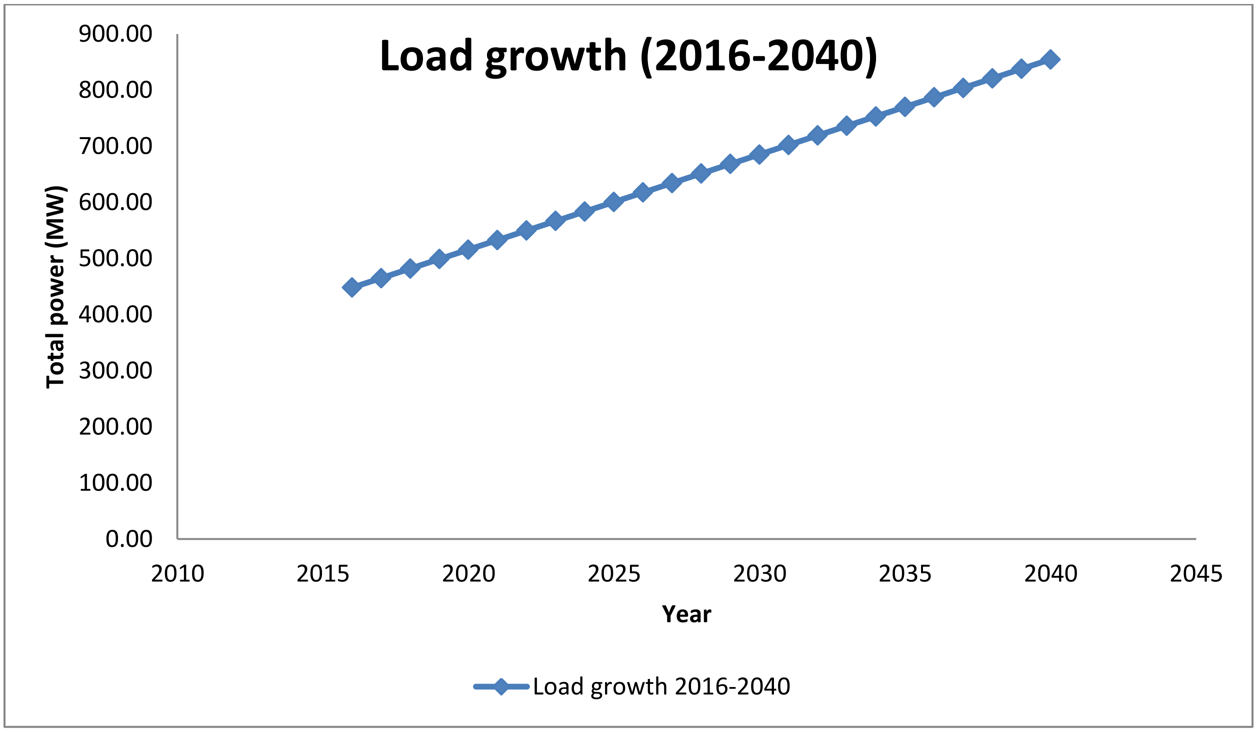


Figure 2.3: Load growth from 2016-2040 (JEDCO Distribution area)

We use the population growth and the average per capita consumption shown in Fig 2.4 and Fig 2.5 respectively to ensure the study.

$$\text{Population growth} = 312.7769x^2 - 1{,}236{,}265.37332x + 1{,}222{,}157 \quad \textbf{(2.2)}$$

$$\text{Population growth (2040)} = 1829834$$

$$\text{Per capita consumption} = -0.0002364262x^2 + 0.9603204054x - 974.68628 \quad \textbf{(2.3)}$$

$$\text{Per capita consumption (2040)} =0.47$$

The expected load growth by using the population growth and the average per capita consumption in 2040 is 0.47× 1829834 = 860022 kW =860.022 MW.

The first study based on load growth and study second study based on the population growth given the same indication for the growth of almost pregnancy.

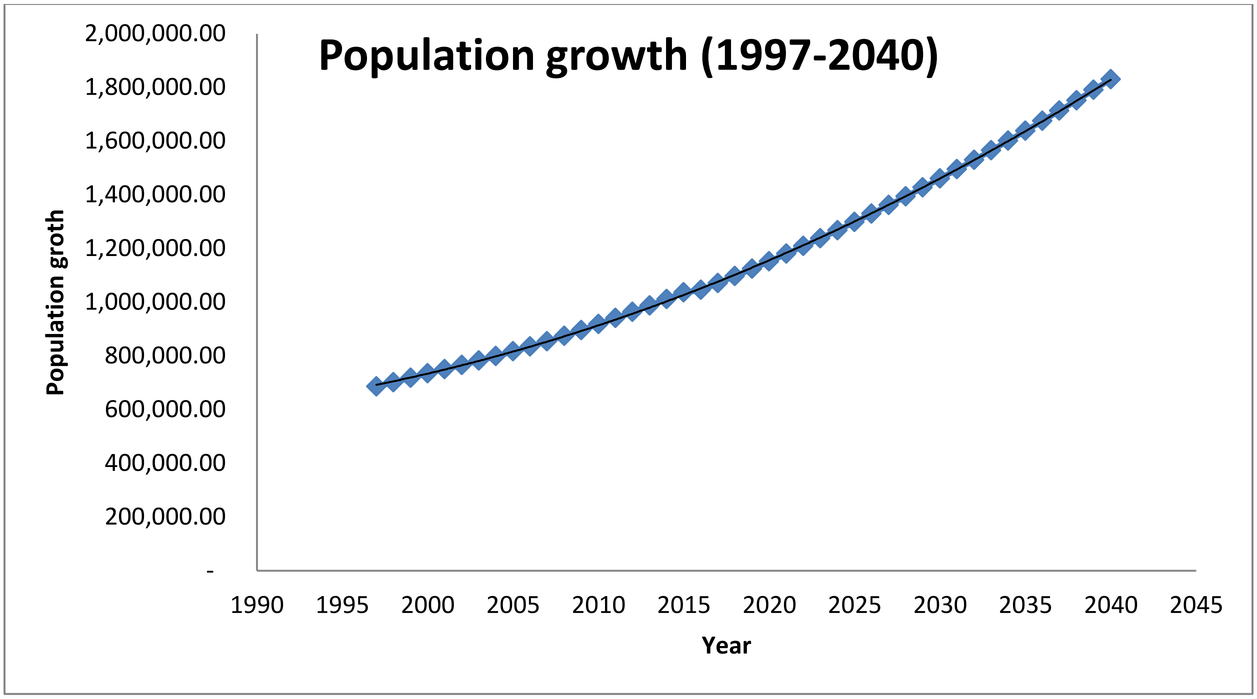


Figure 2.4: Population growth

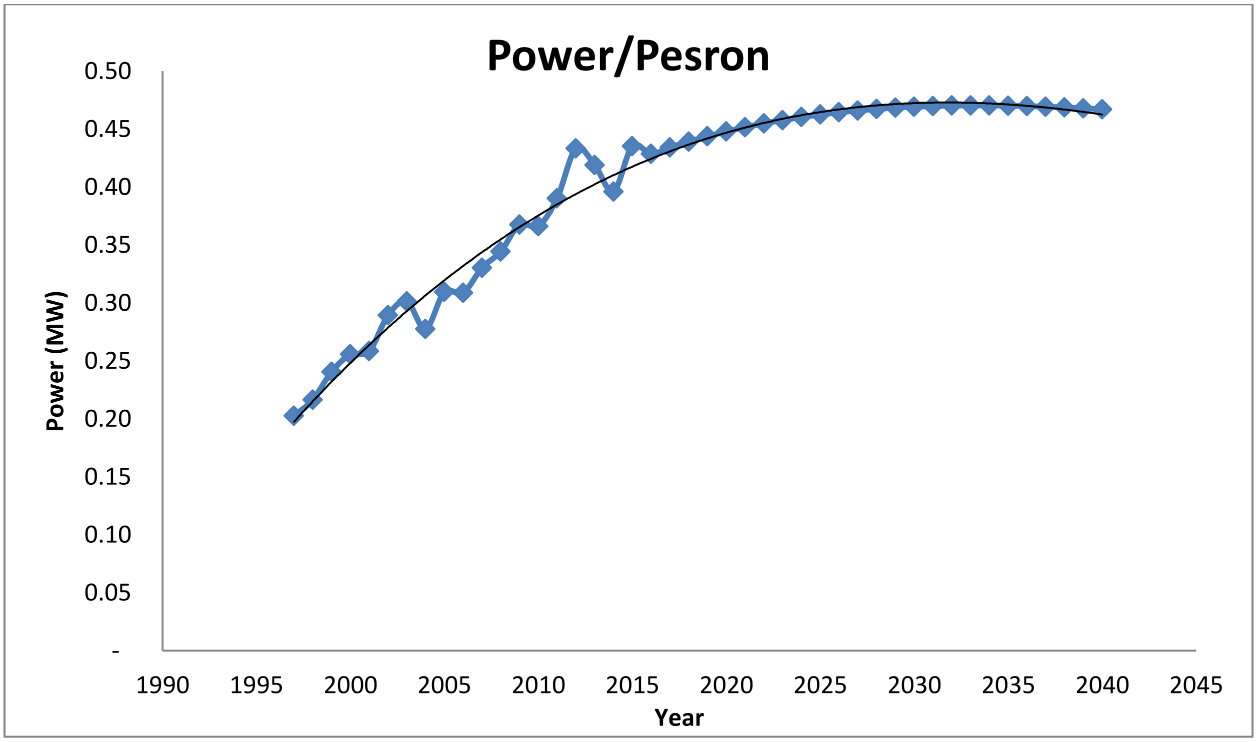


Figure 2.5: Power per person

2.3. Symmetrical components and fault analysis

2.3.1. Faults

A fault in a circuit is any failure which interferes which the normal flow of the current, or a physical change in the power system element; faults mainly caused by insulation failure which effect on the transmission lines as short circuit, open circuit, or earth faults.

Faults Classification

Faults have two main types according to the symmetry of the system:

A. Symmetrical Faults.

In the balanced system the system impedance in each phase are identical and the three-phase voltages and currents through the system are completely balanced.

Faults under symmetrical conditions are caused in the system accidently through:

1. Insulation failure of equipment.
2. Flash over of lines initiated by lighting stroke.
3. Accidental faulty operation.

Symmetrical faults are rare and it's not exceeding 5% of the faults of the system.

B. Asymmetrical Faults.

Unbalanced system can result due to unsymmetrical faults, then system operation may also become unbalanced when load not balanced. Most faults in the system are unsymmetrical so it's very important to pay attention.

The asymmetrical faults can be classified as follow:

1. Single line to ground fault (L-G).
2. Line to line fault (L-L).
3. Double line to ground fault (L-L-G)

2.3.2. Symmetrical Components.

In normal mode of operation the three-phase system is symmetrical, so to analyze this system we analyze one of the phases, the obtained results are the same for each phase but shifted by 120.

In case of faults we cannot apply the previous method to analyze the system due to the asymmetry, and we have to analyze each phase independently; but this method is long and hard to apply, so we use the symmetrical components and Fortescue's theorem.

The calculation of fault and symmetrical component are illustrated in appendix A.

2.4. Reliability of transmission system

Is a measure of the ability system's to transmit electrical power from the power generation points to all consumers, and it gives numerical indices to assess this process. The reliability of the system can be described by two basic functional features are security and adequacy.

Reliability refers to the ability of parts and components of the power system to complete the required functionality properly and in a specific time and also under certain conditions. Reliability is the probability of a component or system work reliably used as a characteristic reliable indicator. The reliability of electrical systems is the application of the theory of reliability and measure for the electrical systems, which provides consumers electrical energy with quantity and appropriate quality and according to the standards and also from the lower number of interruption of electricity.

2.5. Summary

This chapter discussed several important and necessary issues for the transmission system design are also important in for the distribution system design. Is always the first step in the design process is the planning so it necessary to study the load growth in order to select the appropriate equipment for the system. This chapter also talked about the reliability and faults and there are very important things that must be considered when carrying out the transmission system design.

Chapter 3 Design protection system and substation

3.1 Introduction for the Power System Protection

The main function of the power system is to generate, transmit, and distribute the electrical energy to the consumers. These functions need several equipment's. The large system has more equipment. Each power system has a complexity of the equipment's needed. So problems are predictable these problems in the power system are called faults and abnormal conditions.

Protection system is designed to monitor the current and voltage in the power systems through the use of numerous instruments and tools for that purpose. Use of this system is aim to minimize the effects of the existence of any defect in the system, such as fault. Thus ensuring network security, as well as employees in addition to ensuring continued delivery of energy to consumers with quantity and quality appropriate.

There are many devices and tools that are used to protection of the power system and are classified according to the nature of their work. Also are choosing these tools based on the portion to be protected so that appropriate tool for protection with the cost system and its importance in the network.

3.2. Types protection devices

3.2.1. Fuses

Fuse a piece of small metal parts used in all power systems as it works to separate the electrical circuit by melting in the event of a large amount of electrical current flowing through the fuse. Fuse manufactured in the habit of materials needed to low temperatures to melting point and should also the conductivity of these materials is very high, as well as a few affected by oxidation, such as copper, silver and other.

There are many types of fuses that used for the high voltage level Such as:

1. Cartridge type
2. Liquid type
3. Metal clad fuses

Advantage:

1. Required very small time to interrupted
2. Very small size
3. Low cost

Disadvantage:

1. Requires replacement after every interruption operation
2. Low reliability

3.2.2. Circuit breaker

The circuit breaker is one of the most important devices that used in the protection system. The circuit breakers are generally classified based on the way of extinguish the spark resulting from arc. Accordingly, there are four varieties of circuit breakers are:

1. Oil circuit breakers
   The oil circuit breaker is widely used in industrial fields. This type used the oil in the process of extinguish the electrical spark when the electric arc occurrence of bubbles forming working to extinguish the sparks.

2. Air-blast circuit breakers
   These circuit breaker used mainly in the high voltage applications. When the fault happens cause separate the contacts then the electric arc is formed and this leads to rush of air which acts to cool the spark and thus extinguish.

3. Sulphur hexafluoride circuit breakers
   This type of circuit breakers used SF6 gas, which has a great tendency to gain electrons are negative. Upon separation of the gas starts to flow contactors transforms gas to negative ions. Lost electrons leads to the weakening of the electric arc and thus extinguish the spark.

4. Vacuum circuit a breaker
   In this type of circuit breakers uses a vacuum that could be up to 10-7 Tor. This vacuum provides a very high isolation. This isolation leads to extinguish the spark too quickly.

Table 3.1: Comparison between the circuit breakers [5]

	Cost	Size	Reliability	Cost of maintenance	Operation Speed	Probability of Risk
Oil circuit breakers	Very low	Very large	Low Reliability	Very high	Low speed	High probability
Air circuit breakers	High	Large	Low Reliability	Low cost	High speed	Low Probability
SF6 circuit breakers	Very high	Small size	High Reliability	Low cost	High speed	Free
Vacuum circuit a breaker	High cost	Medium	Reliable	Low cost	High speed	Free

We select SF6 circuit breaker for high voltage system.

3.2.3. Autorecloser

Is a self-controlling circuit breaker equipped with mechanism to being able to reconnect the circuit after separating because of a fault in the system.

3.2.4. Current transformer (CT)

This type of transformer is used within the system of equipment protection. This transformer works to step down the current that flowing in it for measurement processes and also protect protection devices where this transformer connect is series with an electrical system.

3.2.5. Voltage transformer (CV)

Like the current transformer, this transformer works to step down the voltage between its parties for different measurement processes where the transformer is connected in parallel with the system.

3.2.6. Surge Arresters

Surge arresters are equipment used to eliminate the sudden impact of the lightning on the system.

Surge arresters used to protect a variety of devices and equipment in the transmission system such as transformers. Increase the reliability of the system a very important issue because it ensures the system works without any problems and therefore deliver electric energy service to consumers with quality appropriate and without interruption for it is to resort to the use of lightning conductors.

Consideration of selection surge arrester

1. Maximum continuous operating voltage
It is the maximum voltage that can be applied across the terminals of a surge arrester.
2. Discharge Current
Is a current that flows in the event of lightning.
3. Discharge Voltage
It is the voltage that appears across the terminal of surge arrester in the event of surge

3.2.7. Function Of Protection System.

A. To detect the faults and abnormal conditions.
B. To indicate the faulty elements.
C. To isolate the faulty elements.
D. To provide a high percentage of continuity of the electrical energy can reach to 100%.

As shown above the power system protection is very important, its importance come from the following abilities:

A. It can minimize the effects of the faults and abnormal conditions.
B. It improves the performance of the power system.
C. It provides approximately a continuous supplying to the loads.

3.2.8. Requirements of Protection System

A. Sensitivity

It means the ability of the protection system to detect all faults and abnormal conditions in the protective zone where the detection needed for the minimum fault current. In this requirement there are three cases:

1. Sensitive:

The protection relays detect the fault current from the beginning of the protective zone to the end of it.

2. Over sensitive:

The protection relays detect the faults outside of the protective zone.

3. Under sensitive:

The protection relays can't detect the fault current in the entire protective zone.

B. Selectivity:

1. Time grading:
   It can be done by giving the foresee protection element (such as CB) the lowest time.
2. Current grading:
   By giving each protection element a different operates current.
3. Time-current grading.
4. Time-impedance grading.
5. Amplitude and/or phase comparison:
   Determination of the direction of the power flow of the fault.

C. Fast operating:

It means the ability of the protection system to isolate the faulty part quickly, which leads to minimize the effect of the fault and increase the stability of the power system.

D. Reliability:

It means the dependability, in other word we can depends in the protection system in all cases such as the arc rare, and it must operate even after years of operation. Reliability can be improved by:

1. Duplication of the protection for the important elements and parts of the power system.

2. Using the high quality of the protection devices.

E. **Economical**

It means obtaining the maximum protection with lower cost, but we have to use a high quality protection devices which means more cost needed.

F. **Simplicity**

The protection system must be simple to help us during maintenance, but the protection level increase the complexity of the protection system. When we select the protection devices or protection level to an element or to a part we have to take in account the followings:

1. The type of the protected element
2. The rated values of the protected element
3. The importance of the protected element
4. The location of the protected element
5. The possibility of the faults
6. Starting currents of the protected element

As in any system in practice, there are some disadvantages, the most disadvantages of the protection system are increasing the complexity of the power system due to the connection between them, and the other disadvantage is increasing the initial cost of the power system under construction and the maintenance cost increases too.

3.2.9. Some Factors Effect on the Protection System

There is various factors effect on the protection system as:

A. Economic factors: where the cost of the equipment needed and protection devices. Also the outage cost must be taken in account.

B. Protection engineer: protection engineers must train in regular phases and can handle with the developments occur in the protection fields, protection engineers must handle with the complexity of the system.

C. Isolating and input devices: such as isolators, CB‟s, grounding switches, etc.

Recording information: recording what happens on the power system is very important to understand, study, and analyze the faults. This recording needs communication channels, and it applied only in digital relays.

3.3. Protection zone:

As mentioned before, the aims of the power system is to generate, transmit, and distribute the electrical energy, these aims need several equipment such as generators, transformers, transmission lines, etc. all these equipment are important so we have to protect it to provide a continuity and safety supplying. We cannot protect it randomly, so we divide the system into zones each zone called protection zone.

The figure below shows a simple power system divided into protection zones.

As shown there are overlapping between the protection zones, and it appears around the CB"s. The purpose is to make certain that no section of the system is left unprotected. The consequence of this practice is that a fault in an overlapping zone opens circuit breakers to isolate more than one element from the system.

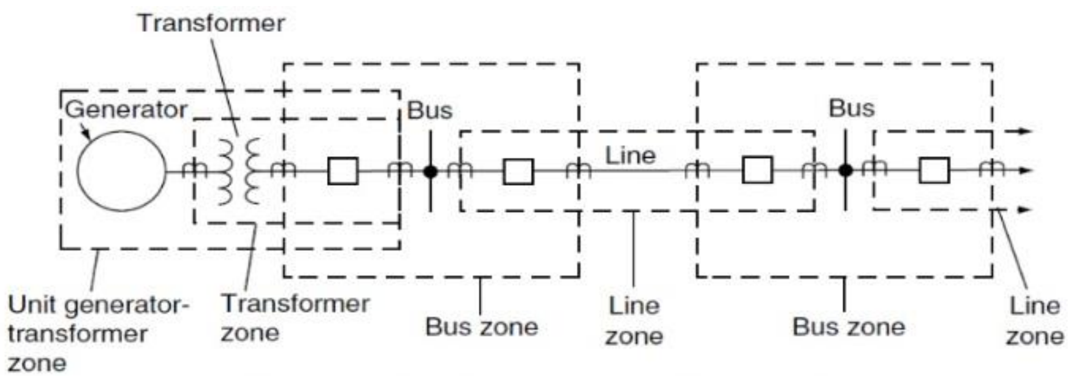


Figure 3.1: Protection zone

3.4. Distance relay

It is a relay has the ability to detect faults that occur a specified distances in the transmission lines. This type of relays depends on the resistance instead of the current and voltage to the process of detecting fault. Each line of the transmission line has a specific resistance value and when the fault occurrence in the system the relay senses the fault through the measured difference in resistance value. The distance relay use CT and VT to measure the resistance of the cable.

Distance relays used for three main protection zones Z1, Z2 and Z3 and it may increase to five zones in digital and numerical distance relays. The relay protects nearly 80% only of the line in Z1 and with no delay. The same relay protects a distance up to 20% of the Z2 with delay approximately 200ms. And this relay protects distance up to 10% of the Z3 with delay approximately 800ms.

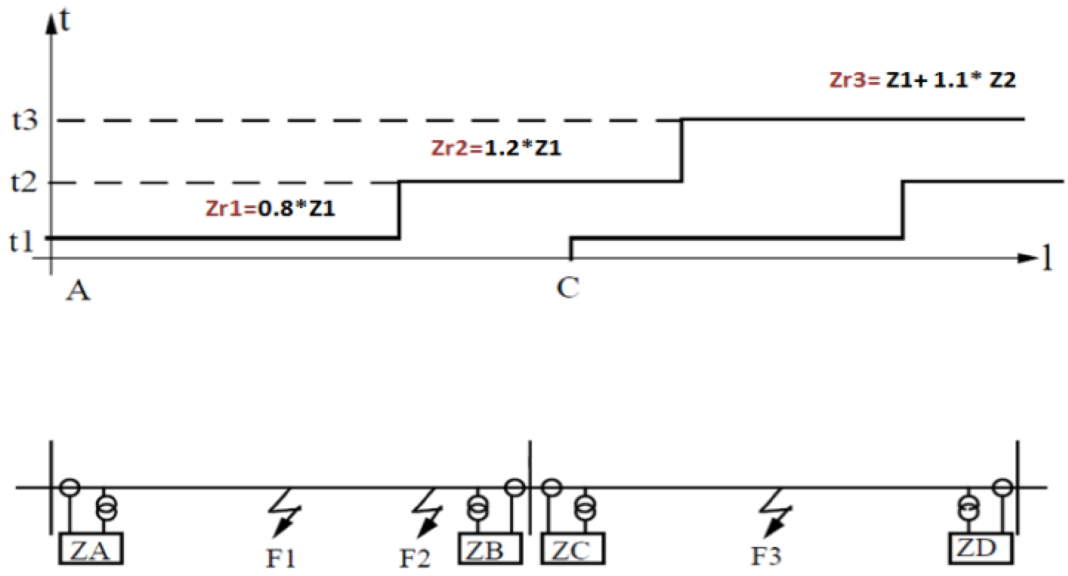


Figure 3.2: Distance protection

Calculation of distance relay

The impedance of transmission line is:

Z=0.1468+j2841

The impedance of each zone for the distance relay:

Zone1:

$$Z_{zone1} = 0.8*Z1 \quad \textbf{(3.1)}$$

$$Z_{zone}1=0.8*(0.1468+j0.2841)*10.5$$

$$=1.2331+j2.3864$$

Zone2 :

$$Z_{zone2}=Z1+0.2Z2 \quad \textbf{(3.2)}$$

$$Z_{zone2}=(1.2331+j2.3864)+0.2*(0.1468+j0.2841)*14$$

$$=1.6441+j3.1819$$

Zone3:

$$Z_{zone3}=Z1+Z2+0.1*Z3 \quad \textbf{(3.3)}$$

$$Z_{zone3}=(1.2331+j2.3864)+(2.0552+j3.9774)+0.1*(0.1468+j0.2841)*15$$

=3.5085+j6.79

Table 3.2: Impedance of zones for each distance relay

	Impedance of zone1	Impedance of zone2	Impedance of zone3
Relay1	1.2331+j2.3864	1.6441+j3.1819	3.5085+j6.7900
Relay2	1.6442+j3.1819	1.9965+j3.8638	---
Relay3	1.7616+j3.4092	---	---
Relay4	2.9947+j5.7956	---	---

3.5. Differential protection

This protection system is use the current difference as criteria. The differential protection system consisting of:

1. Current transformer (CT).
2. Relay.

The differential protection is used for the very high devices cost such as power transformer which have rating higher than 5MVA because the cost of this system is very high and there are two type of this protection:

1. Balanced current

The principle of this type of protection system is shown in the figure. The current transformers are connected in series with the system. The Relay connected across the midpoint between them and the voltage on the relay is equal zero. When the fault occurs outside the protective zone, there is no current flow through the relay. So the differential relay does not activate.

In the case of the fault occurs inside the protective zone, the difference between the current that flow in the CTs is flow through the relay then the relay interrupted the circuit as shown in the Fig 3.3.

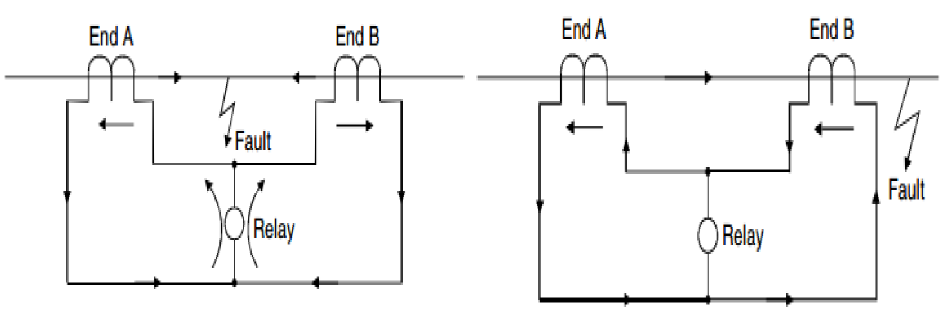


Figure 3.3: Differential protection (Balanced current)

2. Balanced voltage

In this type of differential protection, the current flow the current transformers produce a voltage on the relays. The voltage on the two relays is equal when the occurrence of the fault is outside the protective zone. Accordingly, the Relay does not activate. But if the fault occurs inside protective zone there is difference in the value of current in the secondary of CTs. And therefore the relay activates and makes interruption in the circuit as shown in the Fig 3.4.

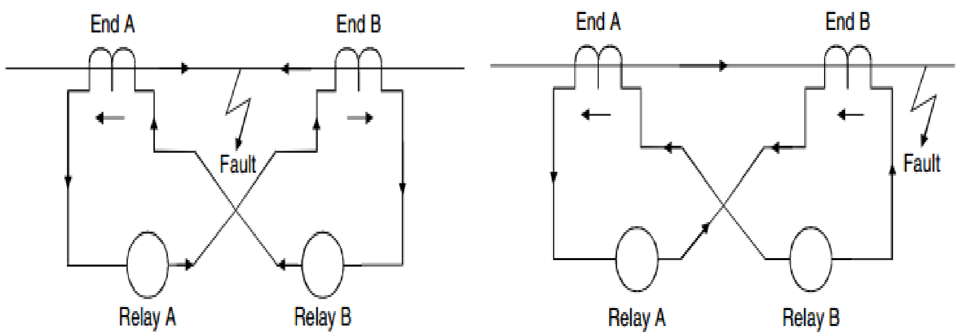


Figure 3.4: Differential protection (Balanced voltage)

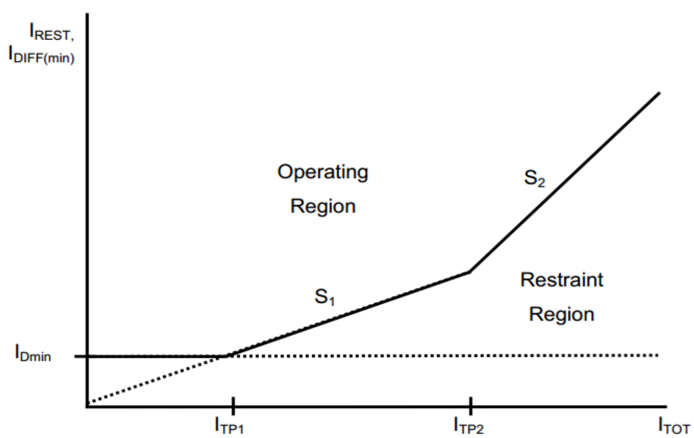


Figure 3.5: Operating region of differential relay

Table 3.3: Rating of current transformer

	Max. Current	Rated of CT
Bethlehem	467.2A	250/5
Jerusalem	1264A	650/5
Ramallah	1119A	550/5
Jericho	216.9A	100/5

3.6. Overcurrent relay

This relay is one of the most relays that used in the power systems, especially protecting the bus-bars. This type of relays detects the increase in current in the system from the allowable limit, which may be dangerous to the equipment in the system. After detecting the increase in the current, the relay gives the signal for the circuit breaker to trip.

3.7. Protection of power transformer

The power transformer is the most important device in the substation. The main function of this transformer is to transform the voltage from the high voltage level (161kV) to the medium voltage level (33kV). The power transformer must be able to withstand the power flow in the network under all circumstances that could face the power system.

To ensure the continuity of the work of the transformer properly and safely and is not exposed to damage must be provided protection systems appropriate for the transformer to face all the problems resulting mainly from the increase of the current that flow through the grid.

Reasons for the increase in current:

1. Internal fault
    1. Winding short circuit fault
    2. Inter-turn fault
    3. Oil-tank fault
2. External fault
    1. Short circuit fault at HV level or LV level
    2. Phase to Earth fault
    3. Thermal overload
    4. Over excitation

The protection methods that could use to protect the power transformer:

1. Differential protection
2. Fuses
3. Over-current relay
4. Buchholz relay

Table 3.4: Comparison between protection devices [5]

	Cost	Reliability	Tran. Rating
Differential protection	Very high	Very high	>5 MVA
Fuses	Low	Low	<1000 kVA
Over-current relay	High	Reliable	<5 MVA
Buchholz relay	Low	Low	50 kVA

The rating of the power transformer that used in the transmission substation is above 5MVA, so the most appropriate protection system is differential protection.

3.8. Design of Substations

Substation planning considers the location, size, voltage, sources, loads, and ultimate function of a substation. If the planning process was not based on scientific foundations, it leads to high cost of establishing the plant and also a lot of problems that need to find solutions.

The substation may be categorized as:

1. Distribution Substations
   kA distribution substation is a combination of switching, controlling, and voltage step-down equipment.

2. Switching Substations
   A switching substation is a combination of switching and controlling equipment arranged to provide circuit protection and system switching flexibility.

3. Transmission Substations
   A transmission substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce transmission voltage to subtransmission voltage for distribution of electrical energy to distribution substations. Transmission substations frequently have two or more large transformers.

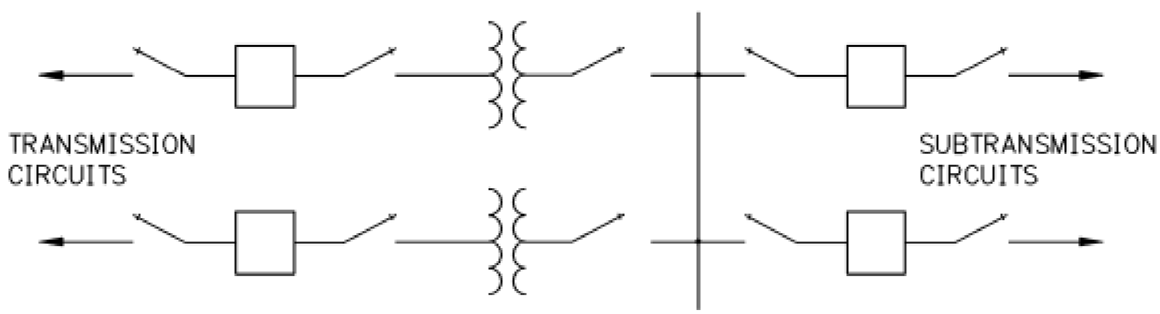


Figure 3.6: Basic Transmission Substation

The components of substation:

1. Power transformers
2. Current transformers & Voltage transformers
3. Circuit Breaker
4. Surge Arresters
5. Bus bars
6. Isolators
7. Wave trap
8. Insulator

9. Earth switch
10. Earthing system
11. Control panel
12. Cables
13. Capacitors

3.8.1. Selection of the location

To design substation there is very important factor and the location is one of these factors. The selection of the location is depending on:

1. Location of present and future load center
2. Location of existing and future sources of power
3. Alternative land use considerations
4. Location of existing distribution lines
5. Soil resistivity
6. Atmospheric conditions: salt and industrial contamination
7. Public safety
8. Security from theft, vandalism, damage, sabotage, and vagaries of weather

3.8.2 Selection of substation equipment:

1. Selection of transformers

   1. Transformer size must be selected according to the maximum expected load and possibility of future expansions.
   2. The size of transformer may be selected from power ratings given below to supply present and future loads

2. Ratings of Circuit Breakers

   1. Rated voltage, rated frequency, rated current, and rated short-circuit breaking capacity of circuit breaker must be determined.
   2. Short circuit capacity of the circuit breaker must be above the maximum short circuit current exists in the location.

3. Ratings of Switch Disconnectors (Load-break switches)

   1. Rated voltage, rated current, and allowed short-circuit current must be determined.
   2. Switch disconnectors must withstand thermally and mechanically against the short circuits

4. Ratings of Isolators (Disconnectors)
    1. Rated voltage, rated current, and allowed short-circuit current must be determined
    2. Switch disconnectors must withstand thermally and mechanically against the short circuits
5. Characteristics of Voltage Transformers
6. Characteristics of Current Transformers

7. Selection of layout system
   The typical bus used in all kinds of substations, whether the transmission, distribution, or switching substation and used to voltage up to 380 kV. The type of bus used varies depending on the type of voltage, the size of the substation and also arrange the equipment at the substation. There are six main types of buses:
    1. Single Bus
    2. Sectionalized Bus
    3. Main and transfer bus
    4. Ring Bus
    5. Breaker-and-a-Half
    6. Double Breaker–Double Bus

   In the planning to set up a substation must take into account several things perhaps one of the most prominent determine the type of bus the will used in the layout of this substation. Therefore, the comparison is very important to this. The following table explains the main differences between the all types of buses previously mentioned:

Table 3.5: Comparison between the buses of layout system [6]

Type of bus	Reliability	Cost	Available Area
Single Bus	Least reliable	Least cost	Least area
Sectionalized Bus	Highly reliable	High cost	Greater area
Main and transfer bus	Least reliable	Moderate cost	Low area
Ring Bus	High reliability	Moderate cost	Moderate area
Breaker-and-a-Half	Highly reliable	Moderate cost	Greater area
Double Breaker–Double Bus	Moderately reliable	Moderate cost	Moderate area

We select the ring bus for layout system

3.8.3. Selection of underground cable

As mentioned earlier, electric power can be transmitted and distributed through the use of underground cables or by using overhead transmission line. The underground cables are an essential part of the substation. It is an assembly of one or more individually insulated electrical conductors, usually held together with an overall sheath. This type of cable is less prone to damage and the cost of maintenance is relatively low. In addition, the voltage drop is very low, but the main disadvantage of this type of cable is its high cost.

Construction of Conductor

1. Core or Conductor
2. Insulation
3. Metallic Sheath
4. Bedding
5. Armouring
6. Serving

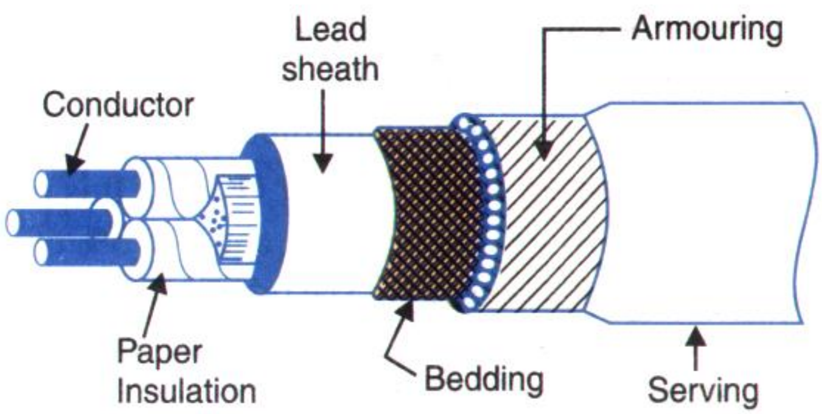


Figure 3.7: Construction of underground cable

Classification of cables:

1. Low tension (up to 1000V)
2. High tension (up to 11, 000V)
3. Super tension (from 22KV to 33KV)
4. Extra high tension (from 33KV to 66KV)
5. Extra super voltage cables (beyond 132KV)

Selection of underground cable:

Depending on the load growth study (from chapter 2), we have chosen the appropriate cable that can be able to withstand the maximum possible current until 2040:

For Jerusalem-substation:

$$I= \frac{S}{\sqrt{3}V} \quad \textbf{(3.4)}$$

$$= \frac{352MW}{\sqrt{3}X161kV} = 1263.7\text{Ak}$$

The current for each circuit = 631.85A

The following table shows the cross sectional area of the underground cable that will used in the substations:

Table 3.6: Cross section area of under ground cable

	Real Power	Current	Cross section area	Cross section area for 0.5GW
Bethlehem	130.13MW	467.20A	70 mm^2	1000 mm^2
Jerusalem	352.27MW	1263.7A	240 mm^2	
Ramallah	311.83MW	1119.6A	185 mm^2	
Jericho	60.380MW	216.78A	25 mm^2	

3.8.4. Selection of power transformer

Based on the study of the load growth (in chapter 2), we can choose substation components
Power = 857 MVAk2
Voltage =161 KV

Ratings of power transformer:

Table 3.7: Rating of power transformer

	Max Power	Voltage	Tran. Rating
Jerusalem	352.27 MW	161 kV	2*(200 MVA)
Ramallah	311.83 MW	161 kV	(150&200) MVA
Bethlehem	130.16 MW	161 kV	2*(75 MVA)
Jericho	60.38 MW	161 kV	(25&50) MVA
Total	857.61 MW	161 KV	1000 MVA

Each substation required tow power transformer as the ratings in the table above.

Table 3.8: Cost of power transformer [13]

Rating of transformer	Estimate cost
390 MVA	$ 2,000,000
150 MVA	$ 1,500,000
75 MVA	$ 1,000,000
500 MVA	$ 4,000,000
1000 MVA	$ 10,000,000

The proposed scheme of the station:

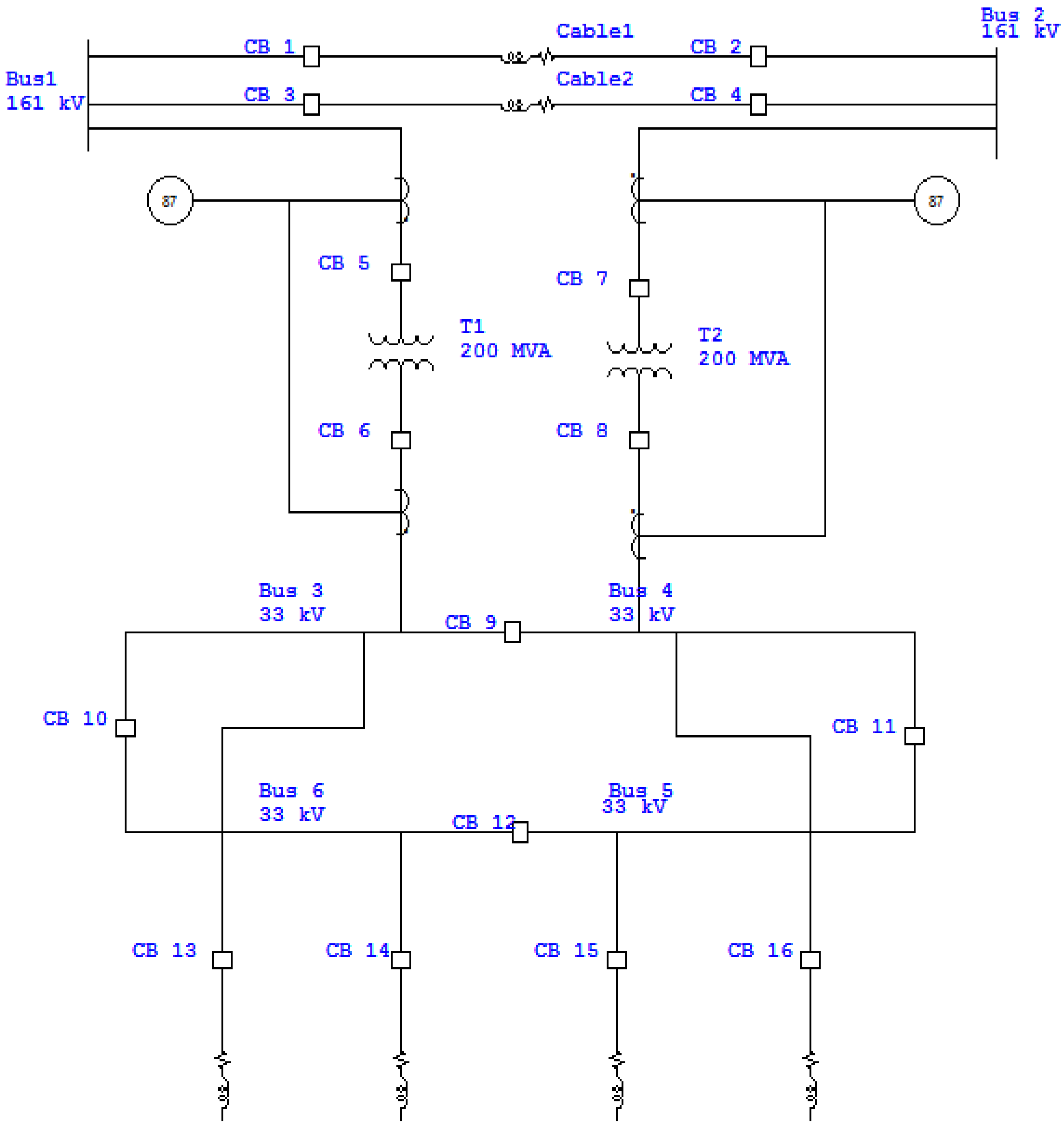


Figure 3.6: Substation sachem

The circuit breaker that selected in this design is SF6 circuit breaker and has the following ratings(For single circuit system) :

Normal current = 4000A

Short circuit current = 40 kA

Frequency = 50Hz

Operating time = 0-0.3s

The circuit breaker that selected (For double circuit system)

Normal current = 2500 A

Short circuit current = 31.5 kA

Frequency = 50Hz

Operating time = 0-0.3s

3.9. Earthing system

The earting of substation is one of the most important procedures that must be encouraged when designing any substation. The earthing system dose not only used to protecting workers in the substation or presence in one of its facilities only, but used to protect all components of the risk of faults and lightning. When designing a system, you must take reliability into consideration.

In principle, a safe earthing design has the following two objectives:

1. The purpose of the process is to provide a path for the current in certain circumstances without affecting the operation of the system.
2. Ensure that no person in the substation is exposed to electric shock due to faults or lightning.

Importance of earthing:

The system is very important for a number of reasons, but all of them are related to the protection of human and equipment located in the station, in addition to ensuring the optimal operation of the system. Among these reasons:

1. The earthing system provides a path for the current with low resistance for protecting both persons and equipment.
2. The earthing system provides low resistance path voltage transients such as lightning and surges or overvoltages.
3. Equipotential bonding helps prevent electrostatic buildup and discharge, which can cause sparks with enough energy to ignite flammable atmospheres.
4. The earthing system provides a reference potential for electronic circuits and helps reduce electrical noise for electronic, instrumentation and communication systems.

Types of Earthing:

1. System Earthing
   This system relates to the protection of equipment and devices located in the substation by stabilizing the voltage with respect to ground.

2. Equipment Earthing (Safety earthing)
   In this system all the devices are connected with the ground in order to protect workers from the danger of electric shock.

In the earthing of the substations, the system earthing and safety earthing are interconnected to ensure the highest degree of protection and reliability.

Components of earthing system

1. Earth electrode
2. Connecting cables
3. Lightening arrester
4. Earth mat
5. Earth switch

Types of earth electrode

1. Rod electrode.
2. Pipe electrode.
3. Plate electrode.

3.10.2. Earth resistance:

The electrical characteristic of the soil with respect to conductivity. The value is typically given in ohm-meters.

Factors that affect resistivity

1. Type of earth
2. Stratification
3. Moisture content
4. Temperature
5. Chemical composition and concentration of dissolved salt

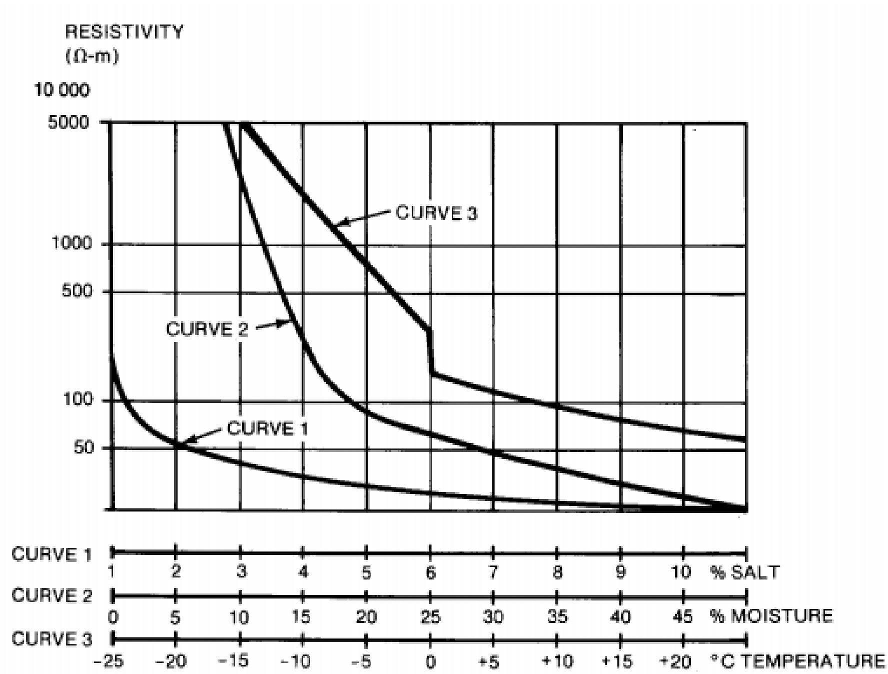


Table 3.8: Factors effect on soil resistivity

$$\rho_o = \frac{4\pi a R}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}} \qquad \textbf{(3.5)}$$

Where:

ρ_o =Apparent resistivity of the soil in W-m

R = Measured resistance in ohms

a = Distance between adjacent electrodes in meters

b = Depth of the electrodes in meters

$$Rg=\rho\left[\frac{1}{LT}+\frac{1}{\sqrt{20A}}\left(1+\frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] \qquad \textbf{(3.6)}$$

Where

ρ = soil resistivity *Ω.m*

Lt = total length of grid conductor *m*

A = total area enclosed by earth grid m^2

h = depth of earth grid conductor *m*

Table 3.9: Soil resistivity

Type	Resistivity (Ohm meter)
Sea water	0.1-1
Garden soil, alluvial clay	5-50
Clay	5-100
Clay, sand and gravel	40-250
Porous chalk	30-100
Quartzite, crystalline limestone	+300
Rock	1000-10000
Gneiss, igneous rock	+2000
Dry concrete	2000-10000
Wet concrete	30-100
Ice	10000-100000

3.10.3. Terms & Definitions

1. **Ground Potential Rise (GPR)**
The maximum voltage that a ground grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. The GPR is equal to the product of the earth current and the equivalent impedance of the grounding system.

$$GPR = (I_G \times R_g) \quad \textbf{(3.7)}$$

where, IG = Maximum earth grid current
Rg= Earth Grid resistance

2. **Step Voltage**
The difference in surface potential experienced by a person bridging a distance of 1 meter with his feet without contacting any other grounded object.

3. **Touch Voltage**
The potential difference between the ground potential rise and the surface potential at the point where a person is standing while at the same time having his hands in contact with a grounded structure.

4. **Mesh voltage**

The maximum touch voltage within a mesh of a ground grid.

5. **Metal-to-metal touch voltage**
   The difference in potential between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

6. **Transferred voltage**
   A special case of touch potential where a potential is transferred into or out of the sub-station from or to a remote point external to the sub-station site. A person standing in a sub-station coming in contact with say rails neutral coming from an adjacent sub-station at the time of occurrence of earth-fault at that substation gets exposed to the transferred potential which equals difference in GPRs of the two substations.

The factors which influence the earth mat design are:

1. Magnitude of Fault Current
2. Duration of Fault
3. Soil Resistivity
4. Resistivity of Surface Material
5. Shock Duration
6. Material of Earth Mat Conductor
7. Earthing Mat Geometry

The design parameters are

1. Size of Earth Grid Conductor
2. Safe Step and Touch Potential
3. Mesh Potential
4. Grid configuration for Safe Operation
5. Number of Electrodes required

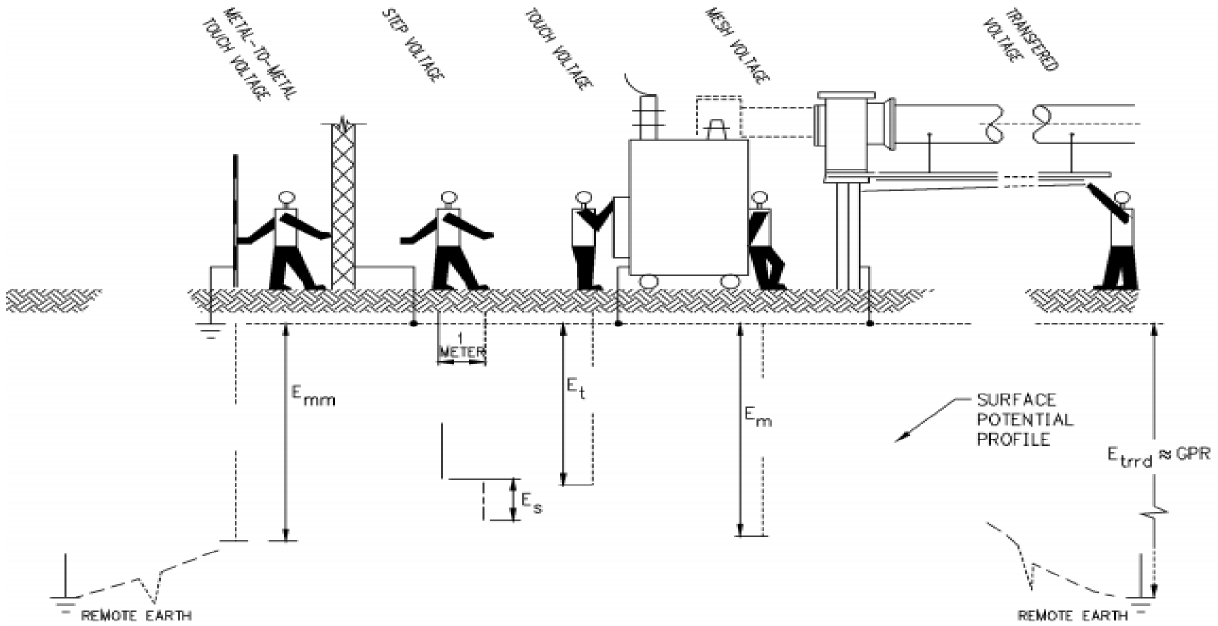


Figure 3.9: Earthing system

3.10.4. Design procedure:

1. If the ground potential rise (GPR) is less than the touch voltage there is a need to add conductor required to provide access to equipment grounds is necessary.
2. If the computed mesh voltage is below the tolerable touch voltage, the design may be complete. If the mesh voltage is less than touch voltage, the initial design of the system must review.
3. If the touch voltage and step voltage exceed tolerable limits, revision of the grid design is required. This problem can be solved by reducing the distance between earth electrons or increasing their number.
4. If the length of the electrode is less than the required length, the voltage will exceed the permissible limit. To solve this problem, the number of electrodes must increase.

3.10.5. Mathematical calculation:

3.10.5.1. Prerequisites:

The following information is required before starting the calculation:

a. A layout of the site.
b. Maximum earth fault current into the earthing grid.
c. Maximum fault clearing time.
d. Ambient temperature at the site.
e. Soil resistivity measurements at the site.

f. Resistivity of any surface layers intended to be laid.

10.3.5.2. Step and touch voltage calculation

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined as follows. For step voltage the limit is:

$$E_{step} = (1000+6C.\rho)\frac{0.116}{\sqrt{ts}} \tag{3.8}$$

$$E_{touch} = (1000+1.5C.\rho)\frac{0.116}{\sqrt{ts}} \tag{3.9}$$

$E_{step:}$ is the step voltage in V

$E_{touch:}$ is the touch voltage in V

$t_{S:}$ is the duration of shock current in seconds.

If no protective surface layer is used, then C_S =1 and $\rho_S = \rho$.

The earth grid conductor size formula is mentioned below:

$$\boldsymbol{A} = \left[\frac{\boldsymbol{I}}{\sqrt{\frac{(TCAO*10^4)}{tc*ar*\rho r}\,\boldsymbol{ln}\left(\frac{Ko+Tm}{Ko+Ta}\right)}}\right] \tag{3.10}$$

Where,

I = rms value in kA

A = conductor sectional size in mm^2

Tm = maximum allowable temperature in ˚C

Ta = ambient temperature for material constants in˚C

$\alpha_\circ$= thermal coefficient of resistivity at 0˚C

α_r = thermal coefficient of resistivity at reference temperature Tr

ρ_r = the resistivity of the ground conductor at reference temperature Tr in uA/cm3

$K_\circ = 1/\alpha_\circ$ or $1/\alpha_\circ$ - Tr

tc = time of current flow in sec

TCAP = thermal capacity factor

Spacing factor for mesh voltage (Km):

$$Km=\frac{1}{\pi}\left[\ln\left(\frac{D^2}{16hd}+\frac{(d+2h)^2}{8Dd}-\frac{h}{4d}\right)+\frac{Kii}{Kh}ln\frac{8}{\pi(2n-1)}\right] \quad \textbf{(3.11)}$$

Where,

D = spacing between conductor of the grid in m

d = diameter of grid conductor in m

Km = spacing factor for mesh voltage

Kii = 1 for grids with rods along perimeter

Kh = Corrective weighting factor for grid depth

Spacing factor of step voltage (Ks):

$$Ks=\frac{1}{\pi}\left[\frac{1}{2h}+\frac{1}{(D+j)}+\frac{1}{D}(1-0.5^{n-2})\right] \quad \textbf{(3.12)}$$

Where

D = spacing between conductor of the grid in m

h = depth of burial grid conductor in m

n = number of parallel conductor in one direction

Actual Step Potential & Touch Potential Calculations

Formula for calculation of mesh voltage are:

$$E_m=\left[\frac{\rho*Km*Ki*Kim}{LL+LB+LA+(1.15*LE)}\right] \quad \textbf{(3.13)}$$

Formula for calculation of step voltage are:

$$E_m=\left[\frac{\rho*Km*Ki*Kis}{LL+LB+LA+(1.15*LE)}\right] \quad \textbf{(3.14)}$$

$$LT=(LL+LB+LA+LE) \quad \textbf{(3.15)}$$

Where

ρ = soil resistivity, ohms-m

Em = mesh voltage at the center of corner mesh in V

Es = step voltage between point in V

Km = spacing factor for mesh voltage

Kis = spacing factor of step voltage

Kim = correct factor for grid geometry

LL= Length of grid conductor along length of switch yard

LB= Length of grid conductor along breadth of switch yard

LA= Length of riser and auxiliary mat in switch yard

LE= Length of earth electrodes in switch yard

LT= Total length of earth conductor in switch yard

Parameters	Value		Parameters (calculation)	Value
Ambient temperature (Ta)	45c		Earth conductor size	793.1
Maximum allowable temperature (Tm)	450c		Maximum grid current	22 KA
Fault duration time (ts)	1s		Ground resistance	0.301732Ω
Thermal coefficient of resistivity (αr)	0.0032		Ground potential rise	6638.104 V
Resistivity of conductors (ρr)	20		Spacing factor for mesh voltages	0.38039
Resistivity of substation soil (ρ)	200		Spacing factor for step voltages	0..35279
Resistivity of surface material (ρs)	2000		Touch voltage criteria	554 V
Thermal capacity factor (TCAP)	3.93		Step voltage criteria	1724 V
Depth of burial conductor (h)	0.6		Maximum attainable step voltage	389.68 V
Reference depth of grid (h_o)	1		Maximum attainable mesh voltage	374 V
Conductor spacing (D)	7		Total length of earth conductor in switch yard	34405m
Diameter of grid conductor (d)	34			
Length of one earth rod (Lr)	3			

3.11. Summary

In this chapter we choose appropriate protection tools based on several factors, including reliability, economic costs, selectivity and others and explain the protection zones, and function of protection system. The protection system that used for the power transformer is differential protection because this component is the most important part of the substation.

Chapter 4 Design of transmission system

4.1. Transmission System

4.1.1. Main Components

4.2. Transmission line (Conductor)

4.2.1. Classifications of overhead transmission line

4.2.2. Types of overhead transmission line

4.2.3. Design transmission line

4.2.4. Sag of transmission line

4.2.5. Parameters of transmission line

4.2.6. Selection the ground cable and arresters cables

4.2.7. Corona

4.3. Insulators

4.3.1. Transmission line insulators

4.4. Towers

4.4.1. Types of towers

4.4.2. Basics in tower Design

4.4.3. Design the tower

4.4.4. Guys

4.4.5. Tower earthing

4.5. Summary

4.1. Transmission System

The power transmission is the main function of the transmission system. The power transmission means the transfer of electrical energy from the power generation location to the distribution system. The electrical power generation usually at 11-33 kV then steps up this voltage to the high or extra high level of voltage to reduce the loss in the electrical power in the transmission lines. This transmission system connected to the distribution system or load center through subtransmission network that operates at medium voltage (normally used 33 kV).

Figure 4.1: Transmission Line

4.1.1. Main Components

A transmission line consists of different components. The conductors through which the electrical energy is to be transferred are to be supported by insulators and pylons. Therefore basically a main component, which consists in transmission line are:

1. Conductor
2. Earth wire (Ground wire)
3. Insulators
4. Towers
5. Cross arms
6. Foundation

4.2. Transmission line (Conductor)

Transmission lines a pair of electrical conductors that are used to transfer electrical energy from one place to another and the most commonly examples the lines coaxial cable and twisted pair cable. All types of transmission lines have number of parameter a total of variables, capacitance, inductance and resistance. These variables can calculate mathematically, but there is some factors must be known such as the cable length and cross-section area and others. In the early days of cable-making, there would be current leaking through the insulation, but in modern cables the leakage current become very low so this leakage is negligible.

The term transmission lines are not used only for the lines that existing in the high voltage system. But includes all lines that in any part of the power system when the voltage still high such as Subtransmission and distribution. All of these lines, regardless of where they have the same functionality as used to transmit electric energy and also exposed to the same disturbances and problems. But the transmission lines considered the main the reason of the loss.

There is another type of medium that used to transmit the electrical power and it's the underground cable. This cable consists of one or more conductor which covered by using insulating material. But this cable mainly use in the distribution system.

Table 4.1: Comparison between overhead line and underground cable [1]

	underground cables	**Overhead lines**
Cost	**Great cost**	**Low cost**
Crash	**The difficulty of locating crash**	**Ease of locating crash**
Maintenance	**Cheep**	**Expensive**
Loss in transmitted power	**Low quantity**	**High quantity**

So the overhead lines are the main type of cables that used in the transmission system.

4.2.1. Classifications of overhead transmission line

There are two types connection for transmission lines:

- T – Circuit.
- Pi – Circuit.

This is often referred to as a pi model for the line because of its form. Note that the series resistance of the line is neglected in this model. This is a limitation on the accuracy of line representation, the series resistance of a good transmission line is quite small compared with the reactance.

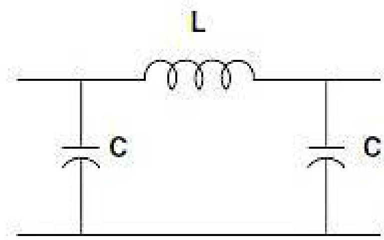


Figure 4.2: Standard ‘Pi’ model for a transmission line

There are three types of transmission lines according to length:

1. Short transmission line
   When the length of an overhead transmission line is less than about 80km or if the voltage is not over 69kv

2. Medium transmission line
   When the length of an overhead transmission line is above 80km and below 250km in length is termed medium length line.

3. Long transmission line
   When the length of an overhead transmission line is above 250km in length are termed medium length line.

4.2.2. Types of overhead transmission line

There are many qualities that should be available in the conductors that are used in the transmission system:

1. High electrical conductivity
2. High tensile strength in order to withstand mechanical stresses
3. Low cost so that it can be used for long distances
4. Low specific gravity so that weight per unit volume is small

The most commonly used conductor materials for overhead lines are copper, aluminum, steel-cored aluminum, galvanized steel and cadmium copper.

The following table shows the most important differences between the types of cables mentioned

Table 4.2: Comparison between types of transmission line [9]

	Copper	Aluminum	Steel-cored aluminum	Galvanized steel	Cadmium copper
Wight	**High**	**Low**	**Low**	**High**	**High**
Conductivity	**High Conductivity**	**Low conductivity**	**High conductivity**	**Low conductivity**	**High**
Tensile Strength	**Very high**	**High**	**Very high**	**High**	**Very High**
Cost	**Expensive**	**Cheap**	**Cheap**	**Cheap**	**Expensive**

We chose Steel-cored aluminum (ACSR) to use in the transmission system and this type of conductor is the most commonly and used.

4.2.3. Design transmission line

The transmission system will operate at 161 KV and also works on the transfer of 1GW.

The current that would flow in the system:

$$I = \frac{\text{Power}}{\sqrt{3}\times\text{Voltage}} \tag{4.1}$$

$$= \frac{1\ \text{GW}}{\sqrt{3}\times 161\ \text{KV}} = 3586.02\text{A}$$

We want to design double circuit system, so the current will be:

$$I = \frac{3586.02}{2} = 1793.01\ \text{A}$$

The current of bundle:

$$I = \frac{1793.02}{3} = 597.7\text{A}$$

This current require conductor with cross sectional area 241.7mm^2.

The clearance between the conductors in every bundle is as following:

$$D = \left(\frac{VPUa}{500K}\right)^{1.667}\text{bc} \tag{4.2}$$

Where:

D: The spacing between the wires.

V: Operating voltage.

PU: maximum switching-surge factor.

a = 1.15, the allowance for three standard deviations.

b = 1.03, the allowance for nonstandard atmospheric conditions.

c = 1.2, the margin of safety.

K = 1.4, the configuration factor for conductor-to-plane gap.

The line to line voltage is =161 KV

$$\text{Line to ground voltage} = \frac{161\text{KV}}{3} = 92.5\text{KV} \ \&\text{PU}=2.35$$

$$D=\left(\frac{92.5\times2.35\times1.15}{500\times1.15}\right)^{1.667}\times1.03\times1.2 = 31 \text{ cm}$$

4.2.4. Sag of transmission line

Exposed transmission lines for many of the unrest and tension because of several factors, the most important of the this factors is earth of gravity, as well as other factors such as temperature, snow, wind speed.

Sag is the difference between the level of support towers and the lowest point of the conductor. When the conductor suspended between the towers, it takes shape as in Fig.3.

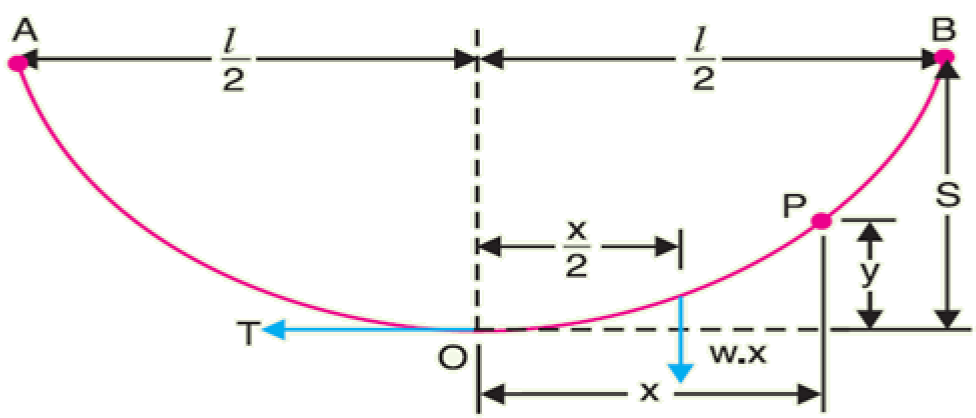


Figure 4.3: Sag when the towers have the same height [7]

Case 1:

As shown in Fig.3 the calculation of sag as following:

$$\text{Sag}= \frac{WL^2}{8T} \text{ (m)} \quad \textbf{(4.3)}$$

Where

W: Wight

L: Length (Span)

T: Tension

Table 4.3: Sag at Ultimate strength and variable span

Span(m)	Ultimate strength(kg)	Horizontal distance(m)	Sag(m) Safety factor = 2	Sag(m) Safety factor = 0
250	8991	125	1.602296741	0.801148371
260	8991	127.5	1.733044155	0.866522078
270	8991	130	1.868918919	0.9344459459
280	8991	132.5	2.009921032	1.004960516
290	8991	135	2.156050495	1.078025247
300	8991	137.5	2.307307307	1.153653654
310	8991	140	2.463691469	1.231845735
320	8991	142.5	2.625202981	1.31260149
330	8991	145	2.791841842	1.395920921
340	8991	147.5	2.963608052	1.481804026
350	8991	150	3.140501613	1.570250806

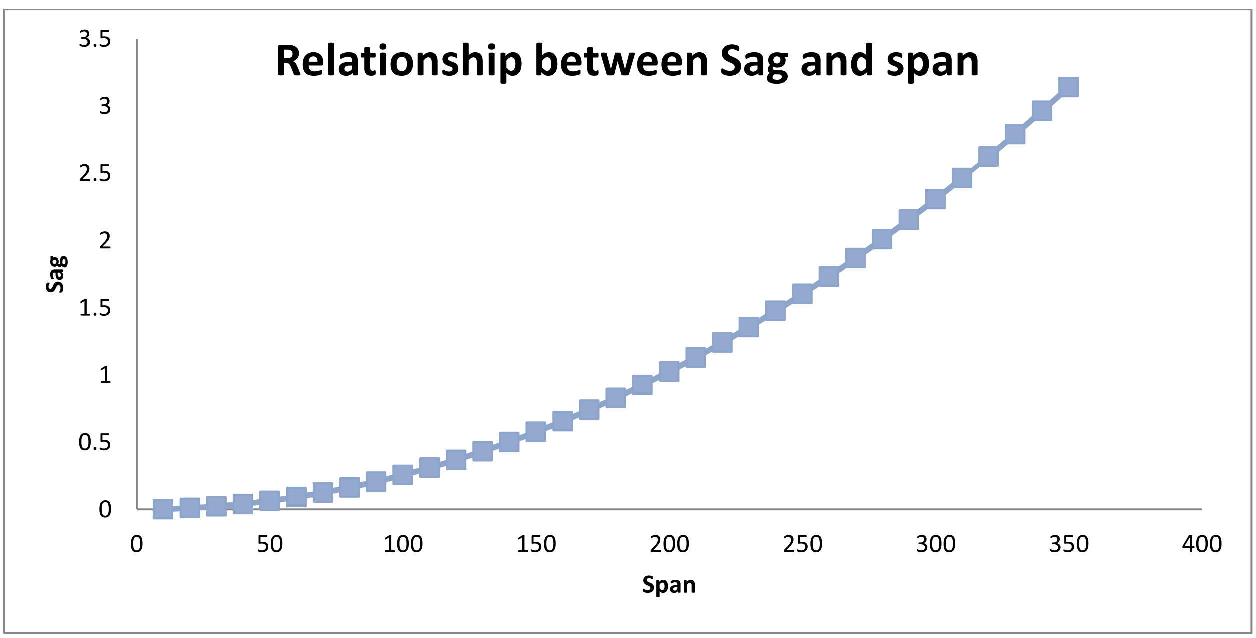


Figure 4.4: Relationship between Sag and span

Table 4.4: Sag at span (300m) and variable tension

Span(m)	Ultimate strength(kg)	Horizontal distance(m)	Sag(m) Safety factor = 2	Sag(m) Safety factor = 0
300	991	150	20.9334	10.4667
300	1791	150	11.58291	5.791457
300	2591	150	8.006561	4.003281
300	3391	150	6.117664	3.058832
300	4191	150	4.949893	2.474946
300	4991	150	4.156482	2.078241
300	5791	150	3.582283	1.791141
300	6591	150	3.147474	1.573737
300	7391	150	2.806792	1.403396
300	8191	150	2.532658	1.266329
300	8991	150	2.307307	1.153654

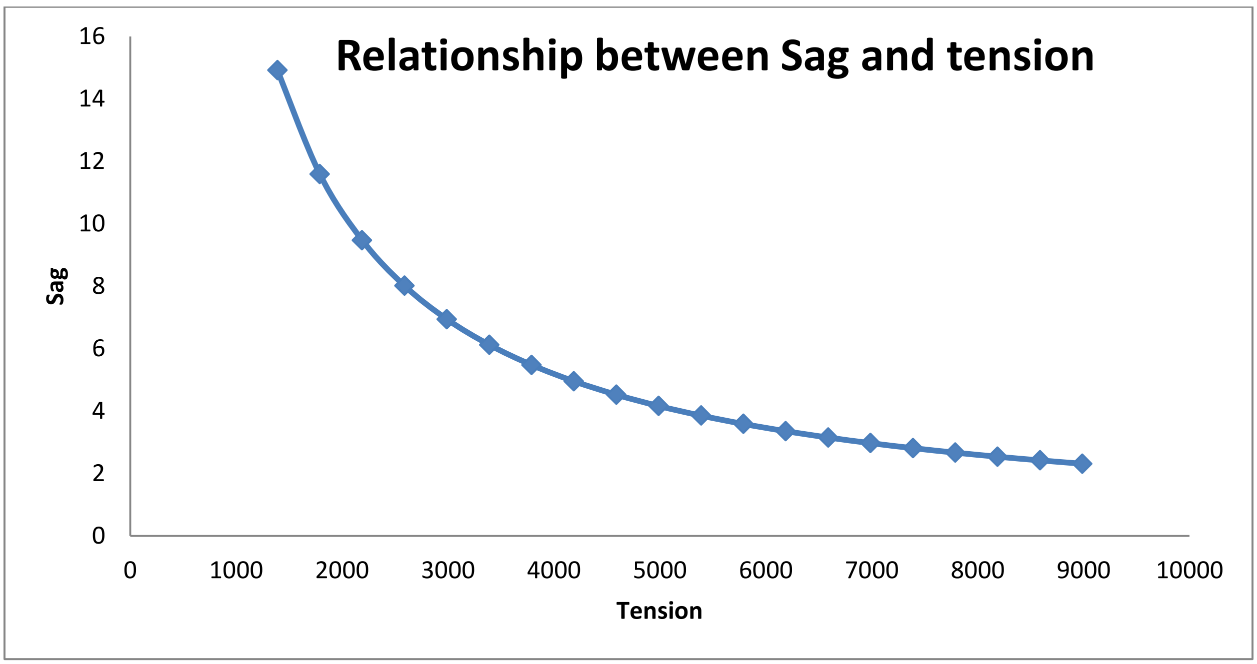


Figure 4.5: Relationship between Sag and tension

Main factors that effect on sag of lines:

1. Temperature
2. Ice
3. Wind speed

The effect of temperature is very low, so we can neglected it.

The effect of ice and wind as follows:

If the wind speed = 80 km/h, Ice thickness = 1cm, Ice density =0.934 g/cm^3

$$W_t = \sqrt{(W + Wi)^2 + (Ww)^2} \quad \textbf{(4.4)}$$

$$W_i = \text{ice density} \times \frac{\pi}{4}[(d + 2t)^2 - d^2] \quad \textbf{(4.5)}$$

$$= 0.00594 \text{ kg}$$

$$W_w = \text{wind pressure} \times (d+2t) \quad \textbf{(4.6)}$$

$$= 2.4 \text{ kg}$$

Where:

W_t: Total weight of conductor per unit length

W: weight of conductor per unit length

W_i: weight of ice per unit length

W_w: wind force per unit length

t: Ice thickness

$$\text{Tan}\theta = \frac{Ww}{W+Wi} \quad \textbf{(4.7)}$$

$$= 0.383$$

$$S = \frac{WtL^2}{8T} \text{ (m)}$$

Sag at 0.35 of ultimate strength and 300 m span is:

$$W_t = \sqrt{(0.00549 + 2.4\,)^2 + (0.922)^2}$$

$$= 2.576 \text{ kg}$$

$$T = 0.35 * 8991 = 3146.85 \text{ kg}$$

$$S = \frac{WtL^2}{8T} = S = \frac{2.576*300^2}{8*3146.85} = 9.2 \text{ m}$$

Sag at 0.25 of ultimate strength and 300 m span is:

$$S = \frac{WtL^2}{8T} = S = \frac{2.576*300^2}{8*2247.75} = 12.89 \text{ m}$$

Case 2:

In some areas there is a difference in the height of the towers and this leads to sag as shown in the figure bellow. The calculation of sag in this case as following:

$$S1 = \frac{WX1^2}{2T} \text{ (m)} \quad \textbf{(4.8)}$$

$$S2 = \frac{WX2^2}{2T} \text{ (m)} \quad \textbf{(4.9)}$$

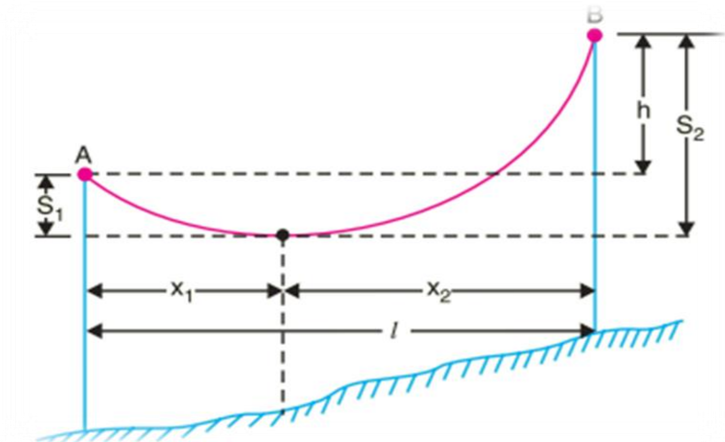


Figure 4.6: Sag when the towers have the different height [7]

$$X_1 = \frac{L}{2} - \frac{Th}{WL} \quad \textbf{(4.10)}$$

$$X_2 = \frac{L}{2} + \frac{Th}{WL} \quad \textbf{(4.11)}$$

Table 4.5: Sag at 0.25 &0.35 of rated tension and 300m span

h	X1 at 0.25 R.T	X1 at 0.35 R.T	X2 at 0.25 R.T	X2 at 0.35 R.T	S1 at 0.25 R.T	S1 at 0.35 R.T	S2 at 0.25 R.T	S2 at 0.35 R.T
1	141.87	138.62	158.13	161.38	4.13	2.82	5.13	3.82
3	125.62	115.87	174.38	184.13	3.24	1.97	6.24	4.97
5	109.37	93.12	190.63	206.88	2.45	1.27	7.45	6.27
7	93.12	70.36	206.88	229.64	1.78	0.73	8.78	7.73
9	76.86	47.61	223.14	252.39	1.21	0.33	10.21	9.33
11	60.61	24.85	239.39	275.15	0.75	0.09	11.75	11.09
13	44.36	2.10	255.64	297.90	0.40	0.00	13.40	13.00
15	28.10	-20.65	271.90	320.65	0.16	0.06	15.16	15.06
17	11.85	-43.41	288.15	343.41	0.03	0.28	17.03	17.28

Where:

R.T: Rated tension.

W=0.922 kg/m.

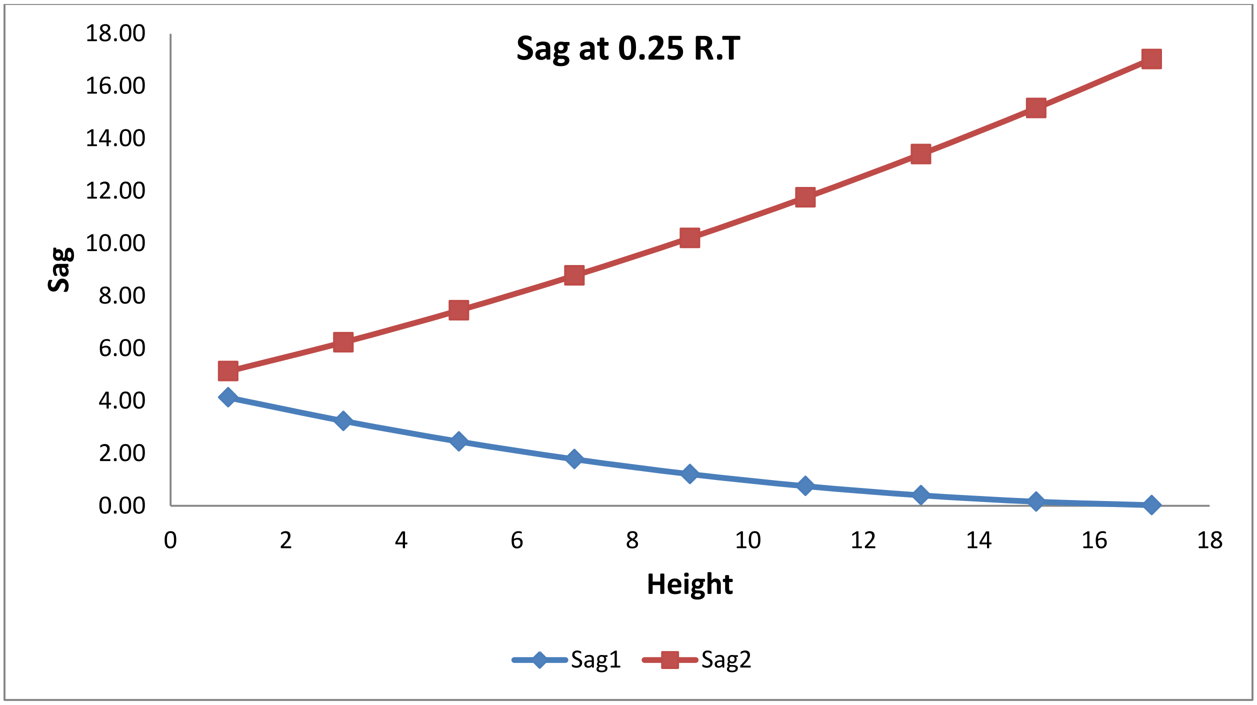


Figure 4.7: Sag at 0.25 of rated tension

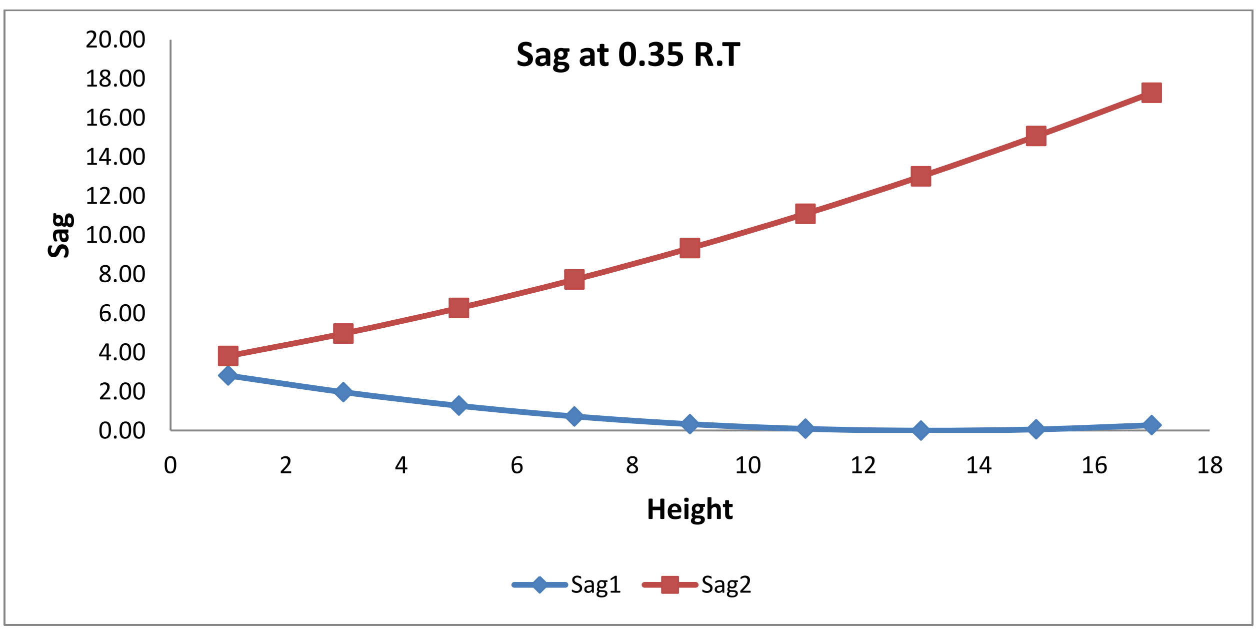


Figure 4.8: Sag at 0.35 of rated tension

4.2.5. Parameters of transmission line:

4.2.5.1. The transmission line resistance

The first transmission line parameter is the resistance of the conductor. The resistance cause I^2R loss and lead to IR voltage drop. Resistance of line depends on the length and cross-section area of the transmission line. The dc resistance of the line given by the following equation:

$$R=\rho \frac{L}{A} \tag{4.12}$$

Where
ρ: The resistivity of the conductor (Ω-m).

The resistance of transmission line affected by the operating temperature of the conductor, where the relationship between temperature and resistance of the conductor is direct relationship. The resistance of conductor dependence on temperature is given by the following equation:

$$R_2=R_1[1+\alpha(T_2-T_1)] \tag{4.13}$$

Where: R_1 & R_2 is the resistance at temperatures T_2 and T_1 respectively.
α: The temperature coefficient of resistance.

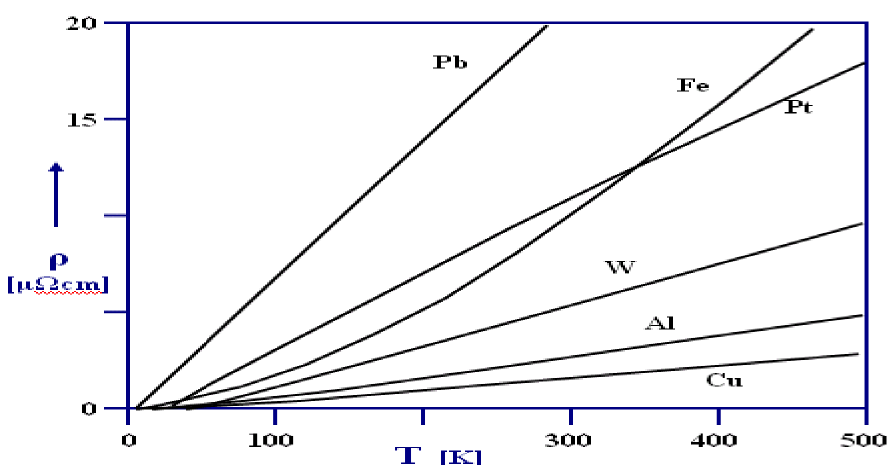


Figure 4.9: The relationship between resistance and temperature

4.2.5.2. The transmission line inductance

The second parameter that effect on the impedance of the transmission line is the inductance. To calculate the inductance for three-phase lines we can use this equation:

$$L=\text{Internal inductance} + \text{External inductance} \tag{4.14}$$

$$\text{Internal inductance} = \frac{\mu_\circ}{8\pi} \quad \textbf{(4.15)}$$

$$\text{External inductance} = 2 \times 10^{-7} \times ln(\frac{Deq}{Dsl}) \quad \textbf{(4.16)}$$

Where:

$\mu_\circ = 4\pi \times 10^{-7}$ H/m

D_{SL}: GMR

$$Deq = (\text{Dx Dy Dz})^{1/3} \quad \textbf{(4.17)}$$

$$Dsl = \sqrt[9]{(Ds \times d \times d)^3} \quad \textbf{(4.18)}$$

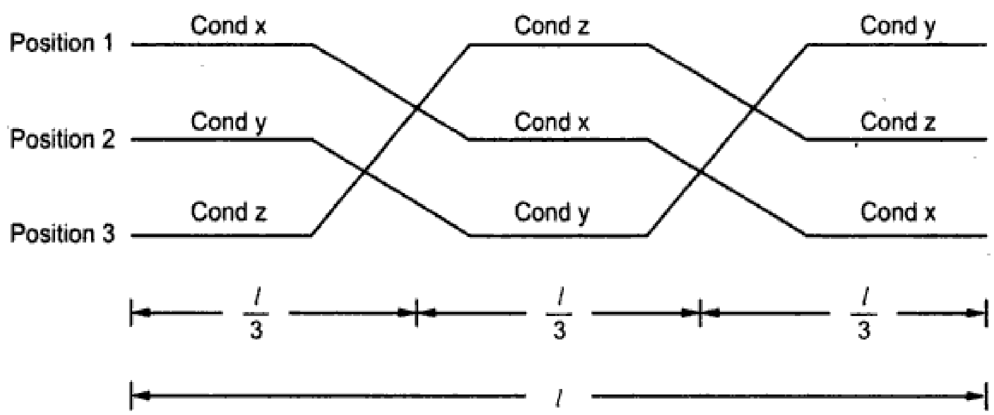


Figure 4.10: Completely transposed three-phase line

$$\text{Ds} = 0.0278 \times \frac{1}{3.28} = 0.0084756 \text{ m}$$

$$Dsl = \sqrt[9]{(0.0084756 \times 0.31 \times 0.31)^3} = 0.09339 \text{ m}$$

$$Deq = \sqrt[3]{(5.085 \times 5.085 \times 10.17} = 6.407\text{m}$$

$$\text{L} = \frac{\mu_\circ}{8\pi} + 2 \times 10^{-7} \times \ln(\frac{6.407}{0.09339}) = 8.9567 \times 10^{-7} \text{ H/m}$$

4.2.5.3. The transmission line capacitance

The capacitance is the last parameter that effect on the transmission line impedance. To determine the capacitance of the conductor we can use this equation:

$$C = \frac{2\pi\varepsilon_\circ}{\ln(\frac{Deq}{Dsc})} \text{ F/m} \quad \textbf{(4.19)}$$

Where:

$\varepsilon_\circ$: The permittivity of free space.

$$Dsc = \sqrt[3]{rd^2} \quad \textbf{(4.20)}$$

$$Dsc = \sqrt[3]{1.01556 \times 0.31^2} = 0.4604\text{m}$$

Deq= 6.407m

$$C = \frac{2\pi\varepsilon_\circ}{\ln(\frac{6.407}{0.4604})} = 21.12*10^{-12}$$

4.2.6. Selection the ground cable and arresters cables

As we as mentioned in chapter 3, Surge arresters are equipment used to eliminate the sudden impact of the lightning on the system.

The parameters of surge arrester:

The energy discharged into the arrester is given by

$$E = Va\ Ia\ t \quad \textbf{(4.21)}$$

Where:

E: The energy discharged

Va: Arrester voltage

Ia: Arrester current

t: The duration of the switching impulse

$$t = \frac{2L}{c} \quad \textbf{(4.22)}$$

Where:

L: Length of line = 42.5 km

c: Speed of surge = $3x10^8$

The arrester discharge voltage and current:

$$V_{SS} = I\,Z_o + V_a \qquad \textbf{(4.23)}$$

Where

I: is the surge current

The operating voltage in the transmission line 161 kV, the length of line 42.5 km, the V-I characteristic of surge arrester is shown in Fig 4.11.

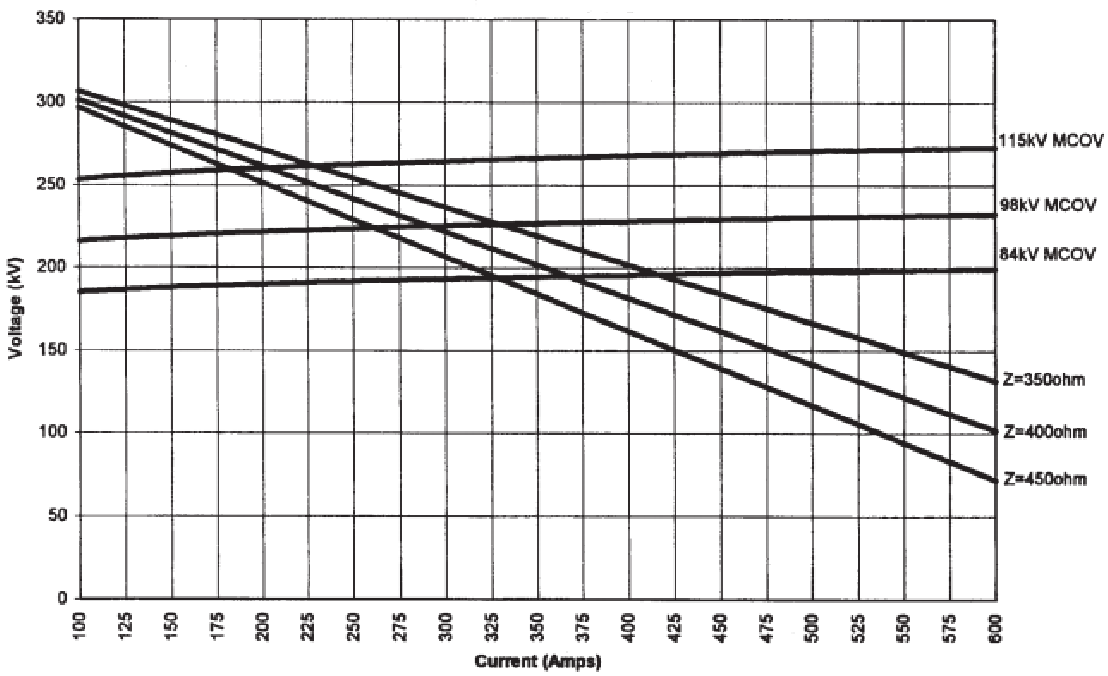


Figure 4.11: Arrester V-I characteristic at operating voltage 161 kV

PVN surge arrester, 98 kV MCOV, Surge impedance 350 ohm. The arrester current approximately 335 A with 230 kV.

$$t = \frac{2L}{c} = \frac{2\times42.5\times10^3}{3\times10^8} = 28.33\times 10^{-5}$$

$$E = Va\ Ia\ t = 230\times 10^3 \times335\times28.33\times 10^{-5} = 21.79 \text{ kJ}$$

The current of the surge arrester is 335 A, So the cross sectional area of the cable that could use is 107.22 mm^2 and the rated current for this cable is 357 A

4.2.7. Corona

Corona is a phenomenon arising in high-voltage systems may be visible around the line where the glow appears. It could be invisible, but in two cases it has an influence on the system. When the voltage increased, the impact of the corona is increased.

Corona appears around the lines because of the ionization of the surrounding air, which leads to increased area of a section of conductor, where the air becomes a conductor.

Factors Affecting Corona:

1. Atmosphere
   Weather a significant impact on the appearance of the corona, where the storm lead to increased ionized molecules around the line.
2. Conductor size
   Corona appearance depends on the line shape and the diameter of the conductor.
3. Spacing between conductors
   The distance between the cables have a significant impact on the appearance of the corona, where increasing the distance between conductors lead to reduce the electro static stress on the surface of conductor.
4. Line voltage
   The greatest influence on the corona is for the operating voltage.

The advantage of the corona:

1. Reduce the effect of transient stability.
2. Increase cross sectional area of conducting medium due to reduce the electrostatic stress between the conductors.

The disadvantage of the corona:

1. Increase the loss
2. Corona leads to nonsinusoidal current and voltage and increase the voltage drop.

Methods of Reducing Corona Effect

1. By increasing conductor size
2. By increasing conductor spacing

Calculation of corona

Critical disruptive voltage: It is the minimum phase to neutral voltage when corona occurs.

Potential gradient at the conductor surface is given by:

$$g_0 = \frac{Vc}{r\log\frac{d}{r}} \quad \textbf{(4.24)}$$

g_o =21.2 kV/cm (rms)

Critical disruptive voltage under standard condition (δ=1):

$$V_c = g_o\, r \log_e \frac{d}{r} \qquad \textbf{(4.25)}$$

When the temperature is higher or lower than 25˚, the air density factor would be:

$$\delta = \frac{3.92b}{273+t} \qquad \textbf{(4.26)}$$

Critical disruptive voltage:

$$V_c = \delta\, g_o\, m_o\, r \log_e \frac{d}{r} \text{ kV/phase} \qquad \textbf{(4.27)}$$

Where:

$m_{o:}$ 1 for polished conductors, 0·98 to 0·92 for dirty conductors, 0·87 to 0·8 for stranded conductors.

Visual critical voltage: It is the minimum phase to neutral voltage when the corona glow appears all along the line conductors.

$$V_v = m_v\, g_o\, \delta\, r\, (1+\frac{0.3}{\sqrt{\delta\, r}}) \log_e(\frac{d}{r}) \qquad \textbf{(4.28)}$$

Where m_v irregularity factor = 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

Power loss due to corona

$$P = 242.2\, (\frac{f+25}{\delta}) \sqrt{\frac{r}{d}}\, (V - Vc)^{2} \times 10^{-5} \text{ kW/km/phase} \qquad \textbf{(4.29)}$$

Where:

f: supply frequency in Hz
V: phase-neutral voltage
V_c: disruptive voltage per phase

Critical disruptive voltage:

d = 5.085m, r = 1.01556, δ = 1, m_o = 0·92

$$V_c = \delta\, g_o\, m_o\, r \log_e \frac{d}{r}$$

$$= 1\times21.2\times0.92\times1.01556\times \log_e \frac{508.5}{1.01556} = 123.6 \text{ kV}$$

$$\text{Line voltage} = 23.6\times \sqrt{3} = 213.9 \text{ kV}$$

$$V_v = m_v\, g_o\, \delta\, r\, (1+\frac{0.3}{\sqrt{\delta\, r}})\, \log_e(\frac{d}{r})$$

$$=0.72\times21.2\times1.01556\times (1+\frac{0.3}{\sqrt{1*1.01556}})\, \log_e(\frac{508.5}{1.01556}) = 125.043 \text{ kV}$$

$$\text{Line voltage} = 125.043\times \sqrt{3} = 216.58 \text{ kV}$$

In these circumstances, Corona will not appear.

4.3. Insulators

Insulators are one of the parts of the overhead transmission systems and are made from the same materials which have high resistance and do not allow the electric charge to moving freely inside. This material prevent provides a path for the current through the tower.

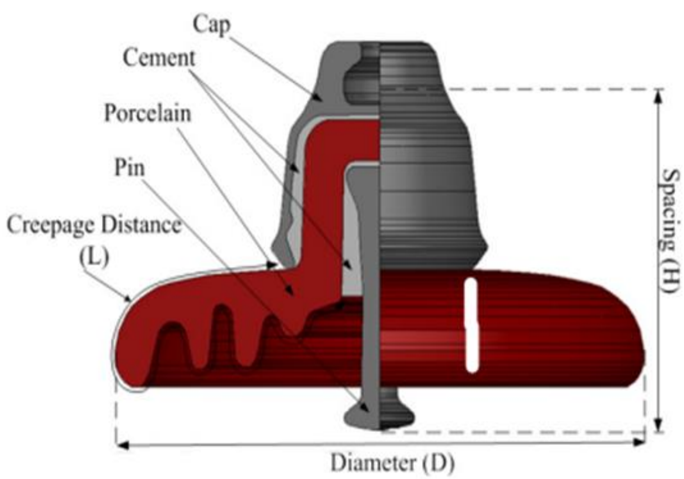


Figure 4.12: Insulator

The function of the insulator is providing insulation of transmission line for the towers. In addition install the conductor on the tower. Even insulators able to carry out these functions, it must have the following properties:

1. High mechanical strength in order to withstand conductor load, wind load etc.
2. High electrical resistance of insulator material in order to avoid leakage currents to earth.
3. High relative permittivity of insulator material in order that dielectric strength is high.

4. The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
5. High ratio of puncture strength to flashover.

Insulators are made of several materials like glass, porcelain, polymers and among others. Each of these materials have different properties can be summarized in the following table, which shows the difference between these types:

Table.4.6: Comparison between the marital of insulator [1]

	Porcelain Insulator	**Glass Insulator**	**Polymer Insulator**
Dielectric Strength	**Low**	**High**	**High**
Compressive Strength	**Very High**	**Low**	**Low**
Tensile Strength	**Very Low**	**Very High**	**High**
Resistivity	**High**	**Very High**	**High**
Cost	**Expensive**	**Cheap**	**Cheap**

The factors affecting in the selection of insulation material:

1. Availability of material
2. Cost
3. Operating condition
   Operating temperature, pressure, operating voltage and current are to be considered for the selection of a particular material.
4. Easy in shaping.

The factors affecting in the breakdown of insulation material:

1. Temperature
2. Moisture
3. Applied voltage
4. Ageing

4.3.1. Transmission line insulators:

1. Pin Insulator
   This type of insulator can make by different type material such as porcelain, glass, plastic or polymer. The number of pieces is directly proportional with the applied voltage, where every piece can beer voltage up to 23 KV.

2. Suspension Insulator
   The suspension insulator is made by porcelain. This type used for the voltage levels that increase 33KV. The number of pieces is directly proportional with the applied voltage.

3. Strain Insulator
   This type is commonly used in medium voltage and low voltage, where the voltage value is 11 KV or less. It can be used in location that are have very high tensile where two or more insulators used, and are connected in parallel.

4. Shackle insulator
   This type is used in medium and low voltage, where it is used as an alternative to the strain insulator.

We select glass insulator for tension and porcelain insulator for suspension.

The pieces number of glass insulator is = 161/23 = 7 pieces.

4.4. Towers

It is one of the most important components of the transmission systems. It operates mainly to support and installs the overhead lines and keep safe distance between them. Also, these towers carrying other parts, such as surge arresters.

Figure 4.13: Double circuit tower

In general, the towers should have the following properties:

1. High mechanical strength to withstand the weight of conductors and wind loads.
2. Having low Wight without effect on the mechanical strength
3. Cheap in cost and economical to maintain
4. Have long life.
5. Easy accessibility of conductors for maintenance

4.4.1. Types of towers

The main types of transmission towers:

1. Tension Towers
2. Suspension Towers
3. Transposition Towers
4. Angle Towers
5. Crossing Towers
6. Terminal Towers

Also it can be classified towers depending on the different considerations which are as follows:

A. According to the angle of deviation there are four types of transmission tower:

1. A type tower (angle of deviation 0 to 2)
2. B type tower (angle of deviation 2 to 15)
3. C type tower (angle of deviation 15 to 30)
4. D type tower (angle of deviation 30 to 60)

B. According the number of circuits:

1. Single circuit tower

2. Double circuit tower
3. Multi circuit tower

C. According method of tower erection:

1. Build-up method
2. Section method
3. Ground assembly method
4. Helicopter method

The Components of Transmission Tower:

1. Peak of the transmission tower
2. Cage of transmission tower
3. Cross arm of the transmission tower:
4. Body of tower

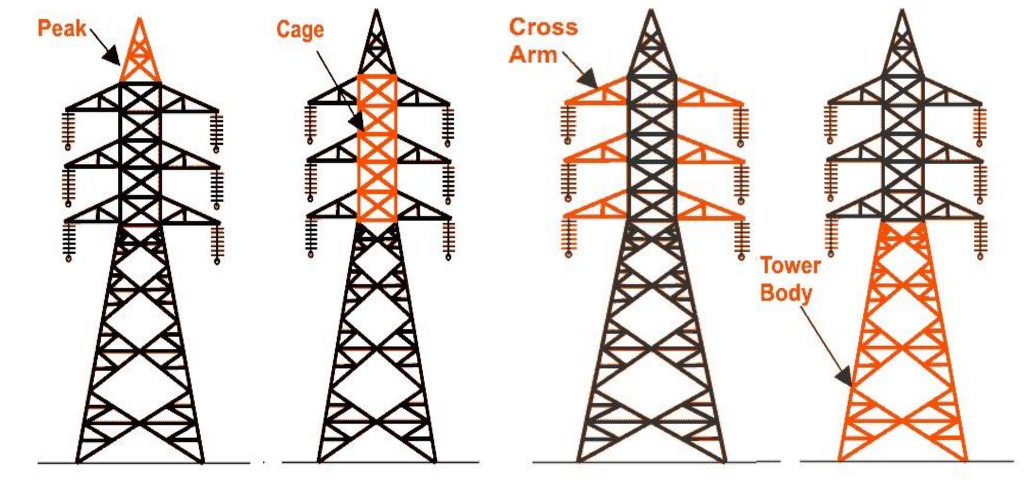


Figure 4.14: Components of tower

And there are other parts such as:

1. Leg of transmission tower
2. Boom of transmission tower
3. Anchor Bolt and Base plate assembly of transmission tower

Selection of Tower Structure:

1. Number of circuits
2. Length of insulator
3. Minimum clearances between the conductors
4. Location of ground wire
5. Mid-span clearance
6. Minimum clearance of the lowest conductor above ground level

4.4.2. Basics in tower Design

The following aspects are considered essential for fixing the tower outline:

1. Maximum sag of lower conductor
2. Height and location of ground wire
3. Length of cross arm and conductor spacing
4. Minimum mid-span clearance
5. Tower width at base and at top hamper

The design of towers includes the design of the following:

1. Tower height
   The height of tower in the system with 161 kV approximately 30m as shown in the figure bellow:

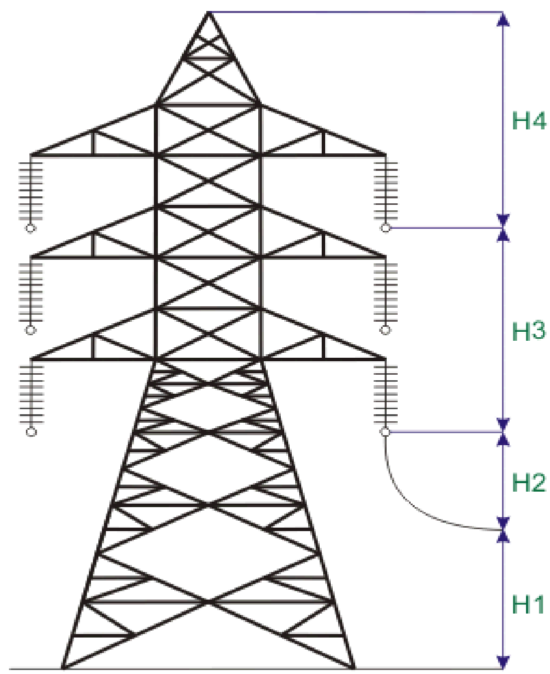


Figure 4.15: Double circuit tower

Height of tower = $h_1+h_2+h_3+h_4$

h_1: Distance represent safety, the distance between the last line on the tower and the ground. We can calculate it by using the following equation:

$$CL(h1) = 5.182 + 0.305 \times K \quad \textbf{(4.30)}$$

Where:

$K = \frac{V-33}{33}$

V: Voltage (kV)

$$h_1 = 5.182 + 0.305 \times \frac{161-33}{33} = 6.365\text{m}$$

Table 4.7: Standard ground clearance [9]

Voltage level	Clearance
Up to 33 KV	5.8m
33 KV - 66 KV	6m
66 KV - 132 KV	6.7m
132 KV - 273 KV	7m
275 KV - 400 KV	7.3m

h_2: Maximum distance can line up for it because of sag.

h_3: The distance between the lines. It could calculate by the following equation:

$$Spaeing(cm) = 0.3048 \times V + 4.010 \frac{D}{W} \sqrt{S} \quad \textbf{(4.31)}$$

$$Spaeing(cm) = 7.5\sqrt{S} + \frac{V^2}{2000} \quad \textbf{(4.32)}$$

$$Spaeing(cm) = 6.5\sqrt{S} + 0.7E \quad \textbf{(4.33)}$$

$$Spaeing(cm) = 8\sqrt{S+L} + \frac{E}{1.5} \quad \textbf{(4.34)}$$

Where:

V: Voltage (kV)

E: Voltage (kV)

D: Diameter (cm)

W: Wight (kg/m)

S: Sag (cm)

L: Length of insulating string

h_4: The distance between the ground wire and the transmission lines.

2. Base width

It is tightly installed towers in the land. Where the base tower placed at a depth of 4 in the land. Base tower up to 4 * 4 meters are installed through a large amount of concrete and be the size of 6 * 6 * 3.

The tower mass and the expected mass of the tower play a major role in the process of determining the dimensions of the base of the tower. The mass that will be carried by the tower is the mass of transmission line in addition to the insulators on it.

The mass of the transmission line = 922 kg/km

The mass of ground wire = 433.2 kg/km

The total mass = (922*0.3*18)+(433.2*0.3*1) =5108 kg

Width is the distance between the center of gravity of the leg to the center of gravity in the adjacent corner leg.

$$B = 0.42\sqrt{M} = 0.013\sqrt{m} \tag{4.35}$$

B: Base width in meter
M: Overturning moment about the ground level in ton-meters
m: Overturning moment about the ground level in kg-meters

There are cases where the base consisting of concrete is greater than 6 * 6 m among the most prominent cases to be tension on the tower from one side:

1. For rocky soil: The dimensions of the base in this case are 6.5*6.5*3.5
2. For sandy soil: The dimensions of the base in this case are 7.5*7.5*4

3. Top hamper width

Hamper is a part of the tower is located between the cross arms. The main objective of this part is to ensure the maintenance of the clearance that require between the phases. In In addition ensure of the tower to withstand the mechanical load caused by the lines. The weight of this part is in range between 18-30% of the tower weight.

The width of the tower depends on two main variables:

1. Horizontal spacing between conductors
2. The slope of the legs should be such that the corner members intersect as near the center of gravity of the loads as possible

4. Cross arm's length

The cross arms is a parts of the transmission towers used mainly to install insulators and lines. The cross arm length depends on the operating voltage value.

Number of arms depends on the type of the tower according the number of circuit. Where each circuit needs 3 cross arms and the distance between every arm and other in 161 kV level is 5.085m. And the length of every arm is approximately 3.65 m

4.4.3. Number of towers used and types

The number of towers that needed to cover the specific area on the distance between the starting point and ending point. In addition to the distance between the towers. As mentioned earlier that the distance between the towers selected 300 m. So the number of towers is:

Span = 300 m

The distance between Al-Eizariya and Huwara 53.8 km.

$$\text{Number of towers} = \frac{disnance}{Hpan\ between\ towers + Horizantal\ tower\ base} \quad \textbf{(4.36)}$$

The total number of towers that required in this project is approximately 222.

Table 4.8: Number of towers

Type of tower	Number of tower
Terminal Towers	10
Suspension Towers	187
Transposition Towers	0
Angle Towers	25

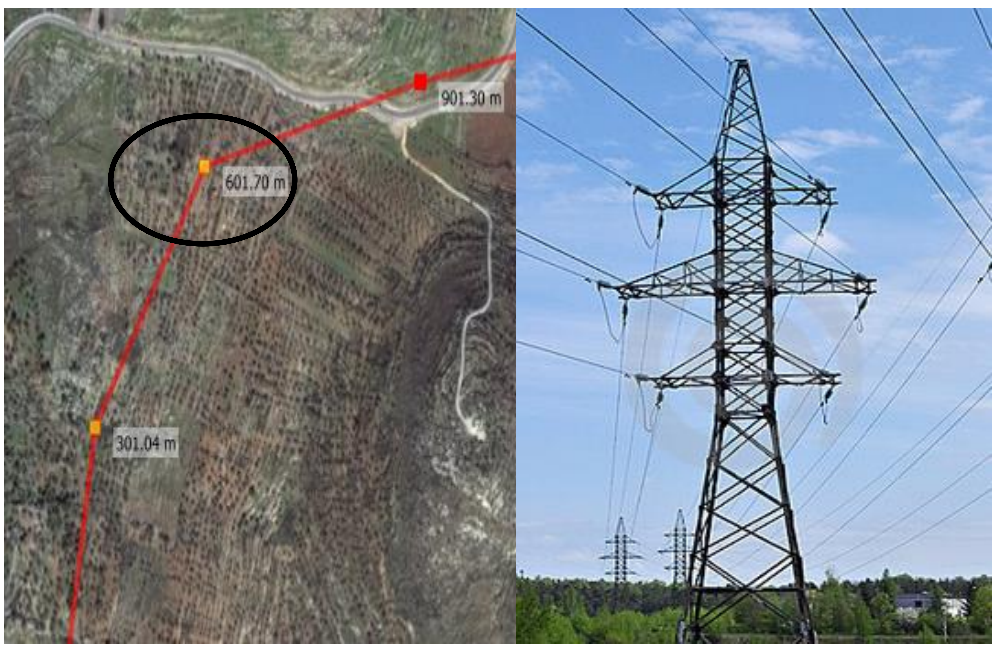


Figure 4.16: Angle tower

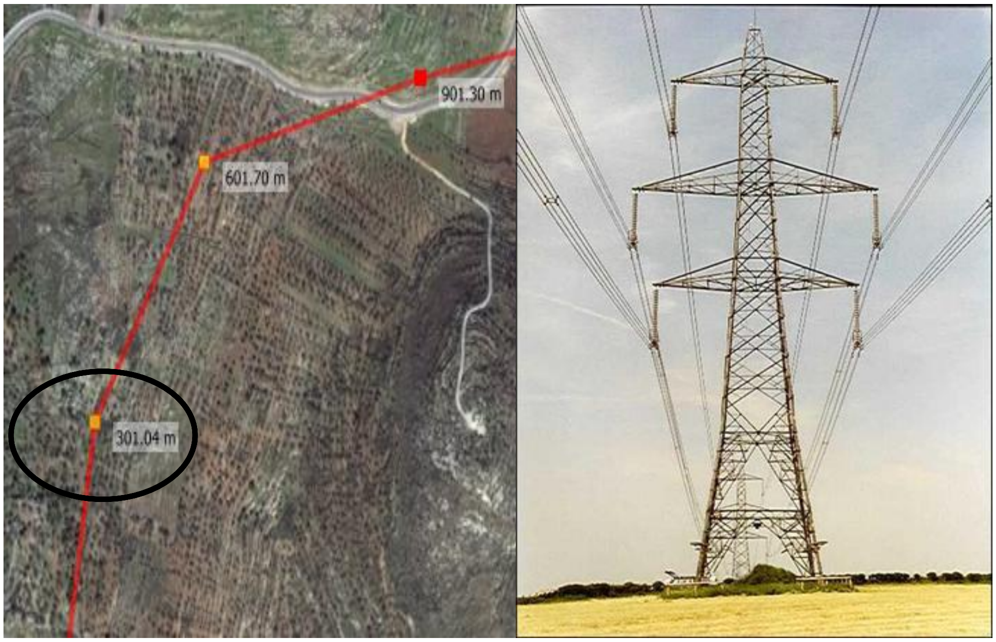


Figure 4.17: Suspension tower

- The ground clearance is 7 m.
- In the voltage level (161 kV), the standard clearance between the conductor is 5.085 m.
- The distance between the ground wire is 3.23 m
- The distance between the two circuits and the tower is 4.2 m and it could be 2.45
- The width of cage of tower is approximately 1.1 m

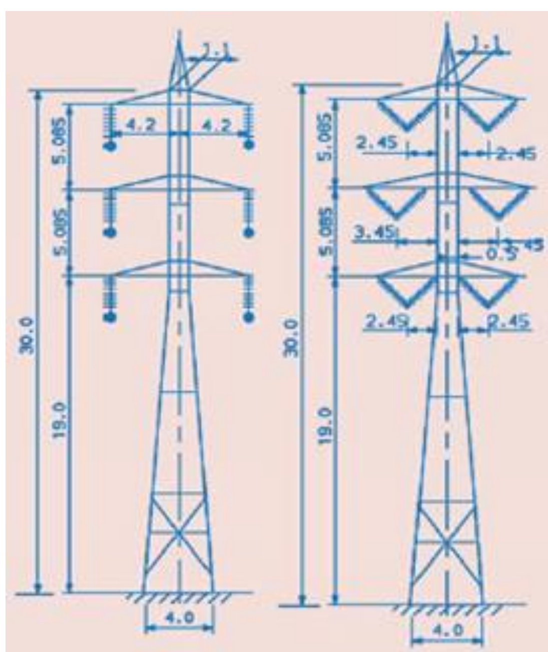


Figure 4.17: Double circuit towers for 161 kV level

4.4.4. Guys

Guyed structure is used to support the installation of the towers of different kinds. They generally have the advantage of light weight, erection ease, pre-assembly, and simple foundation design.

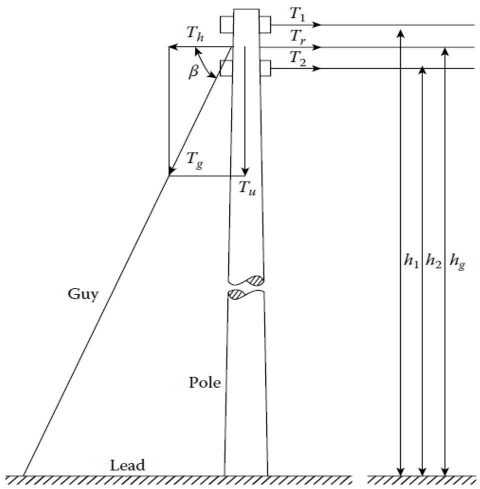


Figure 4.18: Guy

To design of guys, the tension on the tower must know.

The tension in lines:

$$T = \frac{WL^2}{8S}$$

Minimum sag = 3.296 m, Acceleration of gravity = 9.81, Wight= 0.922 kg/m

$$T = \frac{0.922x300^2}{8x3.296} = 3147\text{kg}$$

$$T = 3147 \times 9.81 = 30.872 \text{ kN}$$

$$T_h = \frac{1}{h_g} \left(T_1 \times h_1 + T_2 \times h_2 + T_3 \times h_3 \right) \quad \textbf{(4.37)}$$

Where,

Th is the horizontal component of guy wire tension.

T1 is the horizontal load at height h1.

T2 is the horizontal load at height h2.

T3 is the horizontal load at height h3.

hg is the height of attachment point of guy.

h1 is the height of horizontal load T1.

h2 is the height of horizontal load T2.

h3 is the height of horizontal load T3.

$$T_h = \frac{1}{15}\,(30.872 \times 29 + 30.872 \times 24 + 30.872 \times 19)$$

$$T_h = 148.18 \text{ kN}$$

$$\tan\beta = \frac{h_g}{L} \qquad \textbf{(4.38)}$$

$$\beta = \tan^{-1}\left(\frac{15}{5}\right) = 71.56^{\circ}$$

where L is the lead of the guy. Then, the tension in the guy wire is

$$T_g = \frac{T_h}{\cos\beta} \qquad \textbf{(4.39)}$$

$$= \frac{148.18\text{kN}}{\text{COS } 71.5} = 467 \text{ KN}$$

4.4.5. Tower earthing

Earthing is one of the most important elements in the power systems. This element is designed to ensure the safety of people and equipment in the network of the dangerous of high current flow in the system and this current caused by fault or short circuit and the surge current by a lightning discharge can occur. Therefore, the earthing resistance should be made as low as possible, to ensure a greater amount of current flow through the ground to minimize the impact of this current on the system.

The following figure shows the earthing system:

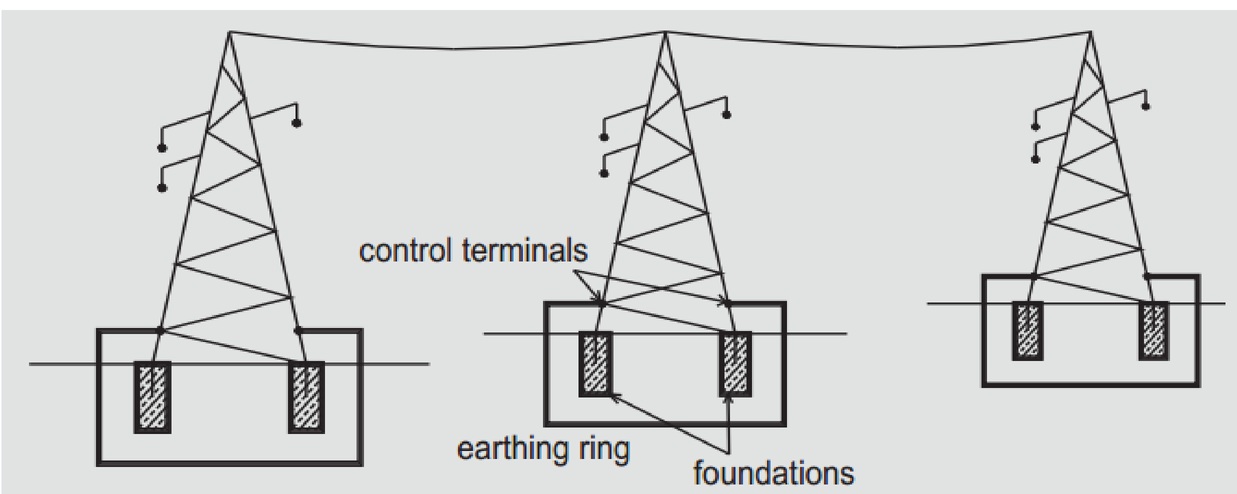


Figure 4.18: Earthing of towers

Earth resistance depends upon soil resistivity. And the tower footing resistance will be 10Ω and should not be more than 20 Ω under any condition throughout the year.

Method of tower grounding:

1. Buried Conductor
   This method is used when resistance is low soil. By using this method one or more conductor connected to the legs of and are buried in the foundations of the tower.

2. Counterpoise wire
   This method is used when the soil resistance is high and the conductivity mostly in the upper layer of the soil. The conductor is buried at a depth of 0.5 m of the earth's surface and are connected to the legs of towers.

3. Rod pipe
   This method is used when increasing conductivity with the increase of soil depth. It is buried conductor length of 3 to 4 m in the ground and connected the conductor with the tower through appropriate wire.

4. Treated earth pits
   The latter method to the process of grounding is used when the resistant around the tower is very high. As in the previous method, the use of connector length of 3-4 meters and buried in treated earth pits to increase conductivity of the soil.

Choose any of the methods previously mentioned is heavily dependent on the resistance to the soil around the tower.

4.5. Summary

In this chapter we select the main components of the transmission system and the most important components the overhead lines and insulators. These components have been selected to be able to withstand the pressure and tensile strength and also carry the influence of some other environmental conditions such as wind and ice.

Also in this chapter we have identified dimensions of the towers used in transmission systems. And ensuring of the tower to withstand stress due to the overhead lines.

Chapter 5 Monitoring system in transmission system

5.1. Introduction

5.2. Monitoring system

5.2.1. Monitoring system benefits

5.2.2. SCADA

5.2.3. Main component of monitoring system

5.3. Measurement Function

5.3.1. Measured Physical Values

5.3.2. Active, Reactive, and Apparent Power measurement

5.4. Control Function

5.5. Operation if measurement devices:

5.1. Introduction

Electrical Power Systems is the largest and most important systems in our life. So it is necessary to monitor these systems in order to take appropriate action in the event of any defect in the system to ensure the continuity of the power supply and maintain the power quality.

Energy monitoring systems are by measuring the voltage, current, power and power factor and others. And because the value of current and voltage in a very high in the power system must use a voltage transformer (VT) and current transformer (CT) to maintain the tools of measurement and prevent damage.

In this chapter we will show the simulation of monitoring system for the transmission system be using Matlab-Simulink (Matlab is a software package which can be used to perform analysis and solve mathematical and engineering problems). The following figure 5.1 shows the transmission system by using Matlab.

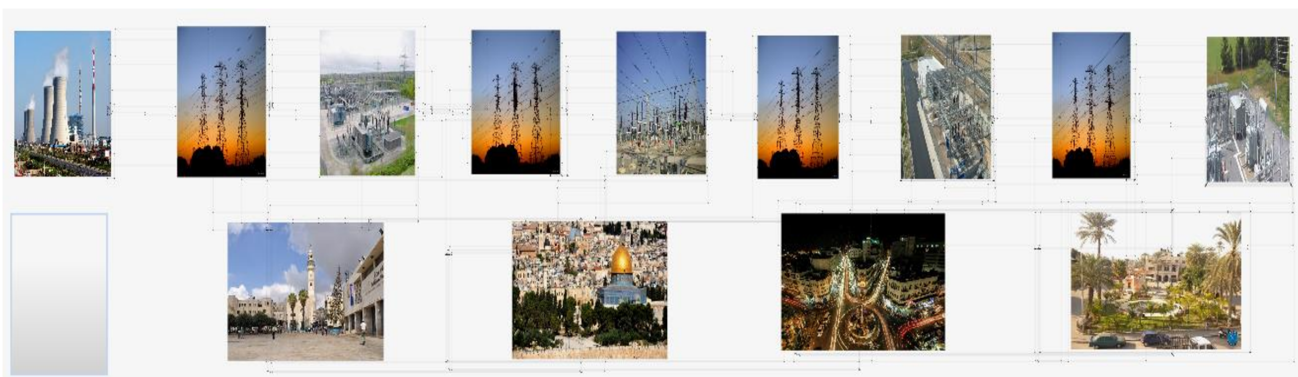


Figure 5.1: Transmission system

5.2. Monitoring system:

The monitoring system is a part of SCADA system. The system use the protective relay in the metering process. This relays connected to the monitoring system by using telephone line or wireless connection. The information collected from the relays in monitoring and control room then. After reminded this information is saved and analyzed and take appropriate action based on this data.

The monitoring system displays a group of diagrams that show system-related information. The monitoring system shows all the events that occur in the power system and provide messages and alarms based on the event that appears in the system.

Single-line diagrams show the status of all the switchgear in the substation in a simplified form so that the substation operator has a quick overview with regard to:

1. Which feeder is connected to which busbar

2. The actual busbar configuration
3. Those feeders that are generating signals

5.2.1. Monitoring system benefits:

1. Increase the reliability through automation
2. Eliminate the need data collection
3. Alarm and system wide monitoring enable operators to quickly spot and address problem
4. Automation protects workers by enabling problem areas to be detected and addressed automatically.
5. Operators can use powerful trending capabilities to detect future problem, provide better routine maintenance of equipment and spot areas for improvement.
6. Historians provides the ability to view data in various ways to improve efficiency.

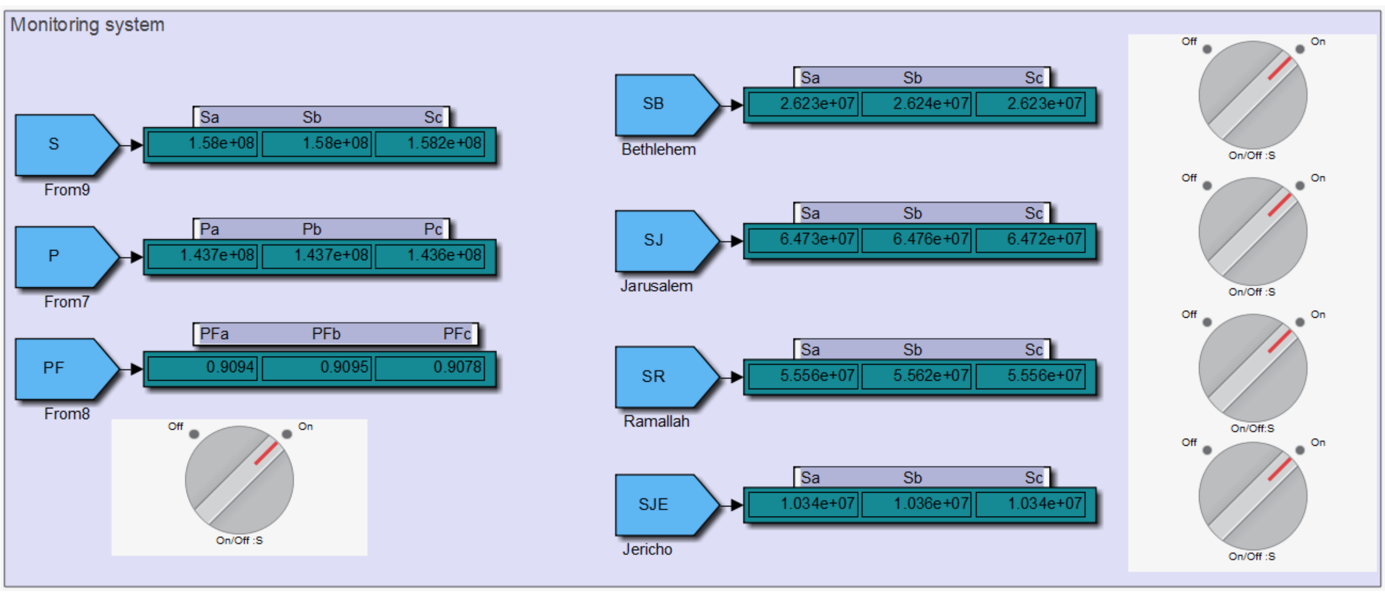


Figure 5.2: Monitoring system

5.2.2. SCADA

SCADA is ‘Supervisory control and data Acquisition’. SCADA systems play a vital role in the monitoring and controlling of electrical systems of all kinds. The using of SCADA is provides all information related to the electrical system. These systems also play an important role in the optimal operation of the system.

A SCADA system for a power system application is a typically a PC-based software package. Data collected from power system, with most of the data originating at substation. Depending on its size and complexity, a substation will have a varying number of controllers and operator interface points.

In a typical configuration, a substation is controlled and monitored in real time by a programmable Logic Controller (PLC) and by certain specialized devices such as circuit breaker and power monitors. Data from the PLC and the devices is then transmitted to a PC-based SCADA node Located at the substation.

One or more PCs are located at various centralized control and monitoring points. The links between the substation PCs and the central station PCs are generally Ethernet-based and are implemented via the Internet, an intranet and some version of cloud computing.

In addition to data collection, SCADA system typically allows commands to be issued from central and monitoring points to substations. If desired and as circumstances allow, these commands can enable full remote control.

Figure 5.3: SCADA system

There are several variables must be monitored in an electrical systems:

1. Current
2. Voltage
3. Active power
4. Reactive power
5. Power factor
6. Total harmonic distortion

5.2.3. Auxiliary component of monitoring system

In the transmission the magnitude of voltage and current is very large. So it must be used:

1. Current transformer
   The current transformer must connect in series with the system where the primary side in transformer will be the busbar. This transformers transfer the current to 5A in the distribution system and to 1A in the transmission system. The number of turns in the secondary side depend on the primary current.

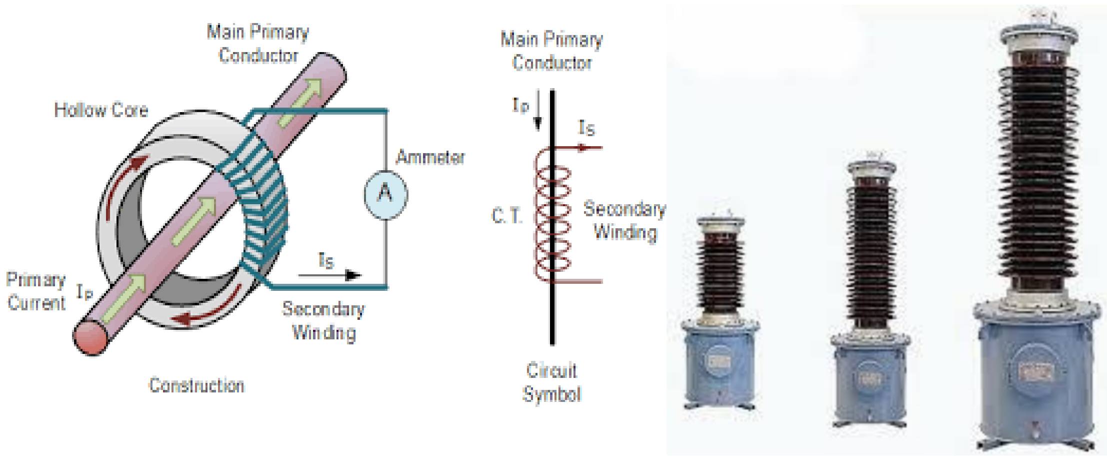


Figure 5.4: Current transformer

2. Voltage transformer
   The voltage transformer must connect in parallel with the system. This transformer step down the voltage to nearly 110V.

Figure 5.5: Voltage transformer

5.3. Measurement Function

This function is one of the most important functions of monitoring systems. This function provides updated information for power system operators. This information includes the following:

1. Active powers.
2. Reactive powers.
3. Voltages.
4. Currents.
5. Temperatures on power transformers.

5.3.1. Measured Physical Values

The protective relay measures the following physical values:

1. Phase currents (3I)
2. Residual current (Ir)
3. Phase voltages (3V)
4. Residual voltage (Vr)

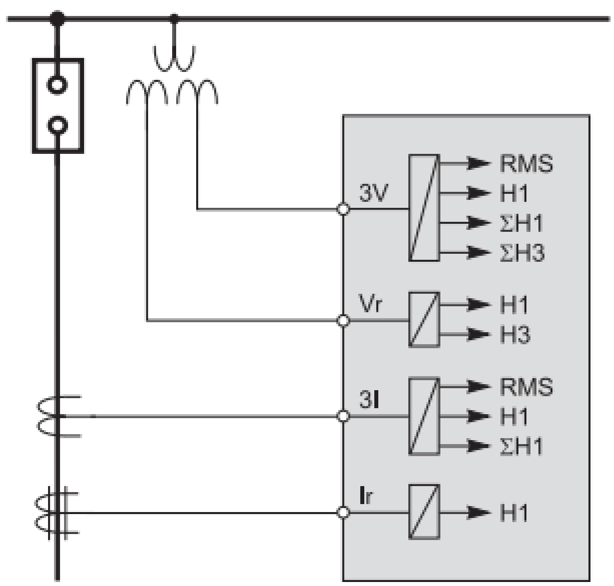


Figure 5.6: Measurement in protective relay

5.3.2. Active, Reactive, and Apparent Power:

Power values are calculated from the phase currents Ia, Ib and Ic:

1. Active power = $\sqrt{3}\, V_{LL}\, I.\cos\angle\theta$ **(5.1)**
2. Reactive power = $\sqrt{3}\, V_{LL}\, I.\sin\angle\theta$ **(5.2)**

3. Apparent power $=\sqrt{3}\ V_{LL}.I.\ S$ **(5.3)**

Power calculations can be based on the two or three wattmeter method depending on the CTs used. The two wattmeter method is only accurate when there is no residual current. It is not applicable if the neutral is distributed. But the three wattmeter method gives an accurate calculation of 3-phase and phase by phase powers in all cases whether or not the neutral is distributed.

Power calculation

By three wattmeter method:

$$P = V_{an} I_a \cos(\theta_V - \theta_I) + V_{bn} I_b \cos(\theta_V - \theta_I) + V_{cn} I_c \cos(\theta_V - \theta_I) \quad \textbf{(5.4)}$$

$$Q = V_{an} I_a \sin(\theta_V - \theta_I) + V_{bn} I_b \sin(\theta_V - \theta_I) + V_{cn} I_c \sin(\theta_V - \theta_I) \quad \textbf{(5.5)}$$

By two wattmeter method:

$$P = V_{ab} I_a \cos(\theta_V - \theta_I) - V_{bc} I_c \cos(\theta_V - \theta_I) \quad \textbf{(5.6)}$$

$$Q = V_{ab} I_a \sin(\theta_V - \theta_I) - V_{bc} I_c \sin(\theta_V - \theta_I) \quad \textbf{(5.7)}$$

$$\text{Apparent Power (S)} = \sqrt{P^2 + Q^2} \quad \textbf{(5.8)}$$

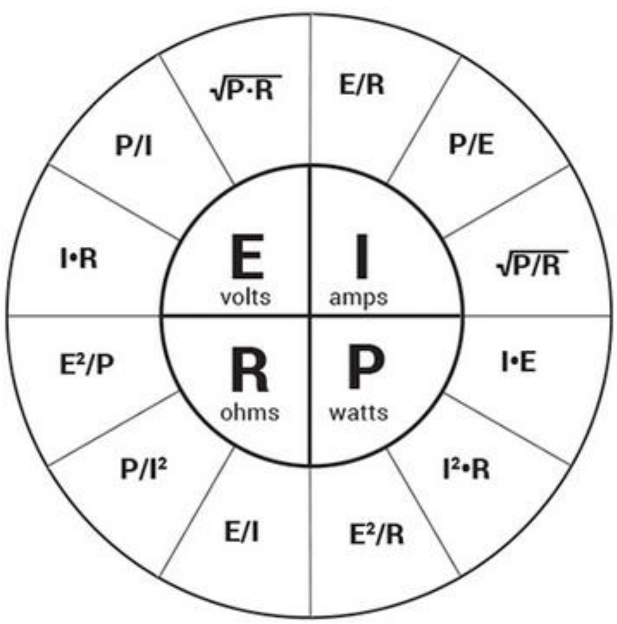


Figure 5.7: Calculation of main electrical quantities

Power Factor (cosθ)

The power factor is defined by PF = $P/\sqrt{P^2 + Q^2}$. It expresses the phase displacement between the phase currents and phase-to-neutral voltages.

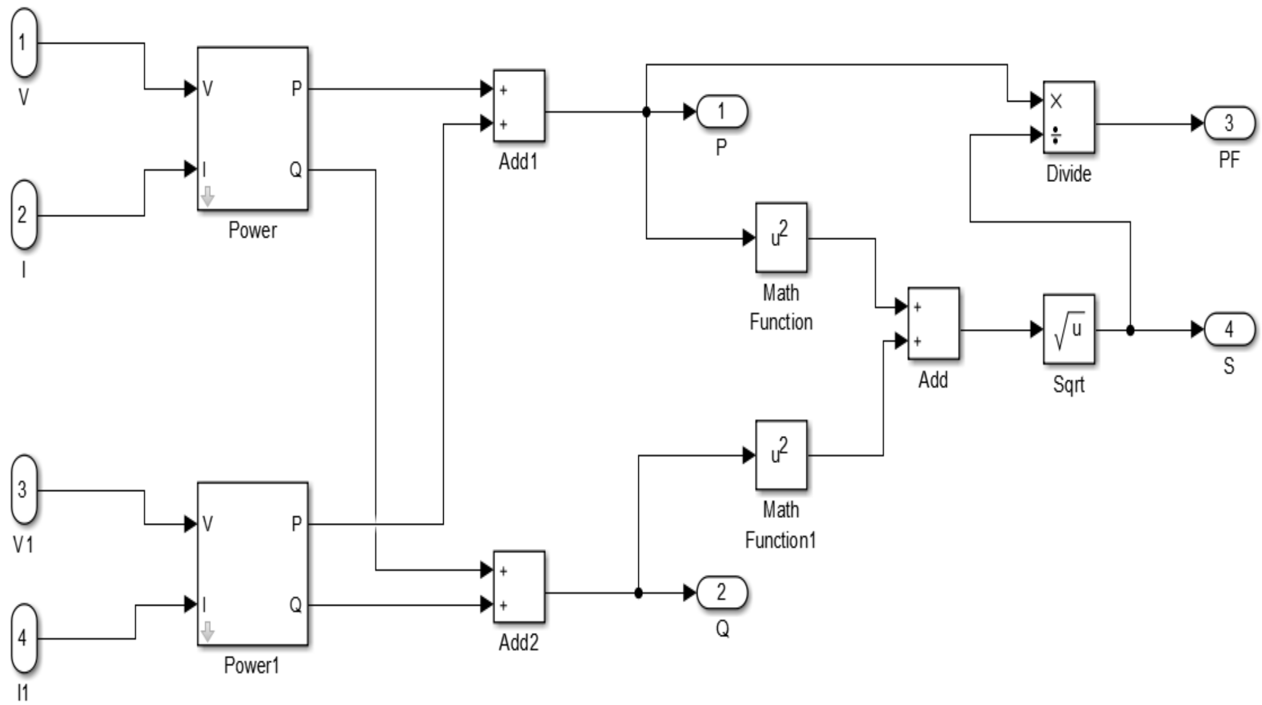


Figure 5.8: Calculation of apparent power and power factor

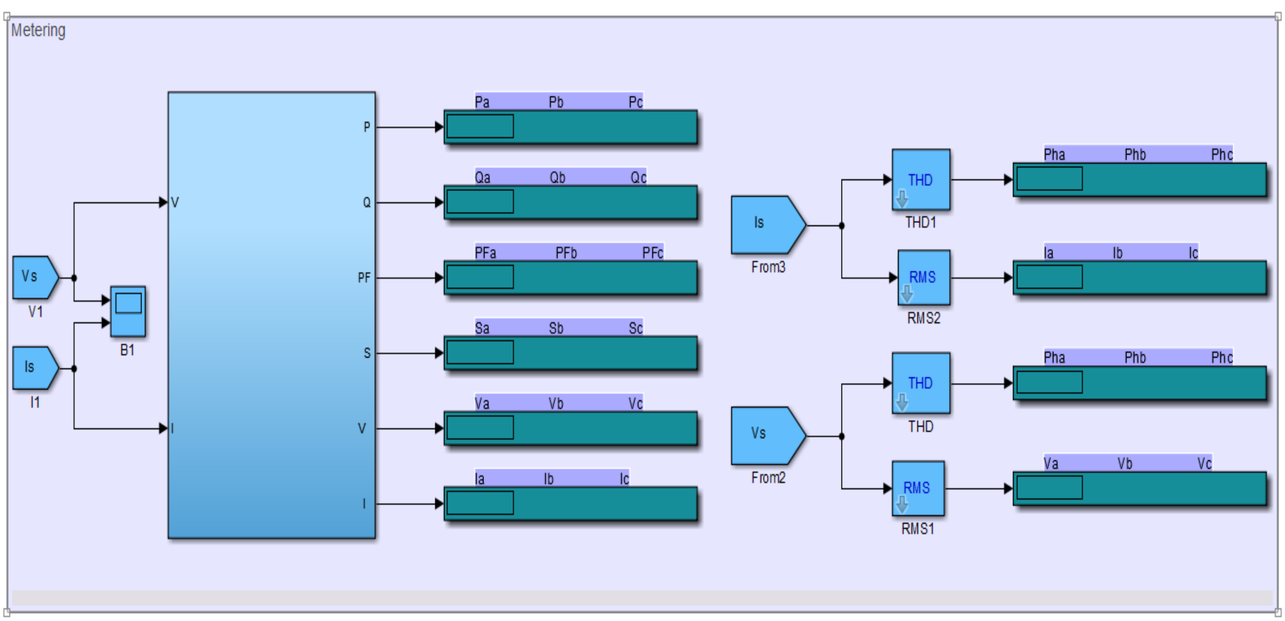


Figure 5.9: Metering system by using Matlab

5.4. Control Function:

For any change in the system such as disconnecting or connecting a substation or transferring the load form transformer to another one for maintenance or other purposes, the system operator opens or closes the breakers that located in these stations. The following figure shows the shutting down for one the stations by giving a signal to the circuit breakers that connecting with this station:

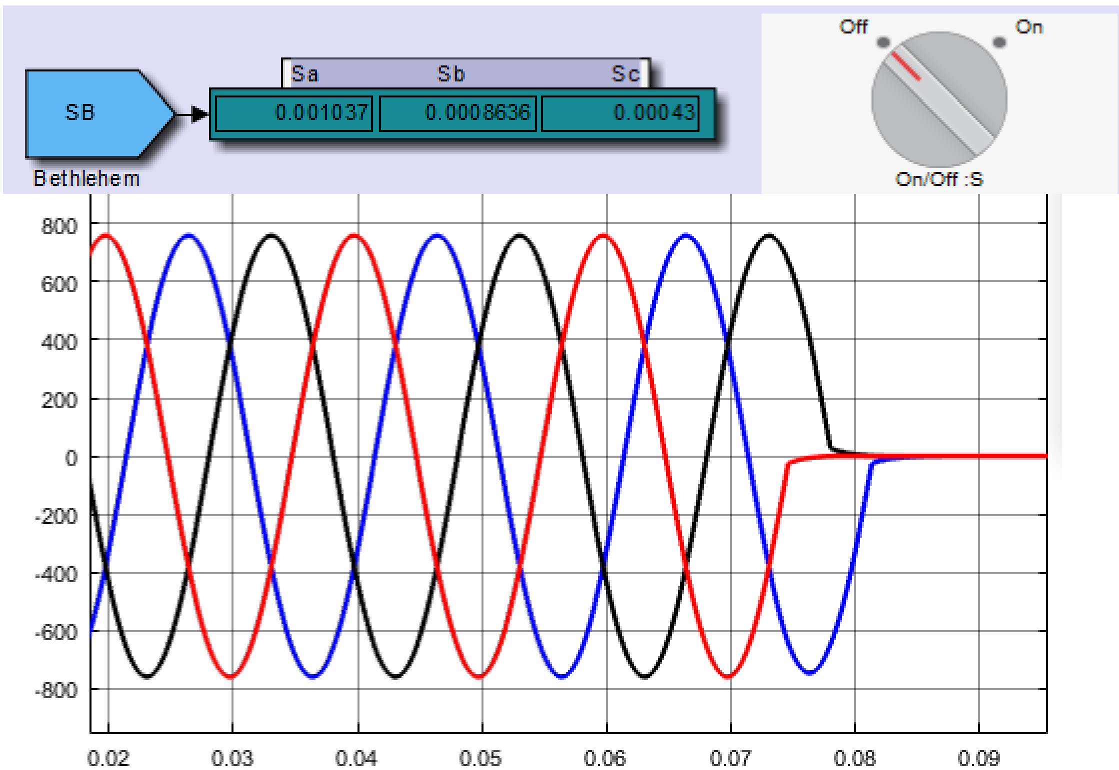
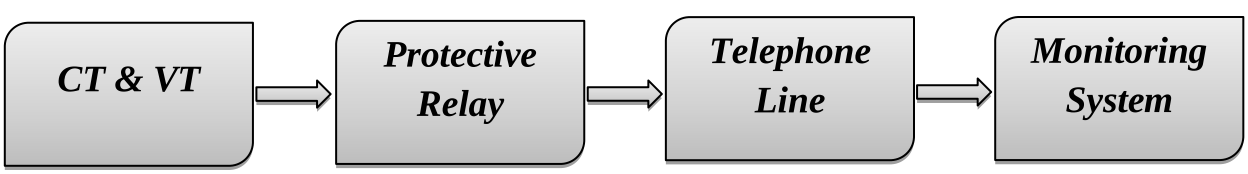


Figure 5.10: Controlling system by using Matlab

5.5. Operation if measurement devices:

As we mentioned earlier the protective relay that used in measurement deals with low value of current and voltage so it use microprocessor to compute the real values of current, voltage and power. After this process the relays use the telephone line to transfer the data form the metering system to the monitoring system.



5.6. Summary

In this chapter we show the operation of the monitoring system that used in the power system. And we used Matlab-Simulink to simulate this monitoring system with the both functions (metering function and controlling function).

Chapter 6 Simulation of transmission system

6.1. Introduction

6.2. ETAP

6.3. Components of the system

6.3.1. Substation

6.3.2. Bus classification

6.3.3. Single line diagram and input data

6.4. Power system analysis

6.4.1. Load flow analysis

6.4.1.1. Case1 (Present load)

6.4.1.2. Case2 (Future load)

6.4.2. Fault analysis

6.4.3. Load profile

6.5. Validation

6.1. Introduction

When design any power system or electrical network or simple line from the beginning or add and removing any electrical line from the network, it will be contains many elements and electrical components and to find out what will happen to the changes on the network and at the same ingredients and choose the component and the element best suited then you have to hold all necessary calculations are accurate and fast at the same time.

So we need program to do all necessary calculation after giving the program the required data for each element. In this project we select two simulation programs and there are:

1. ETAP
2. Matlab (Simulink)

6.2. ETAP

ETAP is the most comprehensive analysis platform for the design, simulation, operation, and automation of, generation, transmission, and industrial power system. ETAP is developed under an established quality assurance program and is used worldwide as high impact software. ETAP program use Newton-Raphson in the analysis.

In the last few years electric engineer have been focusing on the power system studies using software tools. Recent advances in engineering sciences have brought a revolution in the field of electrical engineering after the development of powerful computer based software.

ETAP is a utility that will help electrical in the processes of designing, simulating, simulating, operating and optimizing power system.

ETAP offers a suite of fully integrated electrical engineering solution and large array of tools for power system design. The designed project can be studied by performing an optimal load flow analysis, short circuit analysis, motor acceleration analysis, harmonic analysis, transient stability analysis, relay coordination, cable ampacity, and others.

In our project we selected ETAP software due to its wide range properties, such as power flow studies, short circuit analysis, protection devices coordination, feasibility, availability and ease to use.

Main component in ETAP:

Now, we will show the main component that will used in the system:

- Transformer:

We use the 2-winding transformer MVA sizing. The are many parameter required in the program:

1. Rated MVA
2. Impedance
3. Primary and secondary voltage

- Cables and transmission line:

In this part the program require data of parameter

1. Impedance
2. Length of cable
3. Spacing between cables

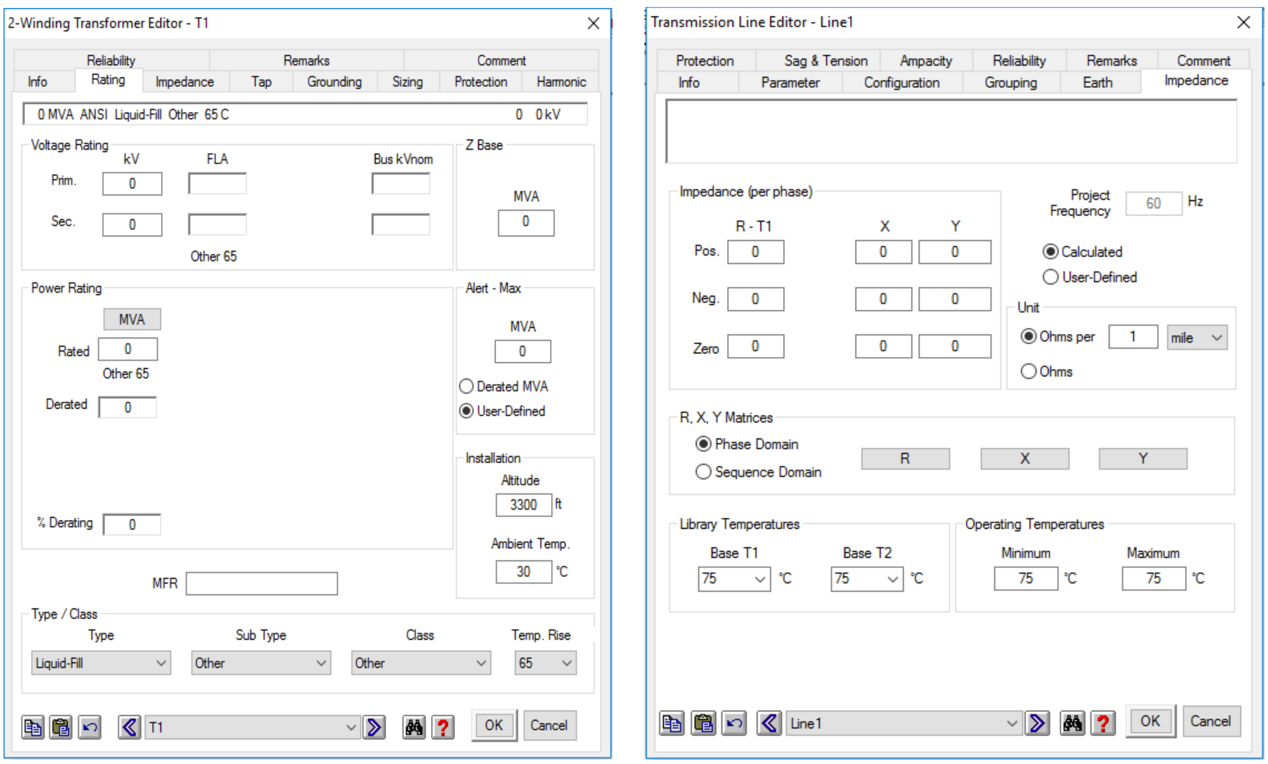


Figure 6.1: Input data of the component in ETAP

Other components:

- Circuit breaker
- Busbars
- Differential relay
- Loads
- Capacitor bank

6.3. Components of the system

6.3.1. Substation:

In the project we use four substations to feed each city. In these substations we use two power transformers with ratings as following:

Table 6.1: Rating of transformer

City	Bethlehem		Jerusalem		Ramallah		Jericho	
Rating of transformer	75MVA	75MVA	200MVA	200MVA	200MVA	150MVA	50MVA	25MVA

And we use ring bus in each substation as shown in the single line diagram of substation. We select differential protection to protect the power transformers in each substation.

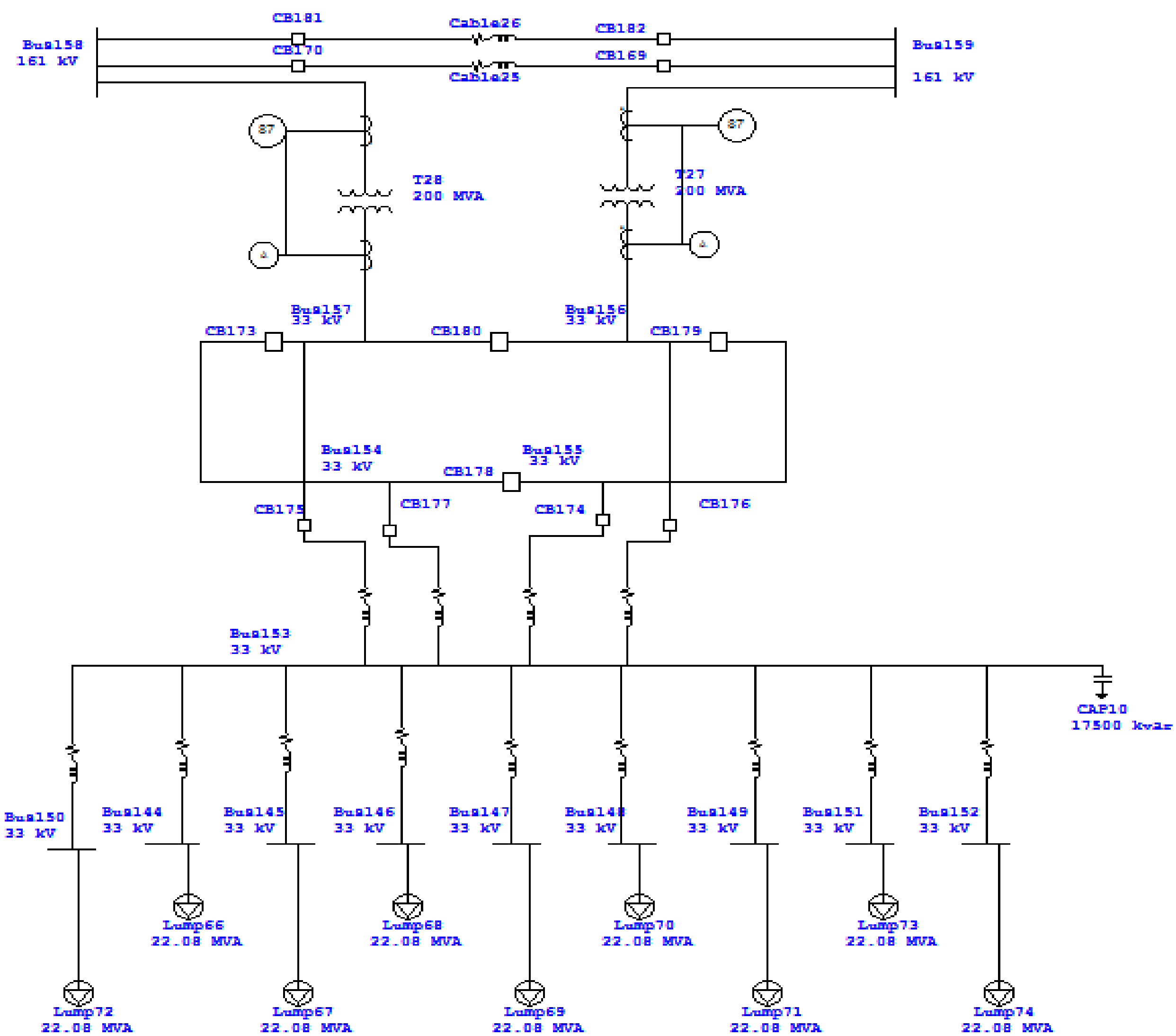


Figure 6.2: Single line diagram of substation

This substation feeds the Jerusalem governorate. And station connected with 9 connection point and each point feeds distribution substation.

The following table shows the ratings of substations and the number of connection point in each station:

Table 6.2: Parameter of substation

	Present load	Primary Voltage	Secondary Voltage	Rating power	Connection point
Bethlehem Substation	73 MW	161 kV	33 kV	150 MVA	8
Jerusalem Substation	184 MW	161 kV	33 kV	400 MVA	9
Ramallah Substation	160 MW	161 kV	33 kV	350 MVA	10
Jericho Substation	29 MW	161 kV	33 kV	75 MVA	3

6.3.2. Bus classification:

Magnitude & phase angle of voltage and real & the reactive power are the main quantities that are associated with the bus or the node in the power system. Based on these four quantities, the bus-bars are classified into three types:

6.3.2.1. Load bus

Active and reactive power of Load bus is specified but phase angle and magnitude of the bus voltage is determined. The load bus that can be allowed to vary the voltage by a permissible value such as 5% would only to specify the active power and reactive power while the voltage phase angle is not that much important.

6.3.2.2. Generator or voltage control bus

In this type of busbars, the power and the magnitude of voltage on this bus-bar are specified. The remaining two values (reactive power and phase angle) are are determined on this bus.

6.3.2.3.Slack or swing bus

This type is the most important type of bus-bars as this bus is feeds the system the full power it needs. In this type of buses the magnitude of voltage and phase angle is specified.

Table 6.3: Bus classification

Bus classification	Specified parameters	Obtained parameters
Voltage control bus	Voltage magnitude, Active Power	Voltage angle, Reactive power
Swing bus	Voltage magnitude, Voltage angle	Active Power, Reactive power
Load bus	Active Power, Reactive power	Voltage magnitude, Voltage angle

6.3.3. Single line diagram and input data

The transmission system scheme in figure shows the transmission line, underground cable, substations, transformers and other component.

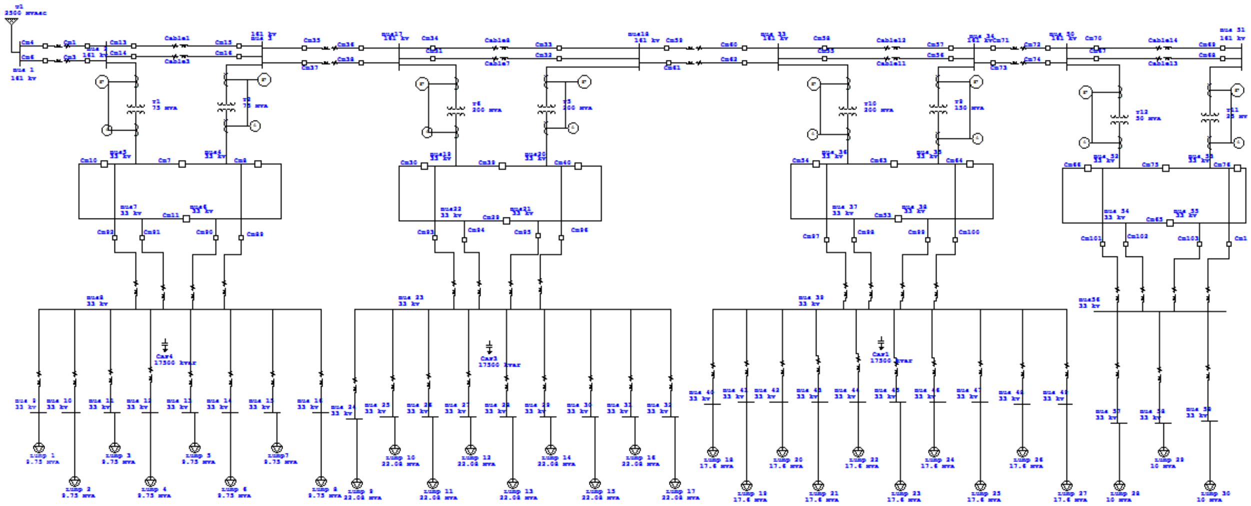


Table 6.3: Single line diagram of transmission system

The following table shows the main components in the transmission system and the input data:

Table 6.4: Component transmission system

Input data	Numbers
Buses	59 (9 Bus for 161 kV, 50 Bus for 33kV)
Transmission line	3293 (3120 with 244 mm^2, 173 with 107 mm^2)
Underground cables	24
Transformers	8

6.4.1. Load flow analysis

The load flow analysis is considered as one of the most important rule in the power system analysis and design. This rule necessary for planning, operation, economic scheduling and exchange of power between utilities. The principal of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. The load flow studies are used to ensure that the electrical power transfer from the generator to the consumers through the transmission and distribution systems is stable, reliable and economic.

Load flow analysis using software is accurate and gives highly reliable results. This study is mainly used to detect problems in the power system and find solutions for these problems. The under voltage is the most problem leading to disturbances in the system. In addition, the decrease in the value of the power factor in the system of the most prominent problems that must be solved.

6.4.1.1. Case1 (Present load)

The result of ETAP in this case:

1. There is no over load component

All components do not over loaded and the following table shows same component and its load:

Table 6.5: Present loading

Transformer	Rated power	Present Load	Present loading
T1	75 MVA	39.884 MVA	53.2%
T2	75MVA	37.538 MVA	50.1%
T3	200 MVA	101.890 MVA	50.9%
T4	200 NVA	91.961 MVA	46.0%
T5	200 MVA	109.618 MVA	54.8%
T6	150 MVA	59.960 MVA	40.0%
T7	50 MVA	20.638 MVA	41.3%
T8	25 MVA	9.014MVA	36.1%

The other component in the system is shown in Appendix.

2. The Voltage drop in the system:

Table 6.6: Voltage drop

Number of bus	Length of line/cable	Voltage
Bus 1	-	100% (161 kV)
Bus 2	2 km	99.71% (160.5 kV)

Bus 3	0.2 km	99.61% (160.3 kV)
Bus 17	10.5 km	97.72% (157.3 kV)
Bus 18	0.2 km	97.65% (157.2 kV)
Bus 33	15 km	96.26% (154.9 kV)
Bus 34	0.2 km	96.24% (154.9 kV)
Bus 50	14 km	96.06% (154.6 kV)
Bus 51	0.2 km	96.06% (154.6 kV)

The Variation in the voltage drop in the transmission line is due to the difference in the quantity of the transmitted current in each part of the transmission line.
There are two methods to correct this problem and there are:

A. Add capacitor bank and this method used to improve the Power Factor(PF)
B. Increase the taps in the transformer

3. The value of power factor will decrease in the power system because of some component in the system such as transformers and some loads like motor. So this problem must be corrected. As we mentioned the power factor is use in the processes as we will explain below:

Table 6.7: Load and PF in Case1

	Real power	Power Factor
Source (Swing Buses)	435 MVA	89.79 lagging
Total Demand	435 MVA	89.79 lagging
Total Motor Load	195 MVA	89.21 lagging
Total Static Load	229.5 MVA	93.62 lagging

The correction of power factor in this case:

$$\text{PF} = \frac{KW}{KVA} = \text{Cos}\theta \qquad \textbf{(6.1)}$$

In the process of correcting the power factor we aim to have a power factor with a value 0.92.

$$\text{Tan}\theta = \frac{kVAR}{kW} \qquad \textbf{(6.2)}$$

Reactive power = 213 MVAR
Real power = 435 MW
Tanθ = 0.426

$$0.426 = \frac{MVAR}{435}$$

MVAR = 185.3 MVAR

New reactive power = 185.3 MVA
The capacitor bank that required to correct the power factor is with rating
The rating of capacitor bank = 213 – 185.5 = 27.5 MVAR

The figure bellow shows a part of the load flow on the secondary side of 161 kV substation carried out using ETAP which depends on Newton-Raphson method. This figure shows the under voltage on the bus-bars resulting from the voltage drop in the transmission line.

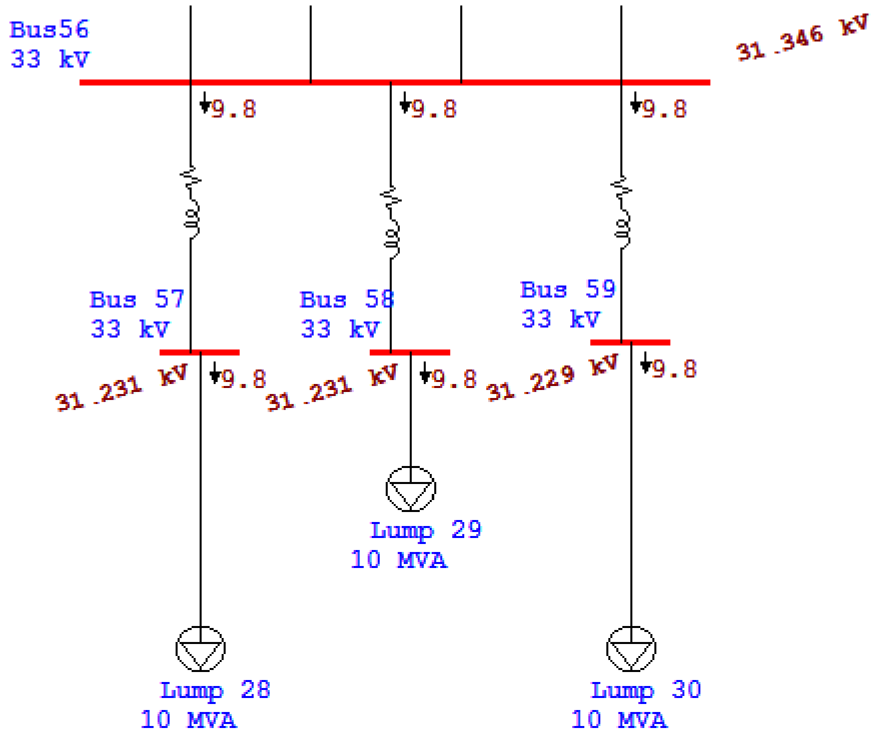


Figure 6.4: Loads in Jericho substation (Case1)

Table 6.8: Load and PF in Jericho

	Rated voltage	Voltage	Power	Power Factor
Bus 56	33 kV	31.346 kV	29.4 MVA	87.5
Bus 57	33 kV	31.229 kV	9.8 MVA	88
Bus 58	33 kV	31.229 kV	9.8 MVA	88
Bus 59	33 kV	31.229 KV	9.8 MVA	87

The under voltage the power factor in the system must be corrected to decease the disturbances in the system the next figure shows the system after correction.

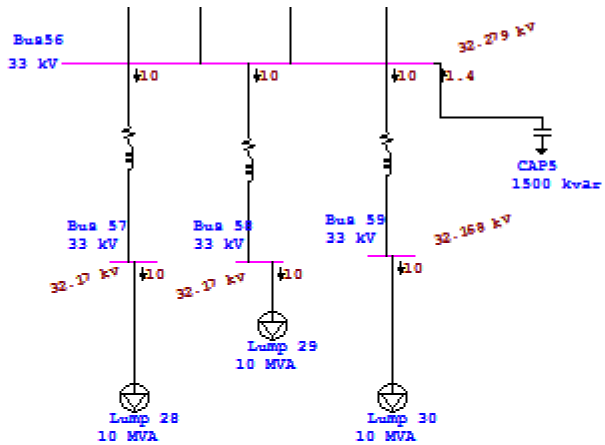


Figure 6.5: Loads in Jericho substation after correction (Case1)

Table 6.9: Load and PF in Jericho after correction

	Rated voltage	Voltage	Power	Power Factor
Bus 56	33 kV	32.274 kV	30 MVA	92.5
Bus 57	33 kV	32.168 kV	10 MVA	91
Bus 58	33 kV	32.27 kV	10 MVA	91
Bus 59	33 kV	32.27 KV	10 MVA	90.5

Table 6.9 shows the load flow results and by comparing it with Table1it can be clearly seen that there is an improvement in the power factor. This improvement in Power Factor and increase voltage due to the increased the taps and connect the capacitor bank in the system.

4. The loss which evaluated in the system:

The present loss = 10.5 MW

$$\text{The percentage of loss} = \frac{\textit{The present loss}}{\textit{The total load}} * 100\%$$

$$= \frac{10.5}{446.125} * 100\% = 2.456\%$$

6.4.1.2. Case2 (Future load)

In this section, we study the future case (Load in 2040) of the transmission system.

The result of ETAP in this case:

1. There is no over load component

All components do not over loaded and the following table shows same component and its load:

Table 6.10: Future Load (Case2)

Transformer	Rated power	Future Load	Future loading
T1	75 MVA	72.6960 MVA	95.6%
T2	75MVA	68.1590 MVA	90.9%
T3	200 MVA	191.272 MVA	95.6%
T4	200 NVA	172.240 MVA	86.1%
T5	200 MVA	195.475 MVA	97.7%
T6	150 MVA	119.122 MVA	79.4%
T7	50 MVA	43.9770 MVA	88.0%
T8	25 MVA	19.2090 MVA	76.8%

The other component in the system is shown in Appendix.

2. The Voltage drop in the system:

Table 6.11: Voltage drop (Case2)

Number of bus	Length of line/cable	Voltage
Bus 1	-	100.0% (161.00 kV)
Bus 2	2 km	99.40% (160.03 kV)
Bus 3	0.2 km	99.30% (159.86 kV)
Bus 17	10.5 km	95.53% (153.80 kV)
Bus 18	0.2 km	95.40% (153.60 kV)
Bus 33	15 km	92.63% (149.13 kV)
Bus 34	0.2 km	92.59% (149.07 kV)
Bus 50	1k84 km	92.18% (148.40 kV)
Bus 51	0.2 km	92.17% (148.39 kV)

In this case the voltage drop become more than twice of voltage drop in the previous case because the value of current in this case become more than twice value of current in previous case (current in case1= 1660A, in this case the current become nearly 3300A)

3. The Power factor values become as shown in the following table

Table 6.12: Load and PF in Jericho (Case2)

	Real power	Power Factor
Source (Swing Buses)	877 MW	87.83
Total Demand	877 MVA	87.83
Total Motor Load	384.573 MVA	89.23
Total Static Load	452.427 MVA	93.59

The correction of power factor in this case:

$$PF = \frac{KW}{KVA} = \text{Cos}\theta$$

In the process of correcting the power factor we aim to have a power factor with a value 0.92.

$$\text{Tan}\theta = \frac{kVAR}{kW}$$

Reactive power = 477 MVAR
Real power = 877 MW
Tanθ = 0.426

$$0.426 = \frac{MVAR}{877}$$

$$MVAR = 373.6\ MVAR$$

Reactive power = 373.6
The capacitor bank that required to correct the power factor is with rating
The rating of capacitor bank = 477 - 373.6 = 103 MVAR

4. The loss which evaluated in the system:

The present loss = 40 MW

$$\text{The percentage of loss} = \frac{The\ present\ loss}{The\ total\ load} *100\%$$

$$= \frac{40}{864} *100\% = 4.62\%$$

6.4.2. Fault analysis

The protection of power systems is one of the most important issues that should be given great care and attention. Therefore, it is to resort to the fault analysis to determine the MVA, the voltage at the time of fault and at fault location and determine the amount of current that feeds the fault in order to select appropriate protection tools such as the fuses and circuit breakers.

Factors affecting on faults in power system

1. Type of fault
2. Duration of fault
3. Sources of fault

4. Location of fault
5. Selection of protective devices
6. Operating time of protective devices for clearance of fault

The value of fault current depend on the following two factors:

1. The location of the fault occurs.
2. The value of MVAsc.

In this section we use Matlab-Simulink for fault analysis. In this transmission system we select three type of protective relay:

1. Differential Relay

   As mentioned in Chapter 3, the Differential relay is one of the most relays used to protect power transformer. As shown in the following figure, the relay works on the difference of the current on both ends of the transformer. If the value of difference in the current is greater than a certain limit, the relay gives a signal to the breaker to trip.

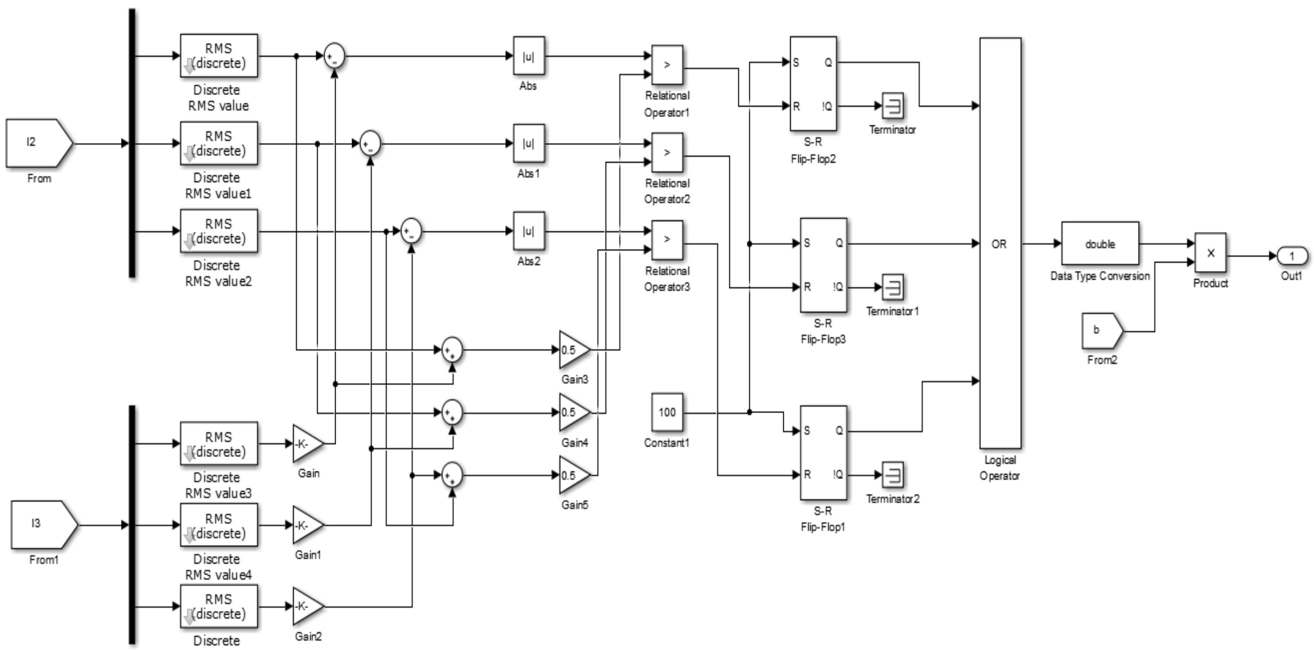


Figure 6.6: Differential relay

Normal conditions

I1 = I2

$I_{diff} = I_1 - I_2 = 0$

Abnormal condition

$$|I1 - I2| > \frac{I1+I2}{2} \quad \textbf{(6.3)}$$

2. Distance Relay

This relay is used in the usual way to protect the transmission lines, where it works to compare the resistance value of the transmission line which is calculated in advance and the value with the resistor during the passage of the current. If there is a large change in resistance, this indicates there is a fault in the system, so the relay will be trip.

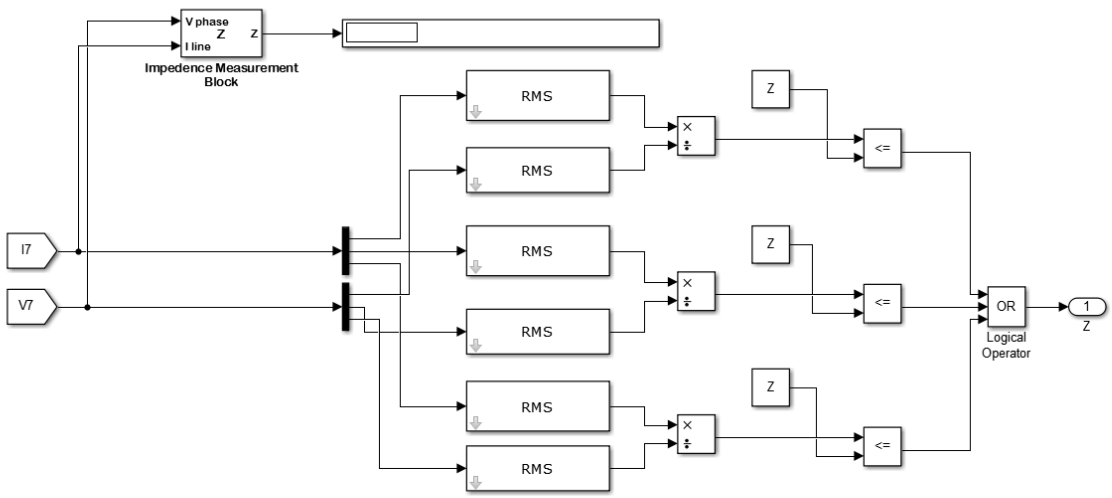


Figure 6.7: Distance relay

$V_R = I_R \times R$

Normal condition

$Z_m = Z_c$

Abnormal condition

$Z_m > Z_c$

3. Overcurrent Relay

This type of relays works by comparing the current flow in the system with allowed current. If its current value is greater than that allowed, the relay will trip.

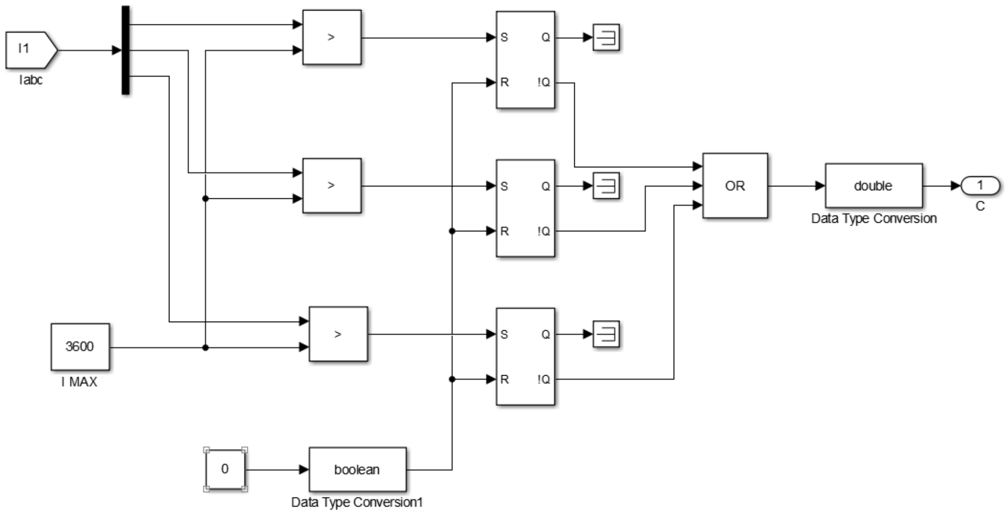


Figure 6.8: Over current relay

Normal condition

$I_1 < 3600A$

Abnormal condition

$I_1 > 3600A$

The following figure shows the fault that occurs in the utility side:

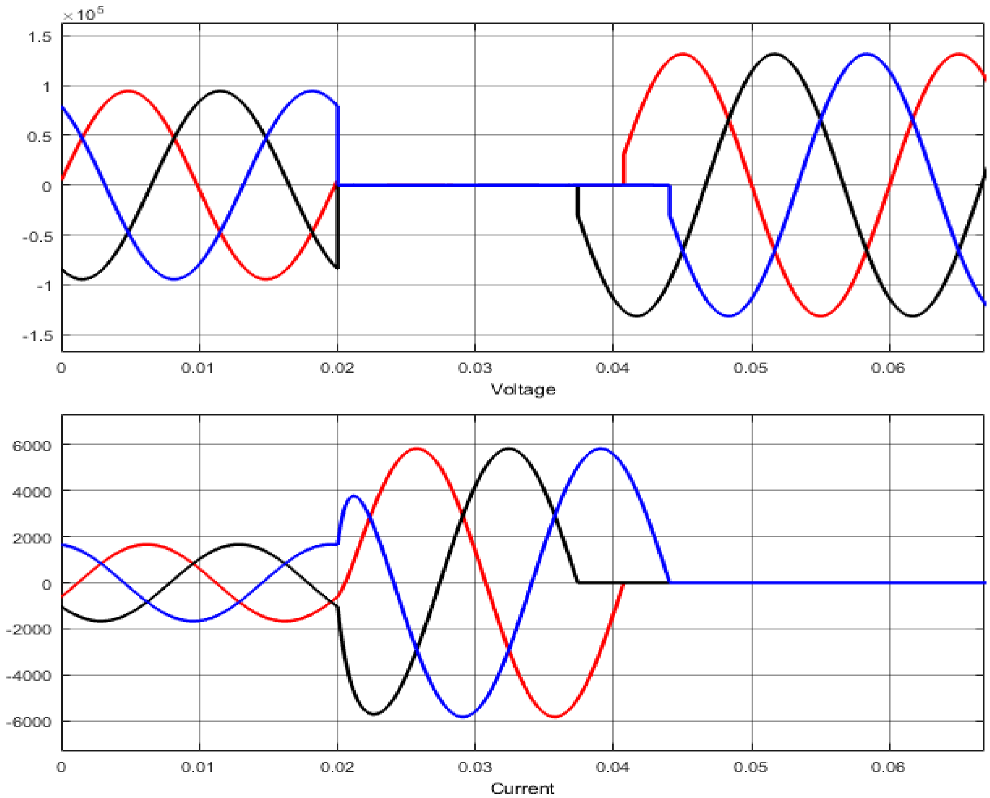


Figure 6.9: Fault detection

As mentioned before, the value of the fault current depends largely on the location of the fault, but in general, the value of the fault current in the high voltage side of the transmission system ranges from 3800A to 7500A. And the fault current in the secondary of substations is ranges from 23kA to 69 kA.

6.4.3. Load profile

Load profile is a graph of the variation in the electrical over time. Load data is crucial for planning electricity distribution networks and optimal production capacity. Through the use of the profile can improve the efficiency of the system where it is easy to choose the time of maintenance work when needed. The load profile gives an accurate indication of peak times as well as can be used to study the load growth in order to increase the reliability of the power system. The following figure shows the load profile in the system for 2017 by using Matlab Simulink:

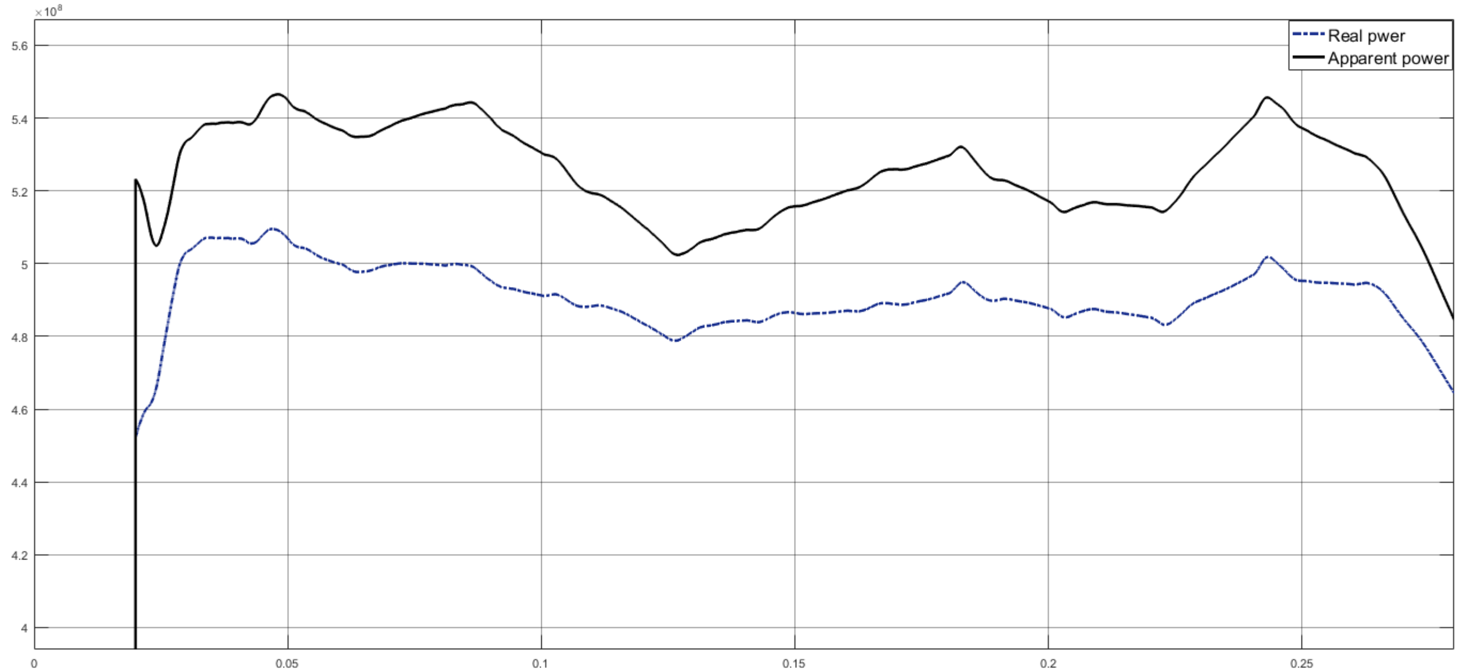


Figure 6.10: Load profile for the transmission system in 2017

This figure shows the total real power and apparent in the system for 12 months (2017). And the next figure shows the total power consumed in Bethlehem.

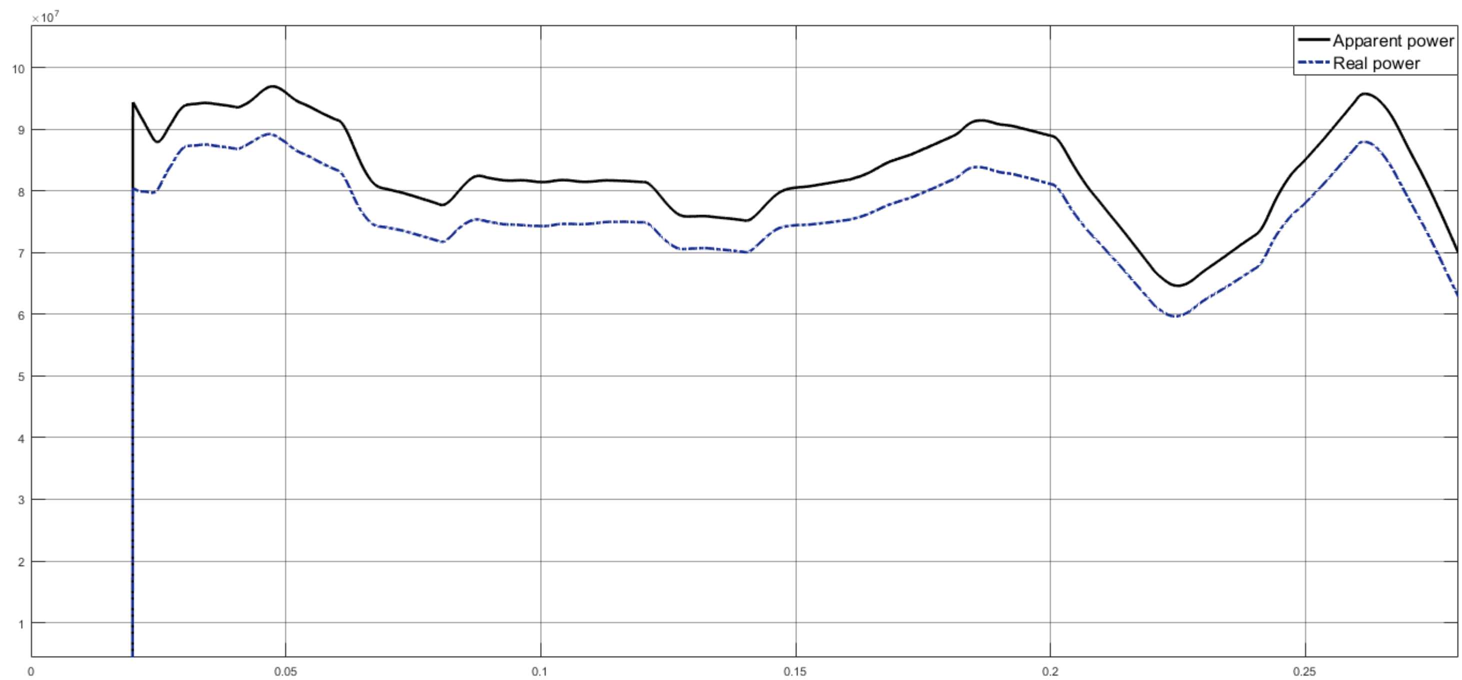


Figure 6.11: Load profile for Bethlehem in 2017

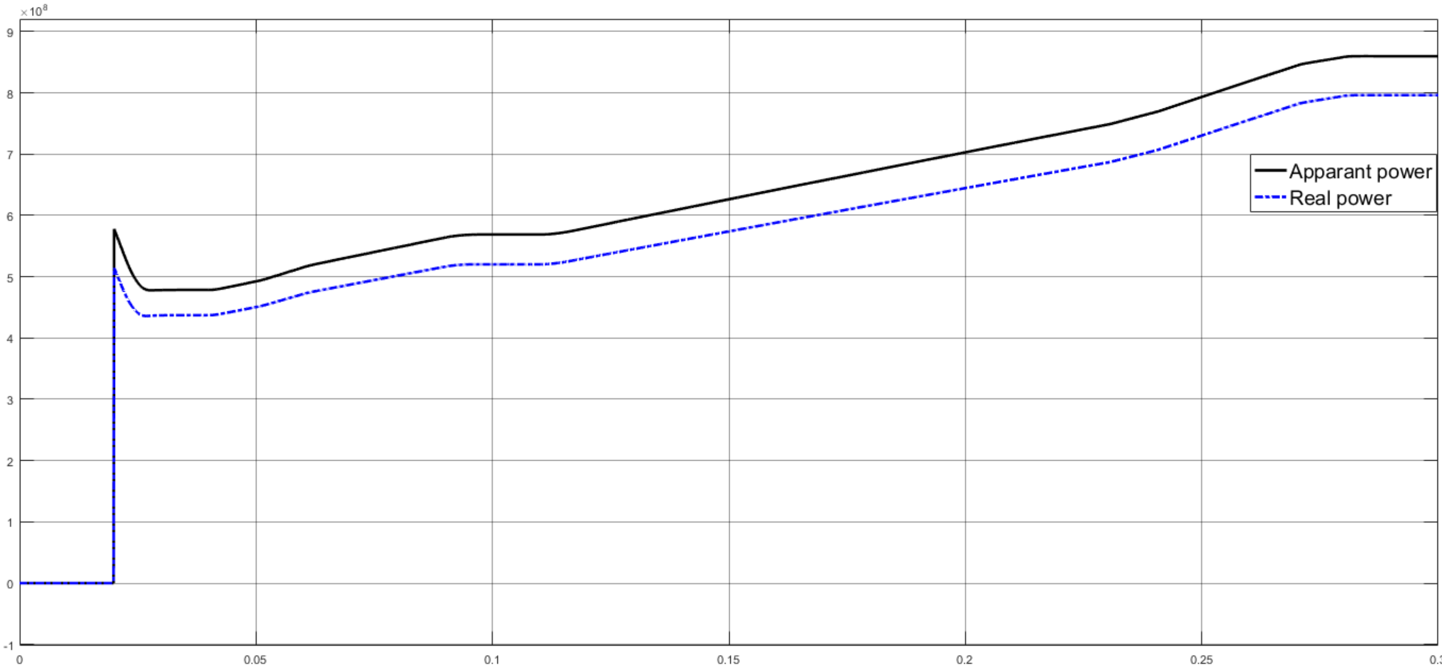


Figure 6.12: Load profile for the transmission system to 2040

6.5. Validation

In this project we simulated the transmission system by using two different simulation programs. But all the variables in the two programs are the same, so the results must be the same in both the programs or close to each other. So we compared the results obtained in both programs before and after correcting the problems in the system and the results were as follows:

Case1 (Present load):

Table 6.13: Load and loss in Matlab and ETAP (2017)

	Bethlehem	Jerusalem	Ramallah	Jericho
Real Power	73 MW	184 MW	160 MW	29 MW
Reactive Power	30 MVAR	75 MVAR	65 MVAR	14 MVAR
Loss in ETAP	10.5 MW			
Loss in Matlab	9.9 MW			

In the primary side of substation:

Table 6.14: Comparison between the results of ETAB and Matlab on the primary side of substation (2017)

	ETAP				Matlab-Simulink			
	Bethlehem	Jerusalem	Ramallah	Jericho	Bethlehem	Jerusalem	Ramallah	Jericho
Current	279A	711A	630	108	280A	703A	615A	111A
Voltage	160kV	157.6kV	155.3kV	154.9kV	159.8kV	158.7kV	155.6kV	154.6kV
PF	0.901	0.901	0.901	0.901	0.898	0.898	0.898	0.898

In the secondary side of substation:

Table 6.15: Comparison between the results of ETAB and Matlab on the secondary side of substation

	ETAP				Matlab-Simulink			
	Bethlehem	Jerusalem	Ramallah	Jericho	Bethlehem	Jerusalem	Ramallah	Jericho
Current	1360A	3477A	3024	500	1366A	3420A	2985A	542A
Voltage	32.6kV	32.2kV	31.7kV	31.5kV	32.75kV	32.55kV	31.9kV	31.7kV
PF	0.913	0.92	0.92	0.906	0.917	0.91	0.9	0.897

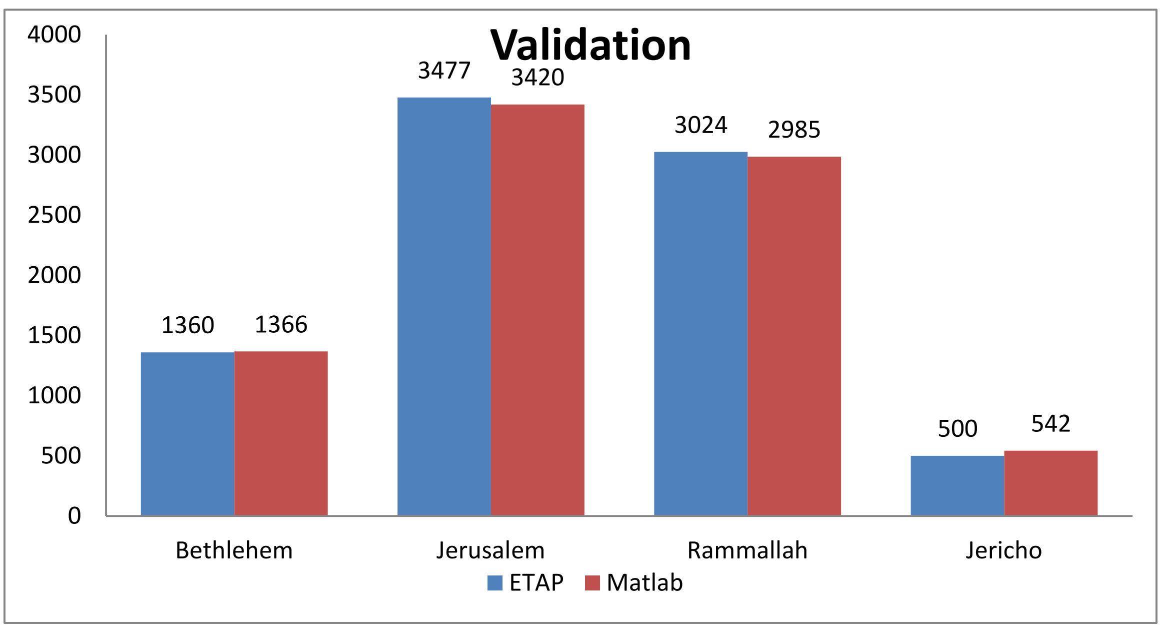


Figure 6.13: Validation (2017)

Case2 (Future load):

Table 6.16: Load and loss in Matlab and ETAP (2040)

	Bethlehem	Jerusalem	Ramallah	Jericho
Real Power	130MW	352.27MW	311.8MW	60.4MW
Reactive Power	55MVAR	145MVAR	133MVAR	25MVAR
Loss in ETAP	40MW			
Loss in Matlab	36MW			

In the primary side of substation:

Table 6.17: Comparison between the results of ETAB and Matlab on the primary side of substation (2040)

	ETAP				Matlab-Simulink			
	Bethlehem	Jerusalem	Ramallah	Jericho	Bethlehem	Jerusalem	Ramallah	Jericho
Current	502.8A	1362.2A	1223A	236.6	497A	1326A	1156.6A	229.4A
Voltage	160.1kV	153.8kV	149.2kV	148.5kV	160.5kV	154.7kV	150.1	148.8kV
PF	87.1	87.1	87.1	87.1	87.2	87.2	87.2	87.2

In the secondary side of substation:

Table 6.18: Comparison between the results of ETAB and Matlab on the secondary side of substation (2040)

	ETAP				Matlab-Simulink			
	Bethlehem	Jerusalem	Ramallah	Jericho	Bethlehem	Jerusalem	Ramallah	Jericho
Current	2453A	6645A	5768A	1149A	2425A	6468A	5641A	1119A
Voltage	32.75kV	31.23kV	30.33kV	29.96kV	32.8kV	31.4kV	30.5kV	29.98kV
PF	91	91	91	90	91.6	88.9	88.9	91

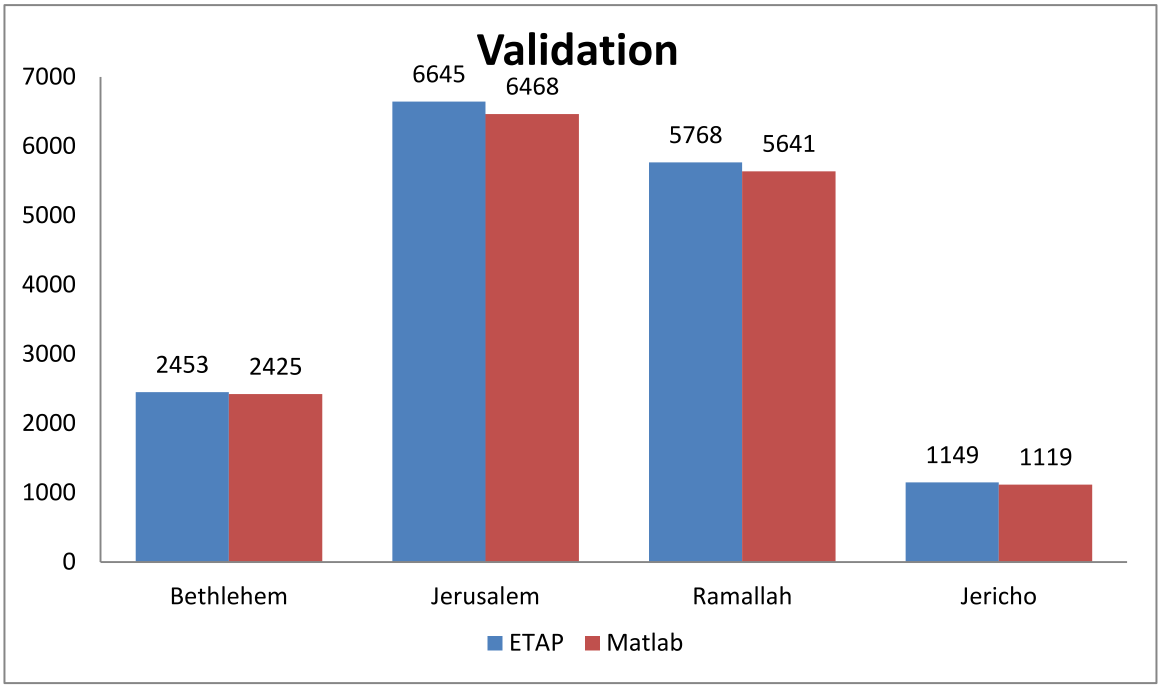


Figure 6.14: Validation (2040)

6.6. Summary

In this chapter we used ETAP and Matlab-Simulink to study the transmission system that designed in this project. And we use many solution to solve the problem that we founded in the system such as the voltage drop and the decrease in the power factor. Then we compered the result of load flow analysis which we got from the tow program to make sure the results are match.

Chapter 7 Conclusions

7.1. Conclusions

- The design of the power systems must be done after studying the load growth of the area to be worked on, to ensure that the system can feed this area for an acceptable period of time.

- When choosing the sites of towers the distance between the towers cannot be the same in all cases where the span must be changed in some cases in order to overcome the problems resulting from the sag. Where terrain plays an important role in determining the distance between towers.

- Present case:

    1. There is no overloaded transformer, underground cable or transmission line.

    2. The load flow analysis shows the power factor in the system is nearly 0.87 although the power factor of all loads is installed at 0.92; the decrease in the power factor of the system is due to the consumption of reactive power by transformer. The solution of this problem is by adding capacitor bank to the system.

    3. The load flow analysis shows another problem in the system which is the voltage drop through the cables and transmission line. And the solution of this problem is by increase the taps in the transformer.

- Future case:

    1. There is no overloaded transformer, underground cable or transmission line.

    2. When the real power that consumed from the transformer increased, the reactive power withdrawn from the source needed by the transformer increases, so the number of capacitors used must be increased to ensure that the value of the power factor remains high.

Appendices

Appendix A: The equations of symmetrical component and fault calculations.

Appendix B: Electrical connection points in the middle of the West Bank

Appendix C: The population growth

Appendix D: The load growth

Appendix E: The growth of consumption rate of person

Appendix F: The component of transmission system by using Matlab

Appendix G: Single line diagram of transmission system

Appendix H: Map

Appendix A

The equations of symmetrical component and fault calculations.

$$V_{b1} = a_2V_{a1} \ , V_{b2} = aV_{a2} \, , V_{b0} = V_{a0} \tag{2.1}$$

$$V_{c1} = aV_{a1} \ , V_{c2} = a_2V_{a2} \, , V_{c0} = V_{a0} \tag{2.2}$$

$$V_a = V_{a1} + V_{a2} + V_{a0} \tag{2.1}$$

$$V_b = V_{b1} + V_{b2} + V_{b0} = a_2V_{a1} + aV_{a2} + V_{a0} \tag{2.2}$$

$$V_c = V_{c1} + V_{c2} + V_{c0} = aV_{a1} + a_2V_{a2} + V_{a0} \tag{2.3}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ a & a^2 & 1 \\ a^2 & a & 1 \end{bmatrix} \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} \tag{2.6}$$

$$A^{-1}.V_{abc} = A^{-1}.A.V_{012} \tag{2.7}$$

$$V_{012} = A^{-1}.V_{abc} \tag{2.8}$$

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} . \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2.9}$$

$$s = \mathrm{trans}([A.V_{012}]).\mathrm{conj}([A.I_{012}]) \tag{2.10}$$

$$s = VT_{012}.AT.A^{*}I_{012}{}^{*} \tag{2.11}$$

$$A^TA^* = \begin{bmatrix} 1 & a^2 & a \\ 1 & a & a^2 \\ 1 & 1 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 1 & 1 \\ a & a^2 & 1 \\ a^2 & a & 1 \end{bmatrix} = 3 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = 3U \tag{2.12}$$

$$s = 3V_{012} * UI_{012}{}^{*} \tag{2.13}$$

$$s = 3V_{a1}I_{a1}{}^{*} + 3V_{a2}I_{a2}{}^{*} + 3V_{a0}I_{a0}{}^{*} \tag{2.14}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} - \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} . \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2.15)$$

$$V_{abc} = E_{abc} - Z_{abc} I_{abc} \quad (2.16)$$

$$AV_{012} = AE_{012} - Z_{abc} AI_{abc} \quad (2.17)$$

$$V_{012} = E_{012} - A^{-1} Z_{abc} AI_{012} \quad (2.18)$$

$$V_{012} = E_{012} - Z_{012} I_{012} \quad (2.19)$$

$$\begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} = \begin{bmatrix} E_{a1} \\ E_{a2} \\ E_{a0} \end{bmatrix} - \begin{bmatrix} Z_{a1} & 0 & 0 \\ 0 & Z_{a2} & 0 \\ 0 & 0 & Z_{a0} \end{bmatrix} . \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \quad (2.20)$$

$$\begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} = \begin{bmatrix} E_{a1} \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} Z_{a1} & 0 & 0 \\ 0 & Z_{a2} & 0 \\ 0 & 0 & Z_{a0} \end{bmatrix} . \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \quad (2.21)$$

$$V_{a1} = E_{a1} - Z_{a1} I_{a1} \quad (2.22)$$

$$V_{a2} = -Z_{a2} I_{a2} \quad (2.23)$$

$$V_{a0} = -Z_{a0} I_{a0} \quad (2.24)$$

$$Z_0 = Z_{l0} + 3Z_g \quad (2.25)$$

$$I_b = I_c = 0 \quad (2.26)$$

$$V_a = I_a Z_f \quad (2.27)$$

$$\begin{bmatrix} I_0 \\ I_1 \\ I_3 \end{bmatrix} = \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix} \quad (2.28)$$

$$I_{a1} = I_{a2} = I_{a0} = \frac{Ia}{3} \quad (2.29)$$

$$V_a = V_{a1} + V_{a2} + V_{a0} = Z_f I_a \quad (2.30)$$

$$I_{a0} = \frac{E_a}{Z_1+Z_2+Z_0+3Z_f} \quad (2.31)$$

$$I_a = 3I_{a0} \quad (2.32)$$

$$V_b = a^2 V_{a1} + aV_{a2} + V_{a0} \quad (2.33)$$

$$V_c = aV_{a1} + a^2 V_{a2} + V_{a0} \quad (2.34)$$

$$3V_{a1} = V_a + aV_b + a^2 V_c \quad (2.35)$$

$$3V_{a2} = V_a + a^2 V_b + aV_c \quad (2.36)$$

$$3(v_{a1} - v_{a2}) = av_b + a^2 v_c - a^2 v_b - av_c \quad (2.37)$$

$$3(V_{a1} - V_{a2}) = a(V_b - V_c) - a^2(V_b - V_c) \quad (2.38)$$

$$3(V_{a1} - V_{a2}) = (V_b - V_c)(a - a^2) \quad (2.39)$$

$$3(V_{a1} - V_{a2}) = I_b Z_f (a - a^2) \quad (2.40)$$

$$(V_{a1} - V_{a2}) = I_{a1} Z_f = I_{a2} Z_f \quad (2.40)$$

$$I_a = \frac{E_{a1}}{Z_1+Z_2+Z_f} \quad (2.42)$$

$$I_b = a^2 I_{a1} - aI_{a2} \quad (2.43)$$

$$I_b = a^2 I_{a1} - aI_{a1} \quad (2.44)$$

$$I_b = (a^2 - a)I_{a1} \quad (2.45)$$

$$I_C = -I_b = (a - a^2)I_{a1} \quad (2.46)$$

$$I_a = 0 \quad (2.47)$$

$$I_a = I_{a1} + I_{a2} + I_{a2} \qquad (2.48)$$

$$V_b = V_c = (I_b + I_c)Z_f \qquad (2.49)$$

$$\begin{bmatrix} V_{a1} \\ V_{b1} \\ V_{c1} \end{bmatrix} = \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (2.50)$$

$$(I_b + I_c)Z_f = 3I_0Z_f = V_b = V_c \qquad (2.51)$$

$$V_{a1} + V_{a2} = \frac{1}{3}(V_a + (a - a^2)V_b) \qquad (2.52)$$

$$V_{a1} = \frac{1}{3}(V_a + 2V_b) \qquad (2.53)$$

$$V_{a0} + V_{a1} = \frac{1}{3}(2 - a - a^2)V_b = V_b \qquad (2.54)$$

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} . \begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix} \qquad (2.55)$$

$$3I_{a0} = I_b + I_c \qquad (2.56)$$

$$(I_b + I_c)Z_f = 3I_{a0}Z_f = V_b = V_c \qquad (2.57)$$

$$V_{a0} + V_{a1} = 3I_{a0}Z_f \qquad (2.58)$$

$$I_{a1} = \frac{E_{a1}}{Z_1 + \frac{Z_2(Z_0 + 3ZF)}{Z_2 + Z_0 + 3ZF}} \qquad (2.59)$$

Appendix B

	Points	MVA	Jerusalem	Ramallah-Beth
1	Atarot - Rama	20	0.00%	100.00%
2	Atarot – KALANDIA	20	1.97%	98.03%
3	Atarot - Al – Barid	20	61.92%	38.08%
4	Jericho	20	51.19%	48.81%
5	Jer. C Shufat –GILO1	20	8.61%	91.39%
6	Jer. D - Erez	20	98.38%	1.62%
7	Jer. C - Sur Baher	20	68.66%	31.34%
8	Jer. D - Rakefet	20	Jerusalem	
9	Jer. D - Hetsav	20		
10	Jer. C - Abo Dis	20		
11	Mishour A. - Al-Tur	20		
12	Jer. D - Zaayem	15		
13	Jer. C - Beit Safafa	2.5		
14	Pizgat Zeev	15		
15	Jer. D – Shakid	20		
16	Bab Al-Khalil	7.5		
17	Atarot - Ramallah	20	Ramallah	
18	Atarot - Ofer/ Avital	20		
19	Atarot - Bereg	20		
20	Atarot - Al-Ram	20		
21	Ariel - Ein Samya	10		
22	Jer. D - Nabe Samuel	7.5		
23	Maale Efraim - Sinjel	20		
24	Atarot - Gilboa -Beit Horon	7.5		
25	Atarot - Nabe Saleh	7.5		
26	Atarot – Beit Eil / Spare	7.5		
27	Atzyon Beit fajjar	10	Bethlehem	
28	Al-Nashahsh	10		
29	Jer. C Bethlehem	20		
30	Hussan / Betar	20		
31	Hebron Hana	20		
32	Hebron - Tquoa	6		
33	Atzyon – JABAE	0.5		
34	Atzyon - Afrat / Spare	20		
35	Mishour A. Aqbat Jabber	10	Jericho	
36	Sweima - JORDAN 1	10		
37	Sweima - JORDAN 2	10		
	Total	556.5		

Appendix C

Year	Jerusalem	Ramallah	Bethlehem	Jericho	Total
1997	320,809	202,759	130,361	31,089	685,018
1998	325,033	209,679	134,525	32,105	701,342
1999	329,274	216,769	138,783	33,145	717,971
2000	333,451	223,896	143,054	34,188	734,589
2001	337,278	230,556	147,037	35,162	750,033
2002	341,108	237,342	151,088	36,154	765,692
2003	344,982	244,328	155,251	37,173	781,734
2004	348,941	251,596	159,574	38,232	798,343
2005	353,157	259,474	164,250	39,378	816,259
2006	357,424	267,598	169,064	40,559	834,645
2007	361,743	275,981	174,022	41,776	853,522
2008	368,394	284,195	178,853	42,964	874,406
2009	375,167	292,629	183,804	44,183	895,783
2010	382,041	301,296	188,880	45,433	917,650
2011	389,298	310,218	194,095	46,718	940,329
2012	396,710	319,418	199,463	48,041	963,632
2013	404,165	328,811	204,929	49,390	987,295
2014	411,640	338,383	210,484	50,762	1,011,269
2015	419,108	348,110	216,114	52,154	1,035,486
2016	411,607	368,403	212,423	52,793	1,045,225
2017	420,130	378,530	218,265	53,970	1,070,895
2018	428,959	388,856	224,214	55,148	1,097,176
2019	438,094	399,381	230,268	56,325	1,124,068
2020	447,534	410,105	236,429	57,503	1,151,571
2021	457,280	421,028	242,695	58,680	1,179,683
2022	467,332	432,150	249,067	59,858	1,208,407
2023	477,689	443,471	255,546	61,035	1,237,741
2024	488,352	454,991	262,130	62,212	1,267,685
2025	499,321	466,709	268,821	63,390	1,298,241
2026	510,596	478,627	275,617	64,567	1,329,406
2027	522,176	490,743	282,519	65,745	1,361,182
2028	534,061	503,058	289,527	66,922	1,393,569
2029	546,253	515,572	296,642	68,100	1,426,567
2030	558,750	528,285	303,862	69,277	1,460,175
2031	571,553	541,197	311,188	70,454	1,494,393
2032	584,661	554,308	318,620	71,632	1,529,222
2033	598,076	567,618	326,159	72,809	1,564,662
2034	611,796	581,127	333,803	73,987	1,600,712
2035	625,821	594,834	341,553	75,164	1,637,373
2036	640,152	608,741	349,409	76,342	1,674,644
2037	654,789	622,846	357,371	77,519	1,712,526
2038	669,732	637,150	365,439	78,697	1,751,018
2039	684,980	651,654	373,613	79,874	1,790,121
2040	700,534	666,356	381,894	81,051	1,829,835

Appendix D

Year	Jerusalem	Ramallah	Bethlehem	Jericho	Total
2016	184.47	160.87	73.25	29.37	447.96
2017	191.46	167.16	75.62	30.66	464.9
2018	198.45	173.45	77.99	31.95	481.85
2019	205.44	179.74	80.36	33.25	498.79
2020	212.44	186.03	82.73	34.54	515.73
2021	219.43	192.32	85.1	35.83	532.68
2022	226.42	198.61	87.47	37.12	549.62
2023	233.41	204.9	89.84	38.41	566.57
2024	240.4	211.19	92.21	39.71	583.51
2025	247.39	217.48	94.58	41	600.45
2026	254.39	223.77	96.95	42.29	617.4
2027	261.38	230.06	99.32	43.58	634.34
2028	268.37	236.35	101.69	44.87	651.28
2029	275.36	242.64	104.06	46.17	668.23
2030	282.35	248.93	106.43	47.46	685.17
2031	289.35	255.22	108.8	48.75	702.11
2032	296.34	261.51	111.17	50.04	719.06
2033	303.33	267.8	113.54	51.33	736
2034	310.32	274.09	115.91	52.62	752.95
2035	317.31	280.38	118.28	53.92	769.89
2036	324.3	286.67	120.65	55.21	786.83
2037	331.3	292.96	123.02	56.5	803.78
2038	338.29	299.25	125.39	57.79	820.72
2039	345.28	305.54	127.76	59.08	837.66
2040	352.27	311.83	130.13	60.38	854.61

Appendix E

Year	Power (MW)	Population	KW/Person
1997	138.72	685018	0.20
1998	151.79	701342	0.22
1999	172.69	717971	0.24
2000	187.70	734589	0.26
2001	193.73	750033	0.26
2002	221.51	765692	0.29
2003	235.56	781734	0.30
2004	221.61	798343	0.28
2005	252.57	816259	0.31
2006	257.63	834645	0.31
2007	281.85	853522	0.33
2008	301.08	874406	0.34
2009	329.36	895783	0.37
2010	336.14	917650	0.37
2011	367.00	940329	0.39
2012	417.50	963632	0.43
2013	413.65	987295	0.42
2014	400.57	1011269	0.40
2015	450.74	1035486	0.44
2016	447.96	1045225	0.43
2017	464.90	1070895	0.43
2018	481.85	1097176	0.44
2019	498.79	1124068	0.44
2020	515.73	1151571	0.45
2021	532.68	1179683	0.45
2022	549.62	1208407	0.45
2023	566.57	1237741	0.46
2024	583.51	1267685	0.46
2025	600.45	1298241	0.46
2026	617.40	1329406	0.46
2027	634.34	1361182	0.47
2028	651.28	1393569	0.47
2029	668.23	1426567	0.47
2030	685.17	1460175	0.47
2031	702.11	1494393	0.47

2032	719.06	1529222	0.47
2033	736.00	1564662	0.47
2034	752.95	1600712	0.47
2035	769.89	1637373	0.47
2036	786.83	1674644	0.47
2037	803.78	1712526	0.47
2038	820.72	1751018	0.47
2039	837.66	1790121	0.47
2040	860.22	1829835	0.47

Appendix F

Tansmission system by using matlab

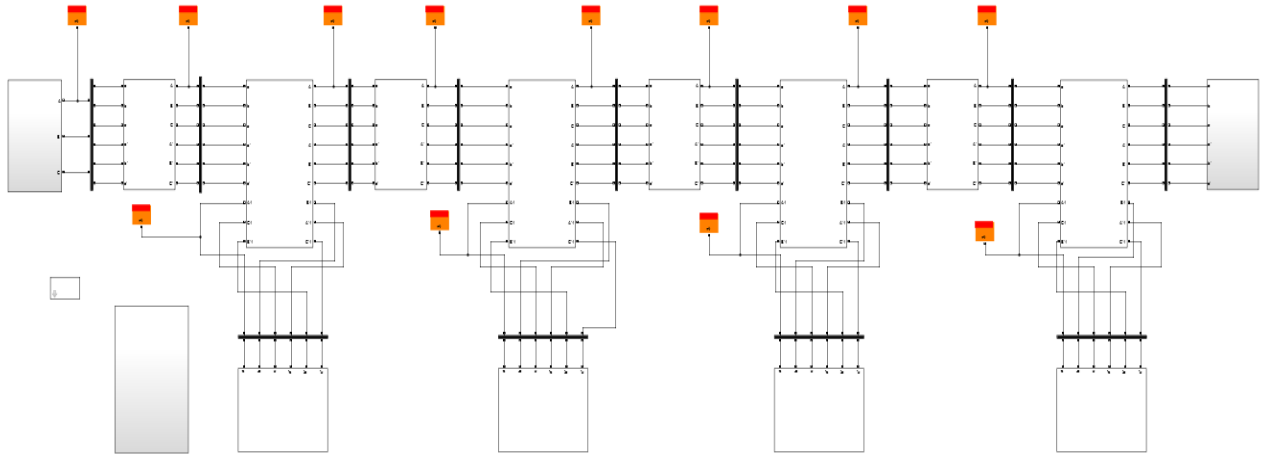


Figure 1: Transmission system using Matlab

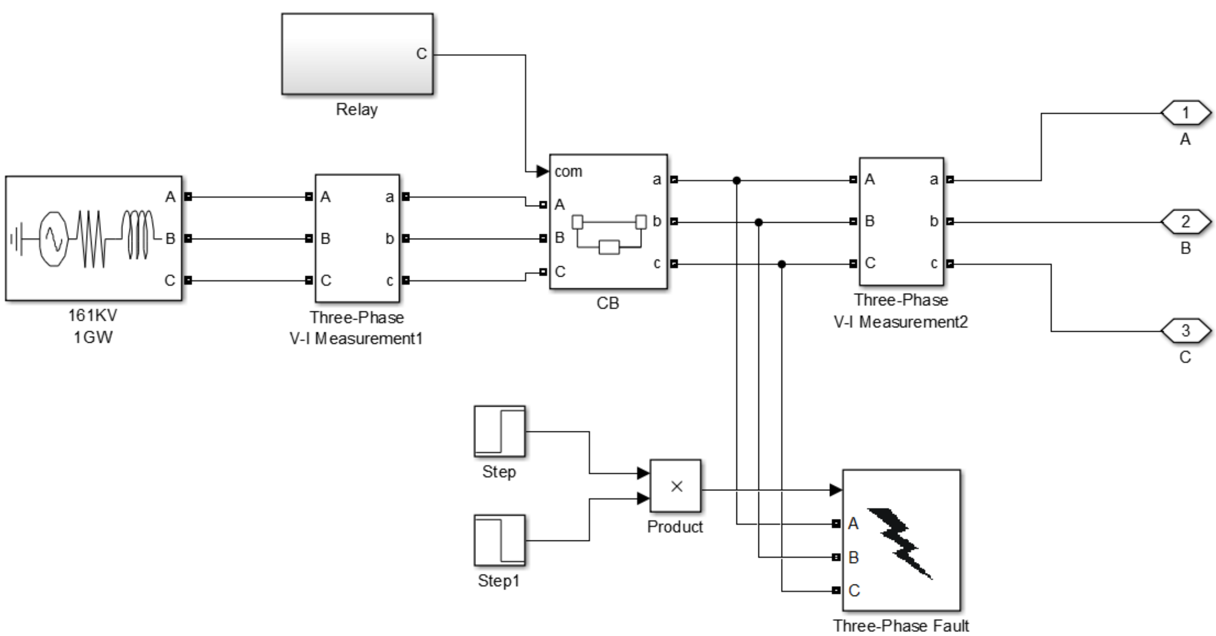


Figure 2: The source

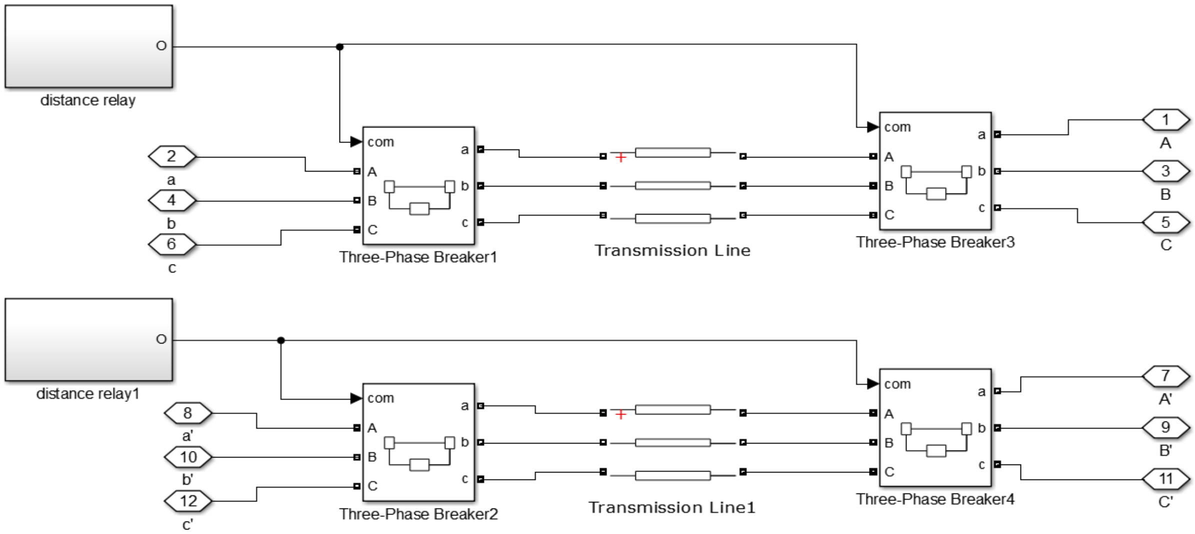


Figure 3: Transmission line

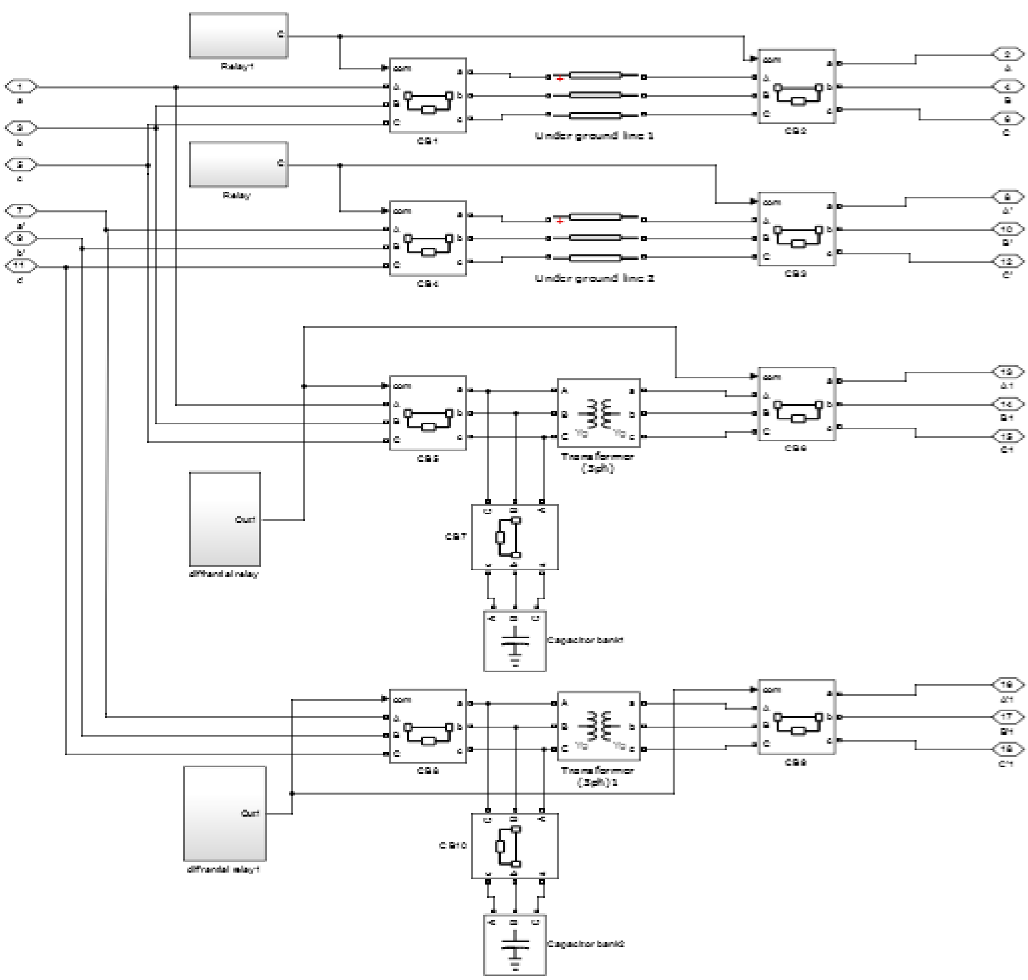


Figure 4: Substation

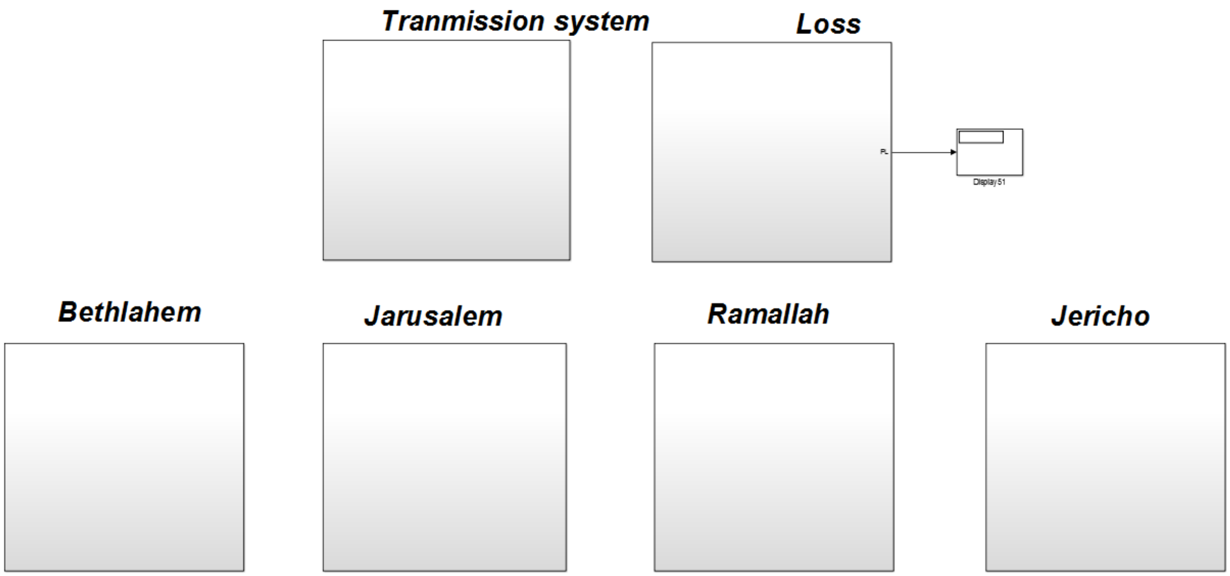


Figure 5: Monitoring system

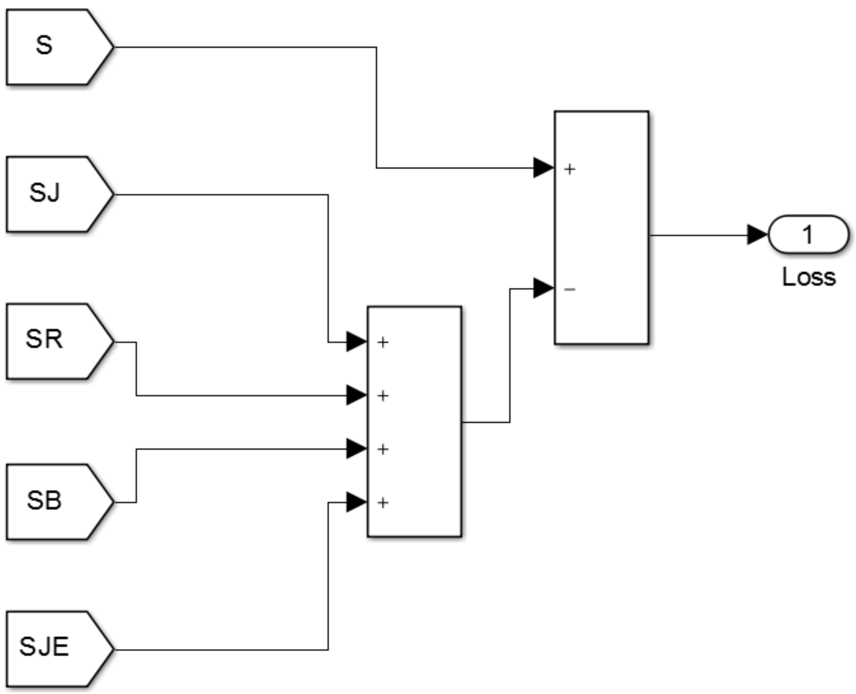


Figure 6: Loss calculation

Appendix G

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