Palestine Polytechnic University

College of Engineering and Technology
Electrical and Computer Department
Industrial Automation Engineering

Graduation Project

Development of Hebron Medium Voltage Electrical
Network by Using the Simulator Program

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According to the project supervisor and according to the agreement of the testing committee members, this project is submitted to the Department of Electrical and Computer Engineering at Faculty of Engineering and Technology in partial fulfillment of the requirements of (B.A.) degree.

Supervisor Signature

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Examining Committee Members Signature

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Abstract:

This project is studying of the medium voltage electric power network of Hebron city by using the Power World Simulator (Simulator) program and making the essential developments and improvements on the network such as reducing the losses, improving the Power Factor, achieving the network stability and increasing its efficiency.

The core of the project is the using of the Power World Simulator program which has the simulation property, which allows us to analyze and study the status of the network more accurately.

After making the studying to the network, we found that it suffers from many problems such as high losses 16%, Power Factor less than 0.92, voltage drop, overloaded conductors and transformers.

To solve the previous problems we performed five developing scenarios, which are re-conductoring, voltage upgrading, power factor correction, adding new substation and over loaded transformers rehabilation.

Dedicated

To

Our Home Land

Our Fathers & Mothers

Our Brothers and Sisters

Our Friends

And

Every One Who Appreciate the Value of Science

Fuad

&

Anas

Acknowledgement

First and for most we should offer our thanks obedience and gratitude to Allah

Our Appreciation To
Palestine Polytechnic University
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" إن صلاتي ونسكي ومحياي ومماتي لله رب العالمين، لا شريك له وبذلك أمرت وأنا أول المسلمين"

صدق ا العظيم

Chapter One

Introduction

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Chapter One

Introduction

1.2 Overview:

The main idea of this project is studying the medium voltage electric power network of Hebron city by using the Power World Simulator (Simulator) program, then making the essential developments and improvements on the network such as reducing the losses, improving the Power Factor, achieving the network stability and increasing its efficiency.

1.2 Project General Description:

As we know, in general, most of the electric power networks in many places (Countries) in the World suffer from many problems such as high losses, low Power Factor, voltage drop and many other problems. Usually, in our country these problems are solved by using traditional and uneconomical methods, and these methods need long time and hard work in order to solve some of the previous problems.

But this project solves these problems by using a new technique that is the Power World Simulator program, and in our project we will solve the problems that are found in Hebron city electric power network, specially the medium voltage network problems.

Our project adopts investigation and analysis and development of Hebron city electric power network (medium voltage) after plotting it on the Simulator program, the program capabilities and properties allow us to study the network (grid) from many sides, show the status of the network components, and solve the existing problems and weakness in the network and develop its operation.

1.3 Project Importance:

This project is the first project in Hebron city that uses the Power World Simulator program in solving the network problems; also it is the first project in Palestine Polytechnic University that concerns with the electric power field.

We know that Hebron city is considered as one of the most important cities specially in West Bank, and generally in Palestine industrially and commercially, also the largest amount of the consumed energy is consumed by the industrial customers, so the electric power that is fed to these fields by the network must be in adequate level and in a continuous pattern.

1.4 Project Scope:

The scope of this project is studying the medium voltage part of Hebron city electric power network. And there are many aims for this project that can be summarized as follow:

- Reducing the network losses.
- Improving the network Power Factor.
- Solving the voltage drop problem.

- Developing and improving the network.

1.5 Project Methodology:

- Plotting the existing network with its actual values on the Simulator.
- Studying and investigating the network.
- Specify the network problems.
- Getting the suitable and required information and statistics from the Simulator.
- Solving the network problems and developing and improving its operation.

1.6 Description of Project Parts:

This project contains six chapters and various appendices, and these chapters can be summarized as follow:

Introduction Chapter: It gives a general idea about the project and its importance.

Hebron City Network Chapter: This chapter describes the status conditions of the network and shows its historical developments electrically, and gives some important statistics about it.

Power World Simulator Program Chapter: This chapter describes the Simulator program and its capabilities.

Electric Power Concepts Chapter: This chapter explains many basic electric power concepts, which are required to understand the project.

Data Analysis Chapter: This chapter includes the results of the load flow of the network, also the results tables of the project scenarios and their analysis.

Conclusions and Recommendations Chapter: This chapter includes the final conclusions of the project and the final recommendations.

Chapter Two

Hebron City Network

2.1 Introduction.

2.2 Description of the Existing System.

2.3 Assessment of the System.

2.4 Subscribers.

2.5 Network Problems and Weakness.

Chapter Two

Hebron City Network

2.1 Introduction:

Hebron lies among mountains in the heart of southern Palestine 35Km south of Jerusalem. According to the PCBS the population of Hebron city is about 150,000 in 1997 census, thus if include the surrounding towns and villages the population of the district becomes 400,000 citizen.

The total area of Hebron city is $30Km^2$ and the district is $1103Km^2$. The areas served by the Municipality in terms of electric power is about $65Km^2$. The electric power system and service are under the responsibility of Hebron Municipality since 1948. The Municipality has a flexibility in its mandate to generate, transmit and distribute electricity to different areas in the district including; Hebron city , Halhoul, Al Ordaseh, Al Buwara, Al Jalajel, Beit Ainon, Wadi Al Jouz, Wadi Samen, Al Amayer, Sinjer, Dweir Ban, Louza, Taphouh road and Farsh Al Hawa. The estimated number of people served by the Municipality in regard to electricity is about 250,000 inhabitant.

In the early of 1973 the Municipality started to deliver the Israeli generated power through distribution network owned by the Municipality. The electric power delivered increased from 24.5MW in 1995 to 46MW in 2004 due to the normal modernization and industrialization increase.

2.2 Description of the Existing System:

2.2.1 Medium Voltage System:

After analyzing and studying Hebron Medium voltage network, we found that this network is fed from four main substations which are Alras Substation, Alfahs Substation, Alduhdah Substation, Alharayek Substation, and these Substations have a various range of apparent power (MVA), number of transformers with various range of voltages, and this can be shown by the following table:

Table 2. 1: Main Substations

AlRas Substation	20MVA	2 transformers of 10MVA	33/11-6.6KV
Alfahs Substation	17.5MVA	1 transformer of 10MVA 1transformer of 7.5MVA	33/11-6.6KV 33/11-6.6KV
Alduhdah Substation	20MVA	2 transformers of 10MVA	33/11-6.6KV
Alharayek Substation	10MVA	1 transformer of 10MVA	33/11-6.6KV

Hebron electric power network has three tie points that connect it with the Israeli Electrical Company; as follow:

- Abu Ayash Tie Point: serves Alras and Alduhdah Substations.
- Alfahs Tie Point: serves Alfahs Substaion.
- Alhawooz Tie Point: serves Alharayek Substation.

2.2.2 Low Voltage Distribution Grid:

The project will deal with the medium voltage grid and we will not study the low voltage grid, although it is suffering from many problems like, high losses, voltage drop, high long feeders, and other many problems.

2.2.3 Distribution Transformers:

Hebron electrical network includes a big number of transformers, approximately 350 transformers, and these transformers have a wide range of (KVA), from (100-1000) KVA, and various ratings of voltages, and this can be shown as follow:

Table 2. 2: Distribution Transformers

VoItage (KV) **Rating (KVA)**	**6.6/0.4**	**6.6-11/0.4**	**6.6-33/0.4**	**33/0.4**
100	4	22	10	—
160	12	21	8	—
250	12	34	7	— ssssssss
315	13	12	—	—
400	14	34	8	1
500	15	25	—	—
630	9	19	2	3
800	3	8	—	—
1000	2	3	—	—
Total	84	178	35	4

2.2.4 Transmission and Distribution Lines:

The total available transmission lines are about 25.5Km of underground cables and about 479.32Km of overhead lines. In terms of voltages, there is a total of 14.82 Km of 33KV lines, 116.4Km of (6.6-11) KV lines, and low voltage network lines

372.6Km. The following is a breakdown according to the voltage and the type of line:

Table 2. 3: Conductors

Category	Under Ground Cables	Over Head Lines
33KV	1.7 Km	13.12 Km
6.6-11 KV	16.9 Km	99.5 Km
400V	6.9 Km	365.7 Km

2.3 Assessment of the System:

2.3.1 Status Condition of Hebron Electricity Grid:

From the status and the actual conditions of Hebron city medium voltage network, we note that one third of the 33KV system is ready for the ring system, and the number of circuit breakers in the main substations is not enough, 30% of the overhead lines require rehabilitation, upgrade the existing 6.6KV network to 11KV underground cables.

2.3.2 Electricity Losses:

Hebron city electrical network has large amount of losses, and these losses resulted from the network various fields and customers and its elements, and the following table shows us the amount of the network losses and the amounts of purchased and billing electricity:

Table 2. 4: Electricity Losses

Year	Purchased Electricity KWh	Billed Electricity KWh	Qty. Losses KWh	% Losses
1995	106,552,080	78,149,418	28,402,662	26.66
1996	116,295,720	84,999,044	31,296,676	26.91
1997	129,024,810	95,696,759	33,328,051	25.83
1998	141,637,860	109,501,581	32,127,279	22.68
1999	158,674,520	128,512,038	30,162,482	19.01
2000	177,817,680	141,630,043	36,187,637	20.35
2001	174,381,360	139,602,209	34,779,151	19.94
2002	164,623,808	138,374,473	26,249,335	15.95
2003	194,285,240	150,778,753	43,506,487	22.4

In this project we will reduce these losses from its high value to a value around the international standard losses.

2.4 Subscribers:

The number of subscribers in 2003 was approximately 27,750. That can be divided into the following categories:

- Households 65 %
- Commercial 23 %
- Industrial 9 %
- Governmental 2 %
- Street lighting 0.5 %

- Water and Sewage stations 0.05%
- Other (Banks, Hotels, Hospitals) 0.45%

The industrial subscribers are divided into three groups as follow:

- From 30 to 60 Amps. 70%
- From 61 to 100 Amps. 20%
- More than 100 Amps. 10%

2.5 Network Problems and Weakness:

The network problems and weakness can be summarized as follow:

1. Hebron electric power network suffers from high losses, shown in table (2.4).
2. Low Power Factor.
3. Unbalanced loads distribution.
4. Voltage Drop.
5. The electricity cutoff problem.
6. The lacks of feeders switching points, so complete feeders are taken out for maintenance even through loop supply points are available, but there are not enough switching devices.
7. Unstability problem.

Chapter Three

Power World Simulator Program

3.1 Introduction to Power World Simulator.

3.2 Power World Interface.

3.3 Toolbars.

3.4 Capabilities and Properties of the Simulator.

3.5 Network Elements Required Data.

3.6 Coding System.

Chapter Three

Power World Simulator Program

3.1 Introduction to Power World Simulator:

Power World Simulator (Simulator) is a power system simulation package designed from the ground up to be user-friendly and highly interactive. Simulator has the power for serious engineering analysis, but it is also so interactive and graphical that it can be used to explain power system operations to non-technical audiences.

Simulator is actually a number of integrated products. At its core is a comprehensive, robust Power Flow Solution engine capable of efficiently solving systems of up to 60,000 buses. This makes Simulator quite useful as a stand-alone power flow analysis package. Unlike other commercially available power flow packages, however, Simulator allows the user to visualize the system through the use of full-color animated oneline diagrams with full zooming and panning capability. Moreover, system models may be modified on the fly or even built from scratch using Simulator's full-featured graphical case editor. Transmission lines may be switched in or out of service, new transmission or generation may be added, and new transactions may be established, all with a few mouse clicks. Simulator's extensive use of graphics and animation greatly increases the user's understanding of system characteristics, problems, and constraints, as well as of how to remedy them.

Simulator also provides a convenient medium for simulating the evolution of the power system over time. Load, generation, and interchange schedule variations over time may be prescribed, and the resulting changes in power system conditions may be visualized. This functionality may be useful, for example, in illustrating the many issues associated with industry restructuring.

In addition to these features, Simulator boasts integrated economic dispatch, area transaction economic analysis, power transfer distribution factor (PTDF) computation, short circuit analysis and contingency analysis, all accessible through a consistent and colorful visual interface. These features are so well integrated that you will be up and running within minutes of installation.

3.2 Power World Interface:

3.2.1 Windows Basics:

Simulator 8.0 runs under Windows 95/98/2000/Me/XP and NT 3.5 and later operating systems. Since much of the interaction between Simulator and the user is accomplished by using the mouse, we have designed the interface to obey consistent conventions for mouse usage. In general, the left-mouse button is used to affect some sort of immediate change or control over a power system element, while the right mouse button is used to gain more information about a power system element or to view a list of available options.

3.2.2 Power World Simulator: Getting Started:

The key to using Simulator is to recognize that it has two distinct modes: the Edit Mode and the Run Mode. The Edit Mode is used to construct new simulation cases or to modify existing cases, while the Run Mode is used to perform the actual power system simulation. You can easily switch between the modes at just about any time using the Edit Mode and Run Mode buttons on the Program Palette. Each mode has its own distinct set of menu commands. The entries on these menus are explained in the following sections.

If you are new to Simulator and seek a quick means of familiarizing yourself with it, you may wish to start with the tutorial; see Creating a New Case. Or if you're interested in trial-and-error learning, you may just wish to open one of the sample cases and start learning.

3.2.2.1 Edit Mode Introduction:

The Edit Mode is used to create a new case and to modify existing cases. To switch to Edit Mode, click on the *Edit Mode* button on the Program Palette, or choose **File > Switch to Edit Mode** from the file menu.

Here is a sampling of things you can do in Edit Mode:

- Create a completely new case.
- Create a new oneline diagram.
- Add new components graphically to an existing case.
- Modify the appearance of the oneline objects.
- View and modify a case using non-graphical lists displays.
- Equivalence a case.
- Append a subsystem to an existing case.

For more information see the appendix D

3.2.2.2 Run Mode Introduction:

The Run Mode is used to solve a single Power Flow Solution, run one of the available load flow tools, or run a time-domain simulation of the power system. To access the Run Mode click on the Run Mode button on the Program Palette, or choose **File > Switch to Run Mode** from the file menu.

The key menu associated with the Run Mode is the Simulation menu. This menu allows you to either perform a single Power Flow Solution (however, it is quicker to use the toolbar), or start a time-domain simulation.

Other key components of the Run Mode include:

- The oneline diagrams, which allow you to view the case graphically.
- The Case Information Displays, which allow you to view the entire power system case using list displays.
- Dialogs to change the simulation options and the Power Flow Solution.
- Various strip-charts for plotting the time-variation in system values.
- Scaling to allow easy variation in the load, shunts, and generation at any number of buses.
- Contouring, which shows a color contour representing the variation in any power system parameter across a system.
- Transfer distribution factor calculations.
- Perform a fault analysis.
- Run Transfer Capability studies.
- Perform an Optimal Power Flow (OPF) or Security Constrained Optimal Power Flow (OPF) analysis.
- Generate PV and QV curves.
- Customization based upon whether you are doing pure power flow studies, or time-domain economic analysis.

3.3 Toolbars:

Simulator 8.0 makes extensive use of toolbars for easy access to its many features. You can move and size these toolbars according to your preferences. The toolbars house several palettes of controls, each of which may be activated with a single mouse click. Simulator provides several palettes that group commonly used functionality. Many of these toolbars are displayed by default, with certain toolbars only available in either edit mode or run mode. To either display or hide toolbars, you can either select the **Window, Toolbars** menu option, or right-click in the toolbar docking area near the top of the oneline diagram. The Toolbars available in Simulator are:

1. Program Palette
2. File Palette
3. Edit Palette
4. Insert Palette
5. Format Palette
6. List Display Palette
7. Zoom Palette
8. Pan/Zoom Palette
9. Options/Info Palette
10. Run Mode Palette

3.3.1 Program Palette:

The program palette gives you the ability to switch between the program's Edit and Run Modes and to control various aspects of the Power Flow Solution. The options available from the program palette include:

Edit Mode:

Switches the program to Edit Mode, which can be used to build a new case or to modify an existing one.

Run Mode:

Switches the program to Run Mode, which can be used to perform a single Power Flow Solution or a timed simulation with animation.

Script Mode:

Opens the Script dialog, which can be used to call script commands or open auxiliary files containing script commands and data modifications.

Single Solution (Run Mode only):

Performs a single solution of the power flow equations, as opposed to a timed simulation.

The single solution button allows you to use Simulator as a standalone power flow.

Log:

Toggles the display of the message log window. The log window shows what is going on with the Power Flow Solution process and may prove useful when you are trying to track down a problem with a non-converging model.

Abort:

Terminates the current Power Flow Solution. If the application is performing a timed simulation, pressing the abort button will pause the simulation.

3.3.2 File Palette:

The File Palette provides access to operating system activities such as saving a oneline diagram or case model to disk, printing a oneline display to a printer, or loading a case or oneline from disk. This palette also offers access to the on-line help system and to Power World’s case validation tool.

3.3.3 Edit Palette:

The Edit Palette (Edit mode only) links to several case edit tools. You can cut or copy single objects on the oneline diagram and paste them into the same or another diagram. You can perform the same operations with groups of elements that have been identified through either the Select By Criteria or the Selection Rectangle tools.

3.3.4 Insert Palette:

The Insert Palette (Edit mode only) contains a number of buttons that allow you to add drawing objects to the current oneline diagram. These objects include power system components such as buses, transmission lines, transformers, loads, generators, areas, and zones, as well as informational objects such as pie charts and analogs. You may also add display objects such as text fields, rectangles, ellipses, arcs, and free-form shapes, which are not linked to objects in the power system model. The buttons on this palette provide access to most of the activities available from the Insert menu.

3.3.5 Format Palette:

The Format Palette (Edit mode only) allows you to control such display object attributes as font, color, line styles, zoom-dependent visibility, and display layer level. This palette also enables you to set default values for various drawing parameters and to reset the default values when necessary. The Format Palette provides access to most of the activities available from the Format branch of the main menu.

3.3.6 List Display Palette:

The List Display Palette provides easy access to many Case Information Display options for formatting and customizing a list display. The buttons on the toolbar will only be available if you have at least one case information display open in Simulator. The list display functions and options available from this toolbar are copying and pasting data, finding data or text, opening an information dialog, setting the display/column options, advanced filtering and sorting, refreshing the display, displaying metrics for a column, auto sizing the grid, and setting the decimal places for columns containing numerical data. All of these options are available through the popup menu of each case information display as well.

3.3.7 Zoom Palette:

To display large detailed power systems, Simulator's onelines possess zooming and panning capabilities. The Zoom Palette enables you to prescribe a zoom level either by directly specifying a zoom value or by selecting a rectangular region of the diagram on which to focus. In addition, this toolbar enables you to save a view location, or recall a previously saved view location. This palette also links to a dialog box from which you can select a bus on which to center the display.

3.3.8 Pan/Zoom Palette:

The Pan/Zoom Palette offers additional zooming and panning control. Use the four-arrow cluster to pan the display horizontally and vertically. Use the other buttons to zoom the display in and out.

3.3.9 Options/Info Palette:

The Options/Info Palette provides quick access to Simulator's many information displays and option settings. Use this palette to set simulation and solution options, define area/zone filters, perform a Single Power Flow Solution, generate quick power flow lists and the bus view displays, and to switch to other open oneline diagrams.

3.3.10 Runs Mode Palette:

The Run Mode palette offers access to various Run Mode activities. It features VCR-like controls for starting, resetting, and pausing the simulation. It also links to Run Mode tools such as contouring, difference flows, and fault analysis.

3.4 Capabilities and Properties of the Simulator:

3.4.1 Oneline Diagram Overview:

The purpose of the oneline diagram is to show information about the power system graphically. Such displays are called oneline diagrams (onelines) because the actual three-phase power system components are represented using a single line. Simulator helps make the onelines "come alive" by providing:

- zooming and panning
- conditional display of objects
- animation

Additionally, a key aspect of Simulator is the ease with which it allows you to examine and modify many of the devices contained on the oneline diagram. For most objects, this is accomplished by positioning the cursor on the object and right-clicking. You may open any number of oneline diagrams, including multiple copies of the same oneline.

3.4.2 Relationship between Display Objects and the Power System Model:

This section is intended for more advanced users familiar with the fundamentals of power system modeling.

A key strength of the Simulator is its ability to allow users to manipulate a power system model graphically. This capability greatly simplifies the work involved in developing or maintaining a power system case for both novice and advanced users. However, it is important to keep in mind the distinction between the display objects shown on the onelines and the actual power system model, consisting of model objects. A key concept is that any number of display objects, including none at all, can be associated with a single model element.

Simulator uses a bus-oriented model. In other words, the model objects are either the buses themselves, objects that are radially attached to a bus (i.e., loads, generators and switched shunts), or objects that join two buses (i.e., transmission lines, transformers or dc lines). As long as there is a one-to-one mapping between display objects and model objects, the distinction between the two could be made entirely transparent to the user.

However, this would limit flexibility. In fact, it is quite reasonable to use more than one display object to represent a single model object. For example, by using the conditional zoom feature, two bus display objects could be used on a single oneline to represent the same bus. One bus might be visible over a particular zoom range, while another, with perhaps a different size/thickness, is visible over another range.

Alternatively the same bus could be represented using display objects drawn on separate onelines.

An ambiguity arises when the user uses the Cut command to delete the bus. Are they deleting just the Display Object or the Display Object and the Model Object?
To get around this difficulty, Simulator prompts you when you are deleting a display object with an associated model object. You can either delete both the Display Object and its associated model object record, delete just the display object, or cancel the delete.

Also, there is no requirement that model objects have a corresponding display object. Thus, you could use the oneline diagram to show just a fraction of the total system buses and other devices.

Also, you can use the Case Information menu to view the model objects directly regardless of whether or not they are shown on a oneline.

3.4.3 Equivalencing:

An equivalent power system is a power system model of smaller dimension than the original system that approximates the behavior of the original system reasonably well. In reality, most power system models are actually an "equivalent" of a much larger interconnected network.

When performing power system studies, it is often desirable to reduce the size of the system model even further so that they may be solved more quickly. You can build power system equivalents in Simulator using the Equivalencing Display. The following paragraphs provide some details on this process.

The most important part of constructing an equivalent is determining which buses should be explicitly retained in the equivalent, and which buses should be *equivalence*d, or removed from the case. Several definitions are useful here:

Study System:

The buses that are to be retained.

External System:

The buses that are to be equivalenced.

Boundary Buses:

Any buses in the study system that are connected to buses in the external system. How well the equivalent system approximates the behavior of the original system depends upon which buses are retained in the study system. Retaining more buses yields results that more closely match those of the original case, but at the expense of greater computation time. The number of buses to retain in the study system depends upon how the equivalenced system will be used. Building system equivalents is as much an art as it is a science, with few solid rules of thumb. However, to improve accuracy, you should retain as many generator units as possible.

The actual equivalent is constructed by performing a matrix reduction on the bus admittance matrix. A result of this process is the creation of "equivalent" transmission lines that join boundary buses equipped with equivalent shunts or loads. Equivalent lines have a circuit identifier of ‘99’. Since many of the equivalent lines created during the matrix reduction have very high impedance values, an option is provided to ignore equivalent lines with impedances exceeding a specified threshold value. Additionally, an option is provided to convert the equivalent shunts added at the boundary buses to constant PQ loads.

3.4.4 Facility Analysis:

3.4.4.1 Overview of Facility Analysis in Power World Simulator:

Facility Analysis is used to study the topological redundancy of interconnect specific electric facilities. This application determines the minimum set of AC transmission lines and transformers that when opened or removed from the system would electrically isolate a set of Facility buses from a set of External buses.

The tool is an application of the augmenting path max flow min cut algorithm with modifications to handle electric networks.

The Facility analysis process has two steps:

1) The Select the Buses dialog is used to specify the External and Facility buses. Multiple selections of the External buses can be done using any of the area or zone selectors. The Facility buses are specified by setting the selected field of buses to YES.
2) The Facility Analysis dialog is used to determine the Min Cut and visualize the branches that belong to the min cut.

The Facility analysis application runs in edit mode and takes into consideration the open or closed status of the branches. Open lines are considered as not present in the system.

3.4.4.2 Graph Flow:

Most network and graph theory applications use the concept of flow to represent any object that can be transported, such as communication packets or trucks, but also connectivity properties of graphs. In the augmenting path max flow min cut algorithm the flow is an artificial concept used to represent topological connectivity of buses. Two buses are adjacent if flow can be sent from one to the other through a branch.

Graph Flow Capacity of a Branch:

Networks that transport some flow are said to be capacitated if its arcs (here synonym of “branches”) have some limit associated to the flow transportation. For instance, capacity of a communication channel, or number of trucks that can be simultaneously on a certain road. The algorithm used in the Facility Analysis assigns a capacity of one to each branch. This means that the branch can be used only once for connecting two nodes.

Graph Flow Capacity of a Cut:

The capacity of a topological cut is equal to the sum of the capacities of its arcs. In the Facility Analysis, the capacity of the min cut is equal to the number of branches in the min cut, since each branch has a capacity of one.

3.4.5 Contingency Analysis:

Contingency analysis is a vitally important part of any power system analysis effort. Whether you are investigating the long-term effects on the transmission system of new generation facilities or projected growth in load, or you are considering whether to accept a transaction for next-hour’s energy trade, it is extremely important that you analyze the system not only for its current topology but also for the system that results from any statistically likely contingency condition.

Industry planning and operating criteria often refer to the n-1 rule, which holds that the system must operate in a stable and secure manner for the loss of any single transmission or generation outage. Therefore, it is very important to pay attention to the effects contingencies may have on the operation of your system.

Power World Simulator is equipped with a set of tools for analyzing the effect of contingencies in an automatic fashion. The current edition of Simulator can process lists of contingencies involving:

1. The opening or closing of transmission lines and transformers.
2. The loss or recovery of a particular generator, load, or switched shunt.
3. The movement of generation, load, or switched shunt MWs or Mvars.
4. The changing or setting of load, switched shunt, or generator MWs or Mvars.
5. The opening of all lines connected to a bus.
6. The opening or closing of all lines or transformers in an interface.

Simulator can be set to use a full Newton solution to analyze each contingency or use a dc load flow method. The full Newton approach is not as fast as dc load flow, but the results tend to be significantly more accurate, and also allow for gauging voltage/var effects.

3.4.6 Fault Analysis:

Fault analysis can only be performed when Simulator is in Run Mode. There are four ways to start a fault analysis study:

- From the **Options/Tools** menu, select **Fault Analysis**…
- From the Run Mode Palette, click the **Fault** button
- Right click on a bus and choose **Fault…** to perform a fault analysis at that bus
- Right click on a line and choose **Fault…** to perform a fault analysis at that point on the line

All four of these options will open the Fault Analysis dialog. If you opened the dialog by right-clicking on a bus or line, the fault information on that bus or line will already be filled in. If you selected the **Fault Analysis…** option from the

Options/Tools menu or the **Fault** button, the information about the location of the fault will need to be provided.

3.4.7 Contouring:

Simulator can create and animate a contour map of various system quantities, such as voltage magnitudes and angles, MW transactions, transmission loading, and real and reactive load. Such displays resemble a contour map of temperatures like that shown on a weather forecast. Contouring can significantly improve understanding of a large interconnected system, helping identify congestion pockets and Mvar-deficient regions and providing an overview of how power flows through the bulk power system. The Contour Options Dialog controls Simulator's contouring capabilities. To access it, either click the right mouse button on an empty area of the oneline and choose **Contouring** from the resulting local menu, or choose **Options/Tools > Contouring** from the main menu.

3.4.8 Distribution Factors:

The Power Transfer Distribution Factor (PTDF) display is used to calculate the incremental distribution factors associated with power transfers between two different areas or zones. These values provide a linearized approximation of how the flow on the transmission lines and interfaces change in response to transaction between the Seller and the Buyer. These values can then be visualized on the onelines using animated flows.

The transaction for which the PTDFs are calculated is modeled by scaling the output of all generators on AGC in the source and sink areas in proportion to their relative participation factors. Generators in the source area increase their output, while generators in the sink area decrease their output.

An important aspect to consider in calculating the PTDF is how the losses associated with the transfer are allocated. Simulator assumes that the Seller increases the output of its generators by 100% of the transfer amount, while the Buyer decreases the output of its generators by 100% **minus any change in system losses**. In other words, the Buyer accounts for the entire change in the system losses. Of course it is possible that a transfer may result in decreased system losses; for that case, the decrease in the Buyer's generation will be greater than 100% of the transfer.

3.5 Network Elements Required Data:

For any network that plotted as a case in the simulator program, each element of the network has a data card (dialog); this dialog includes the required data about the element which the program needs to implement it. In general, each electric power network includes main elements such as Generator, Transformer, Transmission Line, Load, and Switch Shunt.

The internal parameters of some elements dialogs such as transformer and transmission line depend on the approximated equivalent circuits of these elements as shown in chapter 4.

Now we will show the dialog of each element and describe its data parameters:

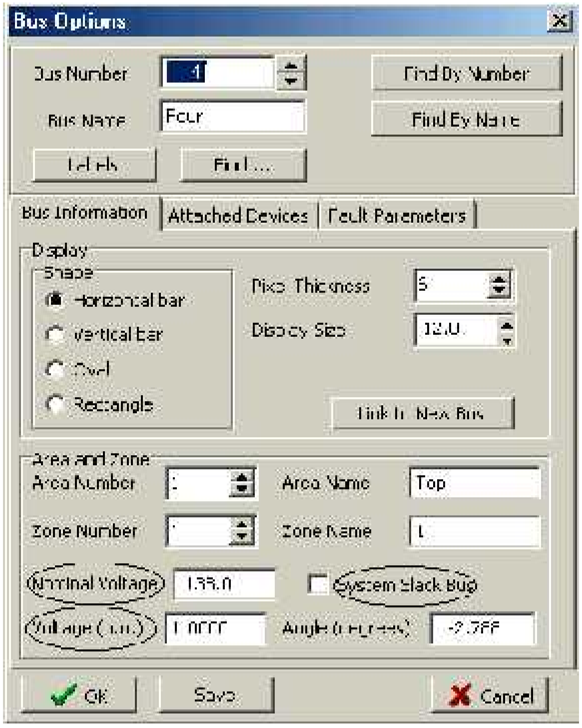
1. Bus Bar Information Dialog:

The essential data of the Bus Bar that must be entered into the spaces which are marked on the following diagram shown as follow:

- **Nominal Voltage:** this value must be filled with the nominal voltage of the bus bar, in KV unit.

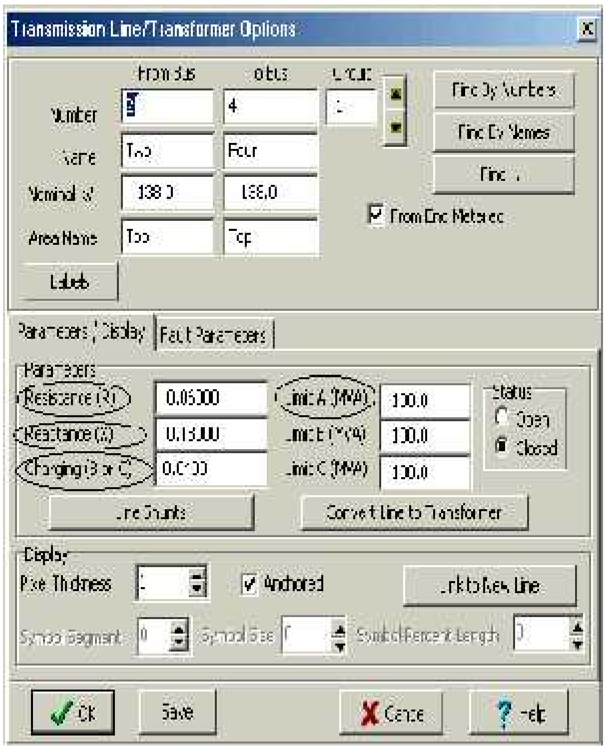
- **Voltage (P.U.):** this value must be filled with the bus bar voltage in P.U. system, and this value is by default equal 1.

- **System Slack Bus:** selected only if the bus bar is a slack bus.



2. Transmission Line/Transformer Dialog:

From the equivalent circuits of the transformer and the transmission line that shown in Chapter 4; we can implement these two elements by the following Parameters:



- **Resistance (R):** this value represents the resistance of the transformer or the transmission line in P.U. system.

- **Reactance (X):** this value represents the reactance of the transformer or the transmission line in P.U. system.

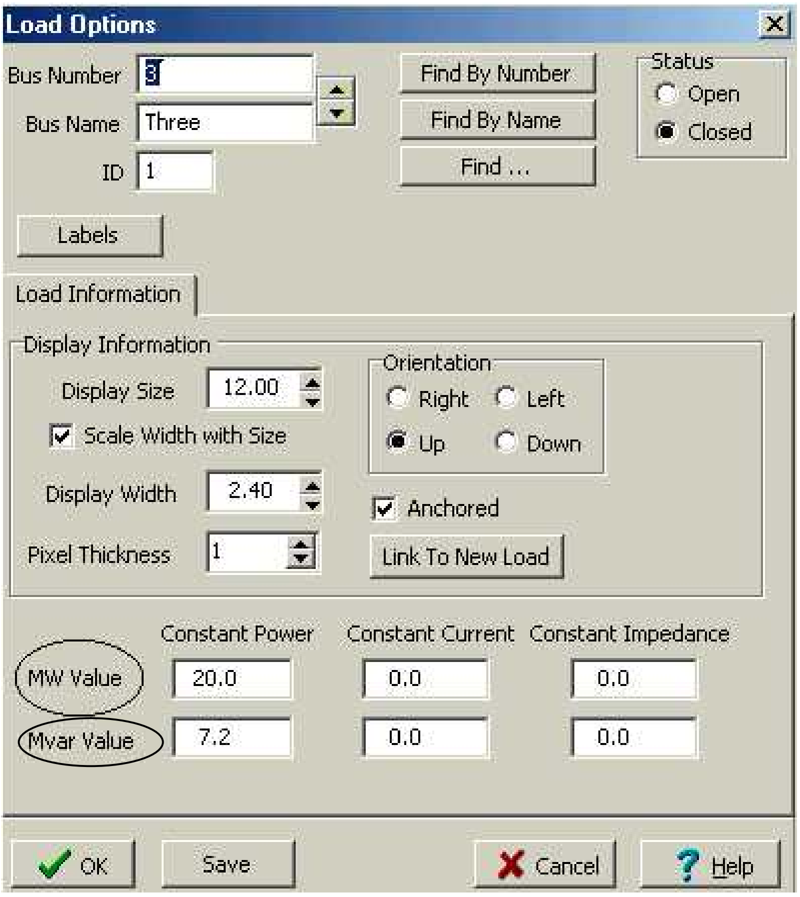
- **Charging (B or C):** this value represents the capacitance of the transformer or the transmission line also in P.U. system.

  The previous values depend on the equivalent circuit of the element which is shown is chapter 4.

- **Limit A (MVA):** this value represents the apparent power of the transformer in MVA unit, and the capability of the transmission line.

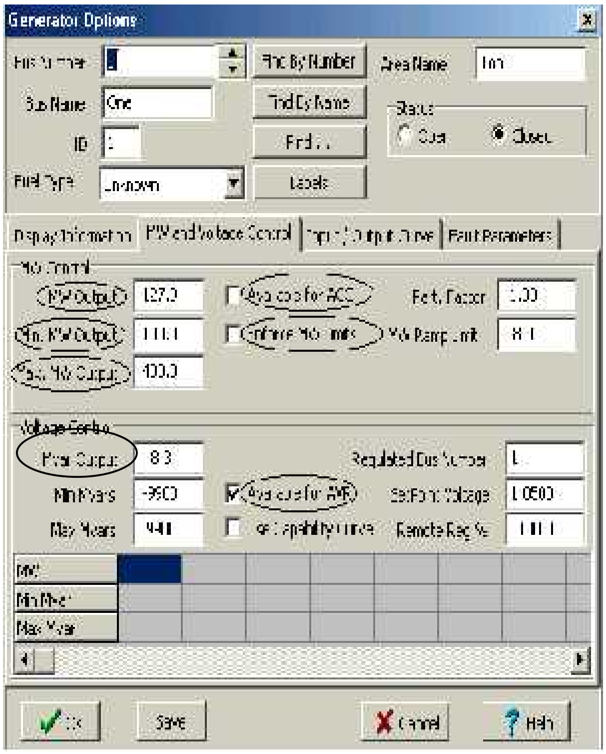
3. Load Dialog:

In the following dialog the essential value that must be filled is the load real consumed power in MW unit and its reactive power in Mvar unit.



4. Generator Dialog:

The essential data of the generator that must be entered into its dialog is marked on the following dialog:



- **MW Output:** in this space we must enter the real output power of the generator in MW unit.

- **Mvar Output:** in this space we must enter the reactive output power of the generator.

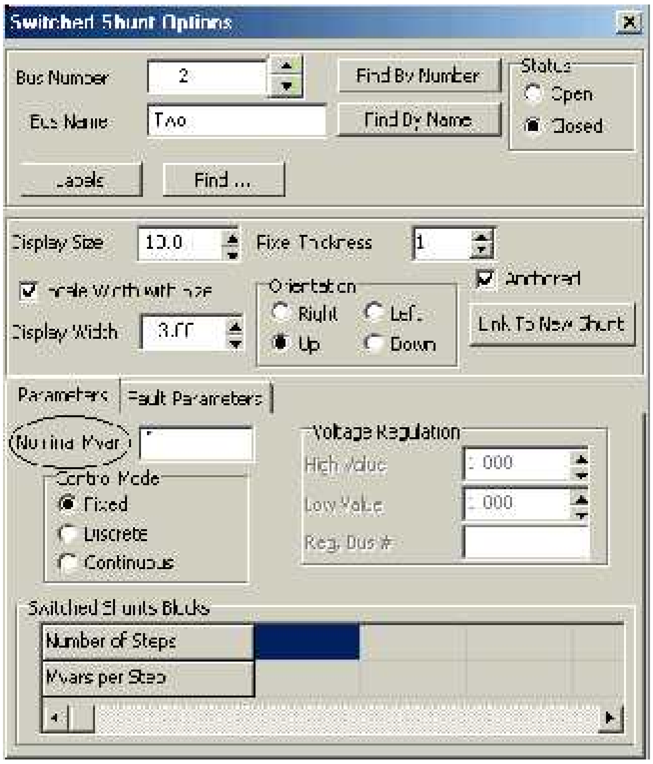
- We can specify the minimum and maximum power of the generator as a range for it.

- For each generator of the network , the following choices are available:

❖ Available for AGC.
❖ Enforce MW Limits.
❖ Available for AVR.

5. Switched Shunt Dialog:

The essential data of this element is the Nominal Mvar which must be entered for any switched shunt.



3.6 Coding System:

For any power system or electric network which has too many number of customers, we must specify a coding system to be able to reach any element of this network quickly and in a simple mode, the importance of the coding system for any network comes from that the network elements specially the loads must be classified in a sequential pattern and not in random way.

Thus; we can summary the coding system aims (targets) by the following points:

- To make it easy to reach any element of the network and very quickly.
- To divide the overall network and specially the large one into a number of areas and also zones if needed.
- To make the network more flexible.

We have many strategies that we can use in order to number the network, with considering that the Simulator allows us to use 8 digits as maximum for any element name, and here are the strategies:

- ➢ We can number the network after dividing it into many or a number of areas with respect to the substations, and then numbering the substations feeders and their loads (elements).
- ➢ We can consider the overall network as one area, and then numbering the network with respect to each substation, and then numbering the substations feeders and their loads (elements).

And for our network we use the second method of numbering, and here are the 8 digits (Name) and their meanings:

1	2	3	4	5	6	7	8

Fig 3. 1: Bus Name Word.

Cell# 1: used to specify the first letter of the substation name.
Cell# 2: used to specify the feeders of the substations.
Cell# 3: this digit may be a number or a letter:

- If it is number→ it means that it is a direct load.
- If it is letter→ it means that it is a branch.

Cells 4, 5, 6, 7, and 8: are used if there is a large number of branches and direct loads.

And we use the letter (S) for the load bus bar always.

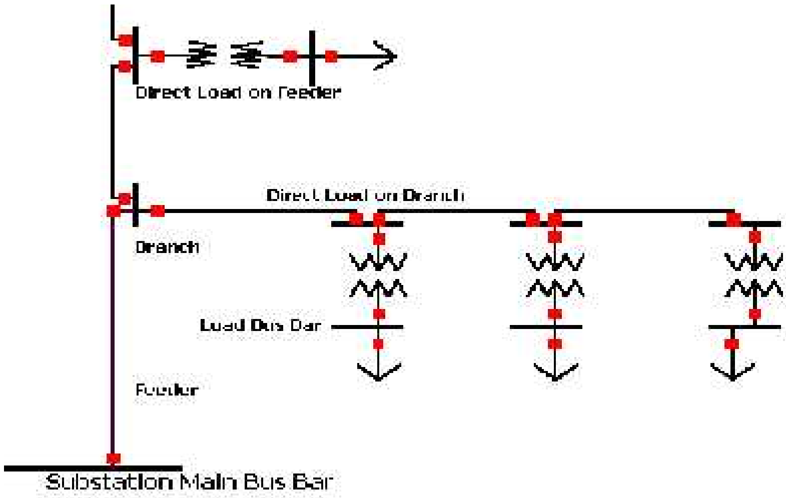


Fig 3. 2: Part from Grid Show Coding System.

Example: we can take a feeder from any substation in our network as an example of coding:-

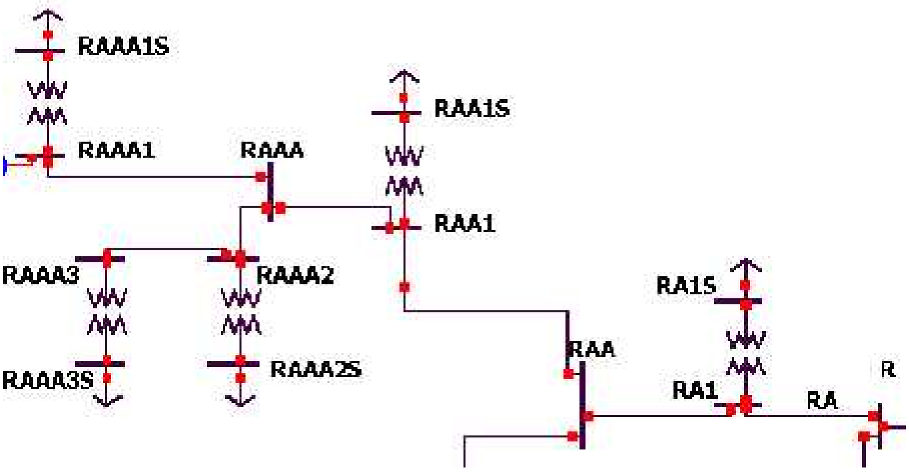


Fig 3. 3: Example.

We use the letter (S) for the load bus bar, where the load is attached.

Our Coding System Advantages:

- Very flexible and useful for the power networks specially, the small and medium ones.
- Easy and effective.
- It simplifies the network.

Disadvantages:

- Not simple for the very large networks.
- Not simple for networks with large number of branches.

Chapter Four

Electric Power Concepts

4.1 Representation of an Electric Power System.

4.2 The Per Unit System.

4.3 Principle of Operation of a Transformer.

4.4 Transmission Lines.

4.5 Transmission-Line Representation.

4.6 Loads.

4.7 Capacitors.

4.8 Power Flow Study.

4.9 Fault Analysis.

4.10 Power Flow Stability.

4.11 Voltage Regulator.

4.12 Distribution System.

4.13 SCADA System.

4.14 Other Basic Electric Power Concepts.

Chapter Four

Electric Power Concepts

4.1 Representation of an Electric Power System:

Any electric power system can be represented as a one-line diagram, and every element of this system has its own graphical symbol which is known as the symbolic representation of element of power system Fig (4.1), and to understand the one-line diagram representation of the power systems, consider the system of Fig (4.2), using the symbols of Fig (4.1) in the system in Fig (4.2), we see that this system consists of two generating stations interconnected by a transmission line, a one-line diagram. From even such an elementary network as this, it is easy to imagine the confusion that would result in making diagrams showing all three phases. The ratings of all generators, transformers and loads are specified and the voltage levels at the buses are assumed to be known. The advantage of such a one-line representation is rather obvious in that a complicated system can be represented simply. A concerted effort is made to keep the currents equal in each phase. Consequently, on a balanced system, one phase can represent all three by proper mathematical treatment. A further advantage of the one-line diagram is in the power flow studies. The one-line diagram rather becomes second nature to power system engineers as they attempt to visualize a widespread complex networks.

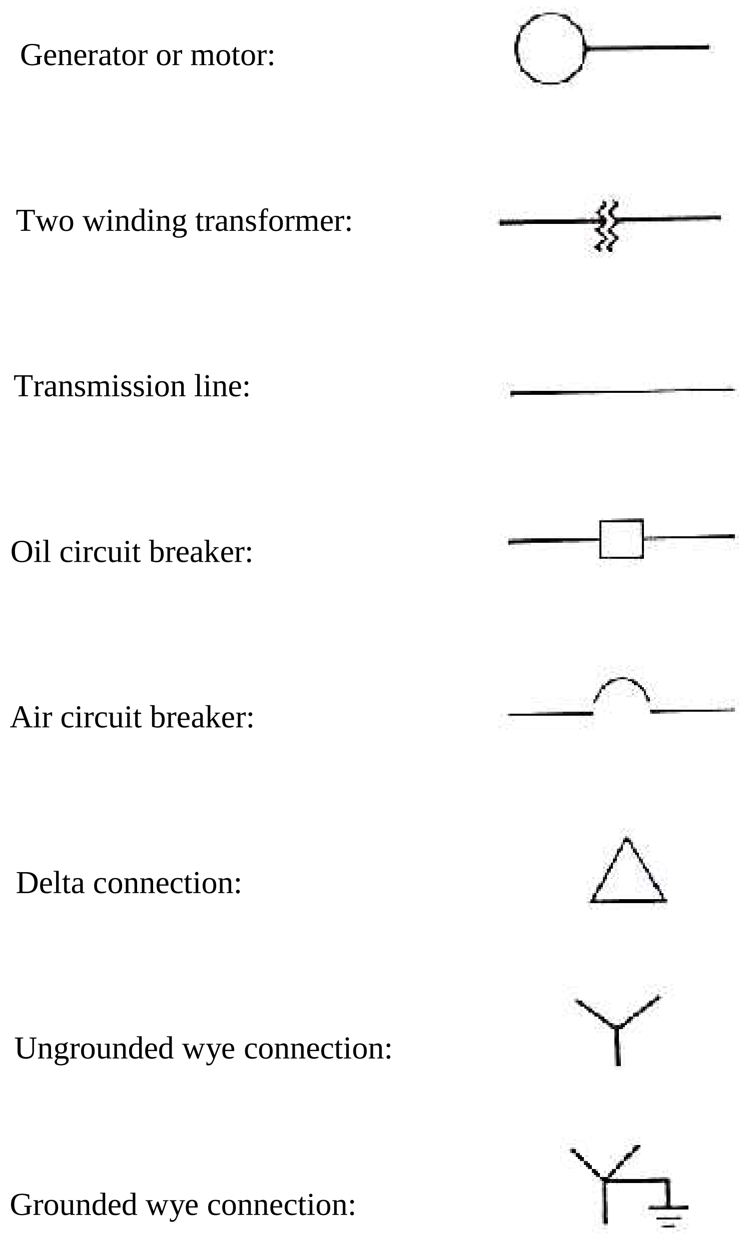


Fig 4. 1: Symbolic Representation of Elements of Power System.

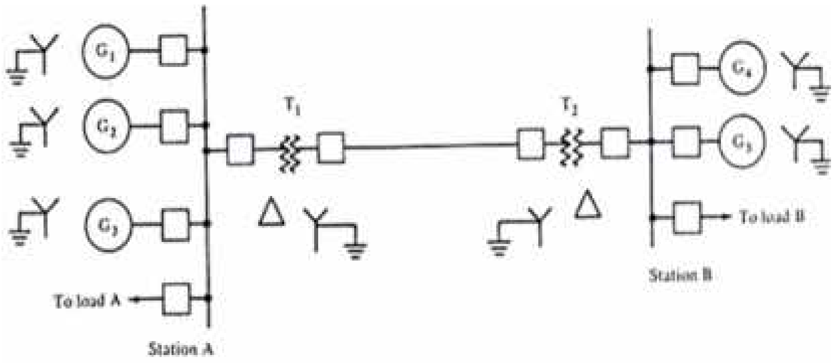


Fig 4. 2: One-line Diagram Representation of the Power System.

4.2 The Per Unit System:

The Per Unit value for any quantity is defined as the ratio of the quantity to its base value expressed as a decimal. We use per unit method when making computation on a power system network having two or more voltage classes; it is very cumbersome to convert currents to a different voltage level at each point where they flow through at transformer.

In many engineering situations it is useful to scale, or normalize, dimensioned quantities. This is commonly done in power system analysis and the standard method used is referred to as the per unit system. Historically this was done to simplify numerical calculations that were done by hand. Although this advantage was eliminated by the use of the computer, other advantages remain, including:

- ✓ Device parameters tend to fall in a relatively narrow range, making erroneous values conspicuous.

- ✓ The method is defined so as to eliminate ideal transformers as circuit components. Since the typical power system contains hundreds, if not thousands, of transformers this is a nontrivial savings.

- ✓ Related to the advantage just mentioned, the voltage throughout the power system is normally close to unity.

Like most things in life, the Per Unit system is not without its drawbacks, which include:

- ☒ The system modifies component equivalent circuits, making them somewhat more abstract. Sometimes phase shifts that are clearly present in the unscaled circuit vanish in the per unit circuit.

- ☒ Some equations that hold in the unscaled case are modified when scaled into per unit. Factors such as √3 and 3 are removed or added by the method.

The basic per unit equation is:

$$\text{Per Unit Value} = \frac{\text{Actual Value}}{\text{BaseValue}} \qquad \text{……………………..(4.1)}$$

The base value always has the same units as the actual value, forcing the Per Unit value to be dimensionless. Also, the base value is always a real number, whereas the actual value may be complex. Thinking of a complex value in polar form, the angle of the Per Unit value is the same as that of the actual.

In a three-phase system, the base KVA may either be chosen as the three-phase KVA and base voltage as line-line voltage, or the base values may be taken as the phase quantities. In either case, the Per Unit three-phase KVA and voltage on the three-phase KVA base and the Per Unit phase KVA and voltage on the KVA per phase base remain the same.

To summarize Per Unit as applied to ac circuits, we realize four quantities are involved: S, V, I and Z. We may pick base values for any two arbitrarily and calculate base values for the other two. Therefore, on a per phase basis the following relationships hold:

$$\text{Base Current} = \frac{\text{base voltamperes}}{\text{base voltage}} \quad \text{amperes} \quad ....(4.2)$$

$$I_b = \frac{S_b}{V_b} \quad \text{amperes}$$

$$\text{Base Impedance} = \frac{\text{base voltage}}{\text{base current}} \quad \text{ohms} \quad ....(4.3)$$

$$Z_b = \frac{V_b}{I_b} \quad \text{ohms}$$

$$\text{Per Unit Voltage} = \frac{\text{actual voltage}}{\text{base voltage}} \quad \text{pu.} \quad ....(4.4)$$

$$V_{pu} = \frac{V_{act}}{V_b} \quad \text{pu}$$

$$\text{Per Unit Amperage} = \frac{\text{actual current}}{\text{base current}} \quad \text{pu} \quad ....(4.5)$$

$$I_{pu} = \frac{I_{act}}{I_b} \quad \text{pu}$$

$$\text{Per Unit Impedance} = \frac{\text{Actual impedance}}{\text{base impedance}} \quad \text{pu} \quad ....(4.6)$$

$$Z_{pu} = \frac{Z_{act}}{Z_b} \quad \text{pu}$$

$$R_{pu} = \frac{R_{(\Omega)}}{Z_b} \quad pu \quad .... \; .... \quad (4.7)$$

$$X_{pu} = \frac{X_{(\Omega)}}{Z_b} \quad pu \quad .... \; .... \quad ..(4.8)$$

The Per Unit impedances of generators and transformers, as supplied from tests by manufacturers, are generally based on their own ratings. However, these Per Unit values could be referred to a new volt-ampere base according to the following equation:

$$(\text{pu impedance})_{\text{new base}} = \frac{\left[(VA)_{\text{newbase}}\right]\left[(KV)^2_{\text{old base}}\right]}{\left[(VA)_{\text{old base}}\right]\left[(KV)^2_{\text{new base}}\right]}(\text{pu impedance})_{\text{old base}} \; ....(4.9)$$

$$(Zpu)_{nb} = \frac{\left[(VA)_{nb}\right]\left[(KV)^2_{ob}\right]}{\left[(VA)_{ob}\right]\left[(KV)^2_{nb}\right]}(Zpu)_{ob}$$

If the old and the new base voltage are the same, (4.9) simplifies to

$$(\text{PU impedance})_{\text{new base}} = \frac{\text{new base voltamperes}}{\text{old base voltamperes}}(\text{PU impedance})_{\text{oldbase}} \; .....(4.10)$$

$$(Zpu)_{nb} = \frac{\left[(VA)_{nb}\right]}{\left[(VA)_{ob}\right]}(Zpu)_{ob}$$

In the project we assumed the base values as shown below:

S_b = 100 MVA = 1pu

V_b = 33 KV = 1pu   for the buses of nominal voltage = 33KV.

$$I_b = \frac{S_b}{V_b} = \frac{100\ \text{MVA}}{33\text{KV}} = 3030.30\text{A} = 1\text{pu}$$

$$Z_b = \frac{V_b}{I_b} = \frac{33\text{KV}}{3030.30\text{A}} = 10.9\Omega = 1\text{pu}$$

And S_b = 100MVA = 1pu

V_b = 6.6KV = 1pu   for the buses of nominal voltage = 6.6KV.

$$I_b = \frac{S_b}{V_b} = \frac{100\text{MVA}}{6.6\text{KV}} = 15151.5\text{A} = 1\text{pu}$$

$$Z_b = \frac{V_b}{I_b} = \frac{6.6\text{KV}}{15151.5\text{A}} = 0.4356\Omega = 1\text{pu}$$

4.3 Principle of Operation of a Transformer:

A transformer is an electromagnetic device two or more mutually coupled windings. Fig (4.3) shows a two-winding ideal transformer. The transformer is ideal in the sense that its core is lossless and is infinitely permeable, has no leakage fluxes, and the windings have no losses.

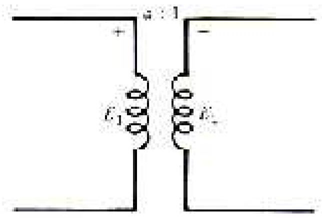


Fig 4. 3: An Ideal Transformer.

The basic components of the transformer are the core, the primary winding and the secondary winding.

4.3.1 Voltage, Current, Impedance and Transformations:

Major applications of transformers are in voltage, current, and impedance transformations, and for providing isolation (that is eliminating direct connections between electrical circuits). The voltage transformation property of an ideal transformer is expressed as:

$$\frac{V_1}{V_2} = \frac{E_1}{E_2} = a \quad \ldots\ldots\ldots\ldots\ldots\ldots(4.11)$$

Where the subscripts 1 and 2 correspond to the primary and the secondary sides respectively. This property of a transformer enables us to interconnect transmission and distribution systems of different voltage levels in an electric power system.

4.3.2 Nonideal Transformer and its Equivalent Circuit:

A nonideal (or an actual) transformer differs from an ideal transformer in that the transformer has hysteresis and eddy current (or core) losses, and has resistive (I^2R) losses in its primary and secondary windings. Furthermore, the core of a nonideal transformer is not perfectly permeable, and the transformer core requires a finite mmf for its magnetization. Also, not all fluxes link with the primary and the secondary windings simultaneously in a nonideal transformer because of leakage.

An equivalent circuit of an ideal transformer is shown in fig (4.4) when the non ideal effects of winding resistances, leakage reactances, magnetizing reactance, and core losses are included.

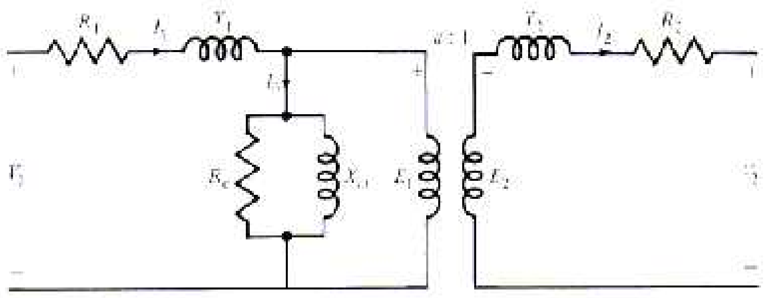


Fig 4. 4: Nonideal Transformer Equivalent Circuit.

4.3.3 Equivalent Circuits of the Transformer:

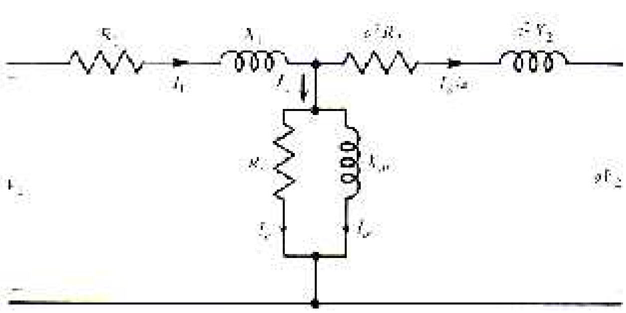


Fig 4. 5: Equivalent Circuit Referred to Primary.

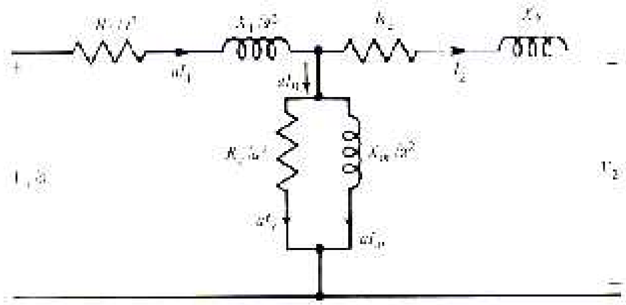


Fig 4. 6: Equivalent Circuit Referred to Secondary.

The various Symbols are:

a: turns ratio. , I_0: no-load primary current.

E_1: primary induced voltage. , R_1: resistance of the primary winding.

E_2: secondary induced voltage. , R_2: resistance of the secondary winding.

V_1: primary terminal voltage. , X_1: primary leakage reactance.

V_2: secondary terminal voltage. , X_2: secondary leakage reactance.

I_1: primary current. , I_m, X_m: magnetizing current and reactance.

I_2: secondary current. , I_c, R_c: core losses current and resistance.

The major use of the equivalent circuit of a transformer is in determining its characteristics. The characteristics of most interest to power engineers are Voltage Regulation and Efficiency.

4.3.4 Transformer Required and Calculated Data:

When we insert a transformer into a case to the Power World Simulator, the following parameters of the transformer are required (needed):

- Transformer Resistance: (calculated in per unit system).

- Transformer Reactance: (calculated in per unit system).
- Transformer Capacitance: (calculated in per unit system).
- Transformer Apparent Power: (from transformer nameplate).
- We must specify if the transformer is available for:
    - No Automatic Control.
    - A.V.R.
    - Reactive Power Control.
    - Phase Shift Control.
- Also we must specify if the transformer status is ON or OFF.

Transformer Calculation:

First of all we must specify or suppose a base system such as:

S_b= 100MVA = 1 pu

V_b= 6.6KV = 1 pu

$$I_b = \frac{S_b}{V_b} = \frac{100\text{MVA}}{6.6\text{KV}} = 15151.5\text{A.} = 1\,\text{pu}$$

$$Z_b = \frac{V_b}{I_b} = \frac{6.6\text{KV}}{15151.5\text{A}} = 0.4356\Omega = 1\,\text{pu}$$

For example we take a transformer with the following parameters:

6.6KV/0.4KV

$S_{(old)}$ = 160KVA

$P_{0\ (\text{Full load losses})}$ = 2.16KW (from appendix B).

$Z_{(old)}$ = 0.04Ω (from appendix B).

For the above transformer find its parameters (Resistance and Reactance) in per unit system?

Solution:

Since the transformer nameplate values differ from the base values (new system), we must make the suitable transformation and calculation:

$$P_{o\,\text{(Full load losses)}} = 3 \times I^2 \times R \Longrightarrow R = \frac{P_o}{3I^2} = \frac{2.16KW}{3(14A)^2} = 3.67\Omega$$

$$\rightarrow R_{(pu)} = \frac{R}{Z_b} = \frac{3.67\Omega}{0.4356\Omega} = 8.43$$

And to find the transformer Reactance, we must find new value of the base Impedance using (4.14) relation:

$$(\text{pu impedance})_{\text{new base}} = 0.04\left(\frac{6.6KV}{6.6KV}\right)^2\left(\frac{100MVA}{160KVA}\right) = 25$$

$$X_{(pu)} = \sqrt{\left(Z_{(b\,new)}\right)^2 - \left(R_{(pu)}\right)^2}$$

$$= \sqrt{25^2 - 8.43^2} = 23.5$$

4.4 Transmission Lines:

The transmission lines are classified as short, medium, and long lines. In short line, the shunt effects are negligible. Often, this approximation is valid for lines up to 80Km long.

In a medium line, the shunt capacitances are lumped at a few predetermined locations along the line. A medium line may be anywhere between 80 to 240Km in length. Lines longer than 240Km are considered as long lines which are represented by (uniformly) distributed parameters.

4.4.1 The Transmission Line Resistance:

The first transmission line parameter to be considered is the resistance of the conductor. Resistance is the cause of I^2R loss in the line and also results in an IR-type voltage drop. The dc resistance R of a conductor of length L and area of cross section A is given by:

$$R = \rho \frac{L}{A} \quad ....(4.12)$$

Where ρ is the resistivity of the conductor in Ω-m.

The dc resistance is affected only by the operating temperature of the conductor, linearly increasing with the temperature.

The temperature dependence of a resistance is given by:

$$R_2 = R_1 (1+\alpha [T_2-T_1]) \quad ……………(4.13)$$

Where R_1 and R_2 are the resistances at temperatures T_1 and T_2, respectively. And α is defined as the temperature coefficient of resistance. The resistivities and temperature coefficient of certain materials are given in table (4.1).

Table 4. ١:Values of ρ and α

Material	Resistivity, ρ, at 20°C (μΩ-cm)	Temperature Coef α, at 20°C
Aluminum	2.83	0.0039
Brass	6.4–8.4	0.0020
Copper		
Hard-drawn	1.77	0.00382
Annealed	1.72	0.00393
Iron	10.0	0.0050
Silver	1.59	0.0038
Steel	12–88	0.001 0.005

4.4.2 The Transmission Line Inductance:

The next parameter of interest is the inductance of the transmission line. For a three phase line, having equilaterally spaced conductors the per phase inductance is:

$$L = \frac{\mu_\circ}{8\Pi}\left(1 + 4\ln\left(\frac{d}{r}\right)\right) \quad H/m \text{ ....(4.13)}$$

Where:

$\mu_0 = 4\ \Pi \times 10^{-7}$ H/m (the permeability of free space).

d is the distance between the centers.

r is the radius of the conductors.

In practice, the three conductors of a three phase line are seldom equilaterally spaced. Thus the spacing d in the previous equation is replaced by the equivalent spacing d_e obtained by:

$$d_e = (d_{ab}\ d_{bc}\ d_{ca})^{1/3} \quad \text{……………………….(4.14)}$$

where the distances d_{ab} and so on, are shown fig (4.7) below:

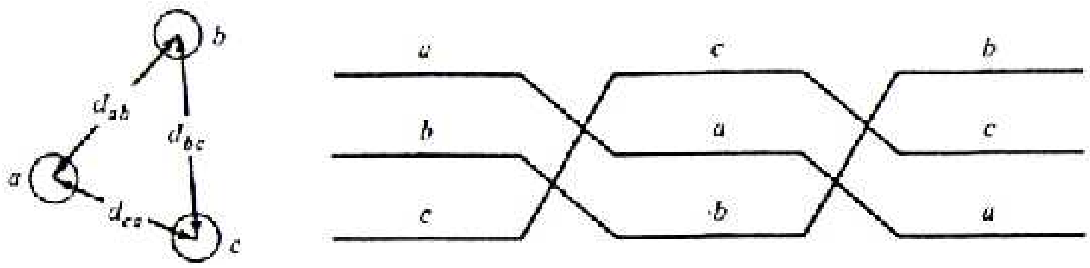


Fig 4. 7: Transposition of Unequally-Spaced Three-Phase Transmission Line Conductors.

From equation (4.13) we conclude the following relations:

- **L α d** ; When r= constant; If d increases. X_L will increase.
- **L α 1/r** ; When d= constant; If r increases. X_L will decrease.

4.4.3 The Transmission Line Capacitance:

The last parameter of interest is the shunt capacitance of the transmission line. For a three phase line, having equilaterally spaced conductors the per phase capacitance is:

$$C = \frac{2\pi\varepsilon_o}{\ln(d/r)} \quad F/m \ldots\ldots\ldots\ldots\ldots\ldots(4.15)$$

Where ε_o is the permittivity of free space.
For unequal spacing between the conductors d in (4.14) is replaced by d_e.

From equation (4.15) we conclude the following relations:

- **C α 1/d** ; When r= constant; If d increases. X_C will decrease.

♦ **C α r** ; When d= constant; If r increases. X_C will increase.

4.5 Transmission-Line Representation:

4.5.1 Short Transmission Line:

For a transmission line up to 80Km long, shunt effects, due to capacitance and leakage resistance are negligible. And is represented by the lumped parameters R and L, as shown in fig (4.8).

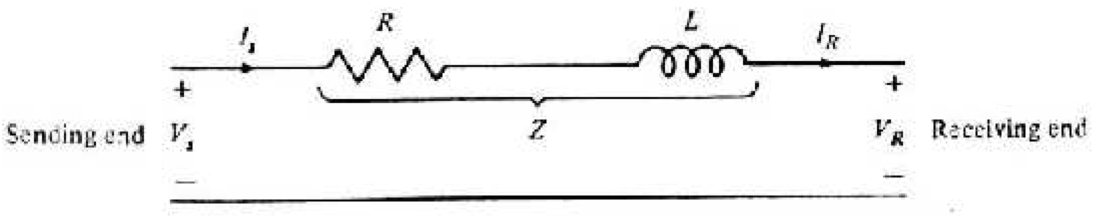


Fig 4. 8: Representation of a Short Transmission Line (per phase basis).

The line is shown to have two ends: the sending end at the generator end and the receiving end at the load end.

$$\text{Transmission Line Regulation} = \frac{|V_R(\text{no load})| - |V_R(\text{load})|}{|V_R(\text{load})|} \times 100\% \quad ...(4.16)$$

$$\text{Transmission Efficiency} = \frac{\text{power at receiving end}}{\text{power at sending end}} \quad ....(4.17)$$

Example:

For a line of ACSR type with a cross section area of 95mm^2 and length 200m. Find it's resistance and reactance in P.U..

Solution:

From appendix B we take the line resistance and reactance as follow:

R= 0.273Ω/Km.

X= 0.330Ω/Km.

And its capability= 2.9MVA.

And the base system values are:

S_b= 100MVA.

V_b= 6.6KV.

I_b= 15151.5A.

Z_b= 0.4356Ω.

$R_{(P.U.)}$ = R*Line Length/Z_b

= 0.273*0.2/0.4356 = 0.125

$X_{(P.U.)}$ = X*Line Length/Z_b

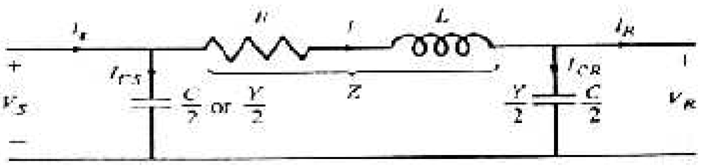
= 0.330*0.2/0.4356 = 0.152

4.5.2 The Medium Transmission Line:

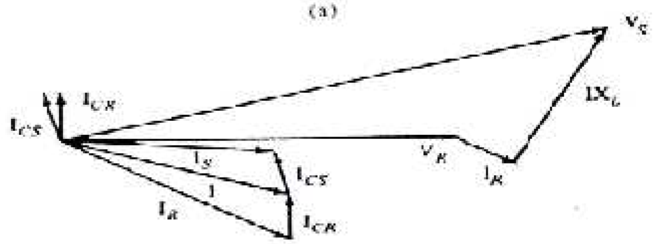
Is considered to be up to 240Km long. In such a line the shunt effect due to the line capacitance is not negligible. Two representations for the medium-length line:

1. Nominal Π circuit of the transmission line:

As shown in fig (4.9).



(a)

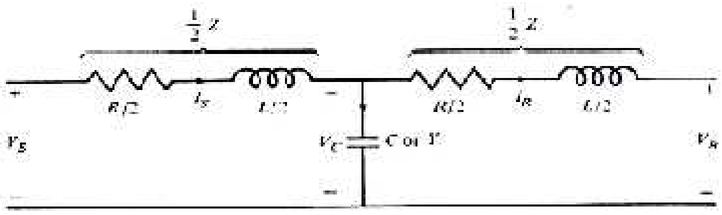


(b)

Fig 4. 9: (a) A nominal- Π circuit (b) Corresponding Phasor Diagram.

2. Nominal-T circuit of the transmission line:

As shown in fig (4.10).



(a)

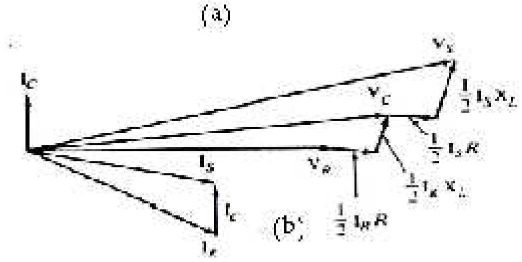


Fig 4. 10: (a) A nominal-T circuit. (b) Corresponding Phasor Diagram.

4.5.3 The Long Transmission Line:

Is considered to be over 240Km long. Parameters of long lines are distributed over the entire length of the line. As shown in fig (4.11).

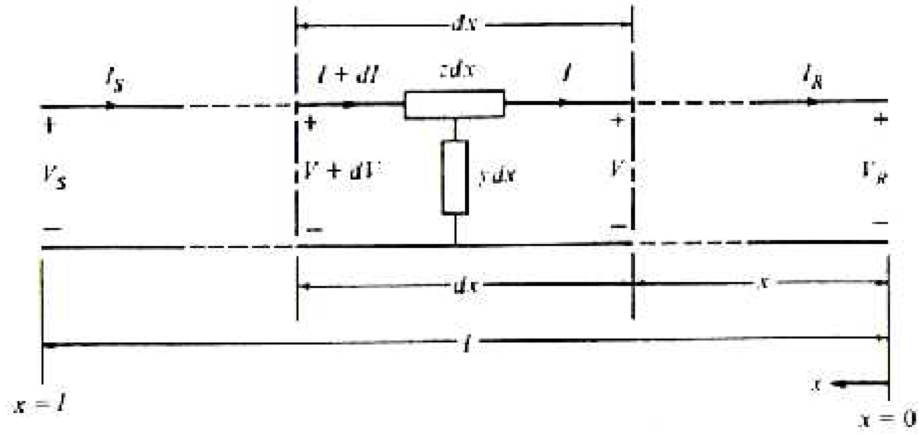


Fig 4. 11: Distributed Parameter Long Line.

4.6 Loads:

Any device that utilizes electric power can be said to impose a load on the system. Viewed from the source, all loads can be classed as Resistive, Inductive, Capacitive, or some combination of them, loads may also be time variant.

The composite load on a system has a predominant resistive component and small net inductive component. Inductive loads such as induction motors are far more prevalent than capacitive than loads. Consequently, to keep the resultant current as small as possible, capacitors are usually installed in quantities adequate to balance most of the inductive current.

4.7 Capacitors:

The main aim of the capacitors in the power systems (networks) is to reduce the inductive current (Power Factor correction), capacitors can be grouped into either transmission or distribution classes. In either case, they should be installed electrically as near to the load as possible for maximum effectiveness. When applied properly, capacitors balance out most of the inductive component of current to the load, leaving essentially a unity Power Factor load. The result is a reduction in size of the conductor required to serve a given load and a reduction in I^2R losses. Static capacitors may be used at any voltage, but practical considerations impose an upper limit of a few kilovolts per unit, therefore, high-voltage banks must be composed of many units connected in parallel. High-capacity transmission capacitor banks should be protected by a high-side circuit breaker and its associated protective relays. Small distribution capacitors may be vault-or pole-top-mounted and protected by fuses.

Industrial loads occasionally require very large amounts of Power Factor correction, varying with time and the industrial process cycle. The synchronous condenser is ideally suited to such an application. Its contribution of either capacitive or inductive current can be controlled very rapidly over a wide range, using automatic controls to vary the excitation current. Physically, it is very similar to a synchronous generator operating at a leading Power Factor, except that it has no prime mover. The synchronous condenser is started as a motor and has its losses supplied by the system to which it supplies capacitive current.

4.8 Power Flow Study:

Power flow studies, commonly known as load flow studies, are extremely important in evaluating the operations of power systems, controlling them, and planning for future expansions. Basically, a power flow study yields the real and reactive power and phasor voltage at each bus on the system, although a wealth of information is available from the printout of a digital computer solution of typical power-flow study conducted by a power company. As a consequence of a power-flow study, we can optimize the system operation with regard to system losses and load distribution. The effect of temporary loss of generation capacity or transmission circuits can also be investigated via a power flow study.

Whereas the principles of a power-flow study are straightforward, a realistic study relating to a power system can be carried out only with the digital computer. In such a case, numerical computations are carried out in a systematic manner by an iterative procedure. Two of the commonly used numerical methods are the Gauss-Seidel method and the Newton Raphson method.

4.9 Fault Analysis:

Under normal conditions, a power system operates as a balanced three phase ac system. A significant departure from this condition is often caused by a fault. A fault may occur on a power system for a number of reasons, some of the common ones being lightning, high winds, snow, ice, and frost. Faults give rise to abnormal operating conditions, usually excessive currents and voltages at certain points on the system. Protective equipment is used on the system to guard against abnormal conditions. For example, the magnitudes of fault currents determine the interrupting capacity of the circuit breakers and settings of protective relays. Faults may occur within a generator or at the terminals of a transformer. However, here we will be mostly concerned with faults on transmission lines.

Various types of faults that occur on a transmission line are depicted in Fig (4.12). In the order of frequency of occurrence are the types of faults shown in Fig (4.12). The balanced three phase short circuit is the least common but most severe fault, and therefore determines the rating of the circuit breaker. Consequently, it is almost invariably included in fault studies. In summary, a fault study includes the following:

1. Determination of maximum and minimum three phase short circuit currents.
2. Determination of unsymmetrical fault currents, as in single line-to-ground, double line-to-ground, line-to-line, and open circuit faults.
3. Determination of ratings of circuit breakers.
4. Investigating schemes of protecting relaying.
5. Determination of voltage levels at strategic points during the fault.

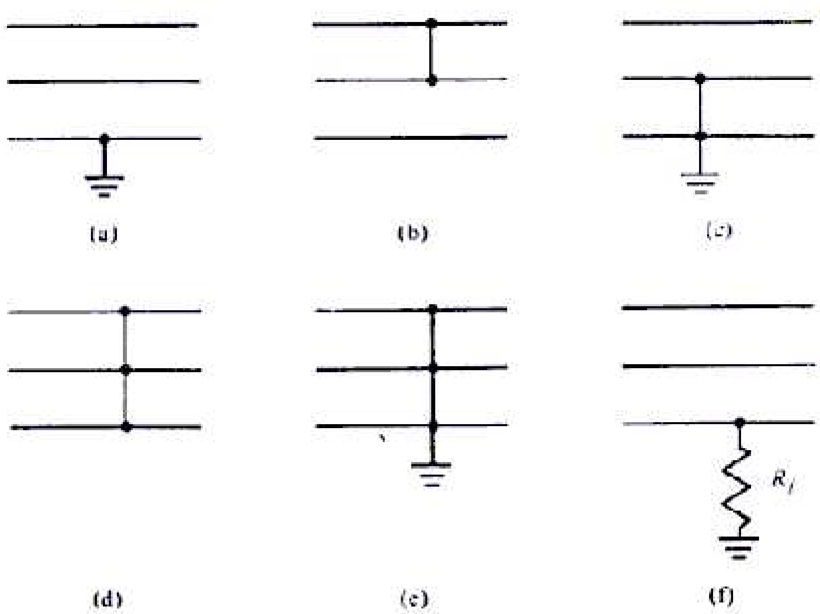


Fig 4. 12: Various Types of Faults: (a) Line-to-Ground; (b) Line-to-Line; (c) Line-to-Line-to-Ground, or Double-Line-to-Ground; (d) Balanced Three-Phase; (e) Three-Phase-to-Ground; (f) Line-to-Ground through a Fault Resistance R_f.

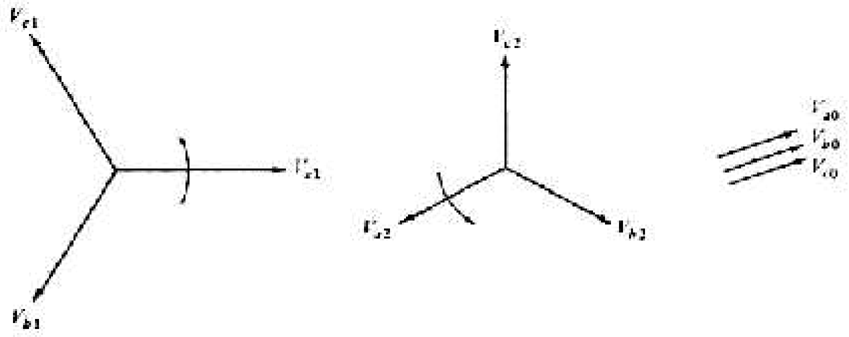
4.9.1 Balanced Three-Phase-Short Circuit:

Balanced three phase fault calculations can be carried out on a per phase basis so that only single phase equivalent circuits are used. Invariably, the circuit constants are expressed in per unit, and all calculations are made on a per unit basis. In short circuit calculations, we often evaluate the short-circuit MVA, which is equal to $\left(\sqrt{3} \times V_L \times I_F \times 10^6\right)$ where V_L is the nominal line voltage and I_F is the fault current.

4.9.2 Unbalanced Faults:

Method of Symmetrical Components:

The preceding method of fault calculations is valid only for balanced three phase short circuits. However, for unsymmetrical faults such as line-to-line and line-to-ground faults (which occur more frequently than three phase short circuits), the method of symmetrical components is used. The method is based on the fact that a set of three-phase unbalanced phasors (voltages and currents) can be resolved into three sets of symmetrical components, which are termed the positive-sequence, negative- sequence, and zero-sequence components. The phasors of a set of positive-sequence components have a counter-clockwise phase rotation (or phase sequence), abc; and the zero-sequence components are all in phase with each other. These sequence components are represented geometrically in Fig (4.13), and can be used to form the unbalanced system of Fig (4.14). In other words, the unbalanced system shown in Fig (4.14) can be resolved into its symmetrical components shown in Fig (4.13). The positive-sequence component is designated with a subscript 1. The subscript 2 and 0 are used for the negative and zero-sequence components, respectively.



(a) **(b)** **(c)**

Fig 4. 13: (a) Positive-Sequence Components; (b) Negatives-Sequence Components; (c) Zero-Sequence Components.

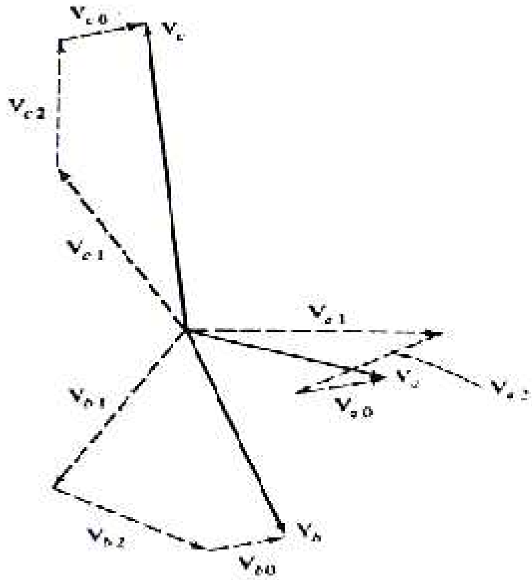


Fig 4. 14: A three–Phase Unbalanced System and Its Symmetrical Components.

4.10 Power Flow Stability:

It is mean by a power system stability that the system will remain in operating equilibrium, or synchronism, while disturbances occur on the system. The three types of stability are:

- Steady-State Stability.
- Dynamic Stability.
- Transient Stability.

Steady State Stability essentially relates to the maximum power capability of a synchronous machine when the load on the machine is gradually increasing, until the machine pulls out of synchronism. The power-angle characteristics of the cylindrical-rotor and salient-rotor machines help to obtain the steady-state stability limit.

Dynamic Stability relates to small disturbances occurring on the system, there by producing oscillations. If these oscillations are of successively smaller amplitudes, the system is considered dynamically stable. If the oscillations grow in amplitude, the system is dynamically unstable. The source of this type of instability is usually an interaction between control systems, and may be slow in becoming apparent. Times of the order of 10 to 30 s are considered sufficient to asses the dynamic stability of the system.

Transient Stability relates to a sudden change of the load, introducing a large disturbance on the system. A large disturbance on the system causes rather large changes in rotor speeds, power angles, and power transfers. The stability of this transient response is usually evident in less than 1 s for a generator close to the disturbance.

Invariably, stability studies of multimachine power systems are carried out on a digital computer.

4.11 Voltage Regulator:

To provide a constant voltage to the customer, a voltage regulator is usually connected to the output side of the step-down transformer.

It is a special type of 1:1 transformer with several discrete taps of a fractional percent each over voltage range of ±10%. A voltage- sensing device and automatic control circuit will position the tap contacts automatically to compensate the low-side voltage for variation in transmission voltage. In many cases the same effect is accomplished by incorporating the regulator and its control circuits into the step-down transformer, resulting in a combination device called a load tap changer (LTC) and the process is known as tap changing under load (TCUL).

4.12 Distribution System:

A low-voltage distribution system is necessary for the practical distribution of power to numerous customers in a local area.

A distribution system resembles a transmission system in miniature, having lines, circuit breakers, and transformers, but at lower voltage and power levels.

Single-phase distribution circuits are supplied from three-phase transformer banks, balancing the total load on each phase as nearly as possible. Three-phase distribution circuits are erected only to serve large industrial or motors loads.

4.13 SCADA System:

SCADA (supervisory control and data acquisition) is a category of software application program for process control, the gathering of data in real time from remote locations in order to control equipment and conditions. SCADA is used in power plants as well as in oil and gas refining, telecommunications, power distribution, energy management, transportation, and water and waste control.

SCADA systems include hardware and software components. The hardware gathers and feeds data into a computer that has SCADA software installed. The computer then processes this data and presents it in a timely manner. SCADA also records and logs all events into a file stored on a hard disk or sends them to a printer. SCADA warns when conditions become hazardous by sounding alarms.

SCADA systems are successful multipurpose utility management and control tools. The state of the art in SCADA has advanced so rapidly, that even experienced utility engineers are not fully aware of all functions provided by SCADA.

The SCADA system linked together the city's power options to use the most efficient power option to meet the power demands on the city's municipal power system. The SCADA system is also used by neighboring communities to control their power systems.

SCADA systems have many functions, and modern SCADA systems may incorporate the following functions:

- **System Monitoring**
    - ✓ Remote status (Digital)
    - ✓ Pulse accumulation
    - ✓ Remote status (Analog)
    - ✓ Status sequence of events
    - ✓ Analog sequence of events

- **System Control**
    - ❖ Electrical breaker control
    - ❖ Voltage regulation
    - ❖ Tap changer control
    - ❖ Capacitor control
    - ❖ Loss reduction
    - ❖ Miscellaneous device control
    - ❖ Load management
    - ❖ Fault isolation
    - ❖ Service restoration

- **System Management**
    - ✓ System data/status archiving

- ✓ System analysis
- ✓ Sequence of events analysis
- ✓ System loss reduction
- ✓ Activity analysis

- **Demand Side Management**
  - ❖ Load shedding/Duty cycling
  - ❖ Voltage control
  - ❖ Supply Side Management
  - ❖ Optimal heat rate/unit commitment

SCADA System Advantages:

- The electric power network will become more controllable and flexible.
- Allows us to control and monitor the networks from far distances.
- By using SCADA System, we can receive signals tell us if hazards occurred in our system.
- It allows us to connect two or more electric systems together, and control them.

4.14 Other Basic Electric Power Concepts:

- ❖ ***Power Systems:*** means the power stations, feeders, substations and apparatus whereby electrical energy, is made available to the customers points of supply.

- ❖ ***Low-Voltage:*** means a nominal voltage less than 0.4KV.

- ***Medium-Voltage:*** means a nominal voltage between 6.6KV and 115KV.

- ***High-Voltage:*** means a nominal voltage between 115KV to 230KV.

- ***Power Station:*** means a site on which electrical energy, is generated and shall also comprise all works necessary or incidental thereto, including buildings and all apparatus up to the point where energy is ready for distribution. It may or may not include any substation situated within the precincts of the power station, as determined.

- ***Station:*** means a power station or a substation.

- ***Substation:*** means a site on which is situated any transforming, switching or linking apparatus forming part of the power system and on which no active power generating aquipment is situated other than auxiliary generating sets. The term substation includes distribution stations and switching stations.

- ***BusBar:*** means a conductor or group of conductors that serve as a common connection for two or more electric circuits within a station.

- ***Feeder:*** means a line or cable from power stations or substations.

- ***Cables:*** means a feeder, and includes the terminations.

- ***Circuit Breaker:*** means a device designed to make or break electric current both under normal and fault conditions.

Chapter Five

Data Analysis

5.1 Introduction.

5.2 Network Insertion.

5.3 Description of the Existing Network.

5.4 Loss Reduction Proposed Projects.

5.5 Comparison between the Scenarios.

Chapter Five

Data Analysis

5.1 Introduction:

In general, the power loss in electrical system can be classified into two main categories:

1) Technical losses.
2) Non–technical losses.

1-<u>Technical losses:</u>

a) The technical power loss: is the loss resulted from the generation, transmission and distribution of electricity to consumers.

b) The important loss: comes from penalty added to the consumers invoice, due to the low power factor (P.F.). The inductive loads connected to the electric supply, like motors and fluorescent lamps, create low P.F..
The acceptable power factor to the electricity suppliers is 0.92. When the P.F. is less than 0.92, the consumers penalize by a certain percentage depend upon the connected P.F..

c) The loss that resulted from the inaccuracy of KWh meters with the well known meters manufacturers.

d) This losses is classified into two types which are:

- Load Losses ($3I^2R$).
- No load Losses.

2-<u>Non-technical losses:</u>

This loss resulted from illegal methods that the consumers use it to avoid paying the cost of electricity they consumed.

This problem can be avoided by:

1. Securing the KWh meters by fixing the meter in a secured transparent box.
2. Hiding the connection to the consumers KWh meters in a way that the consumers cannot get an access to the cables.
3. Employing a technical staff for the periodic check up of the KWh meters and the connections to consumers.

5.2 Network Insertion:

5.2.1 Data Collection:

5.2.1.1 Single Line Diagram:

Hebron Municipality provided us with the single line diagram. It contains transformers locations & sizes, lines & cables types and lengths. A representation of the single line diagram is shown in appendix A.

5.2.1.2 Loads Data:

Hebron Municipality also provided us with a table contains the loads current, shown in appendix C, which represents the actual current for each load.

5.3 Description of the Existing Network:

5.3.1 Network Substations and Feeders Loading:

The present status of the network can be summarized by the following table, which contains actual data of the loads, transformers and conductors for each feeder (zone) in the grid.

Table 5. 1: Zones (Feeders) Loads, Installed Capacity of Transformers

Substation	**Zone No.**	**Zone (Feeder) Name**	**Load (MW)**	**Load (Mvar)**	**Installed Capacity of Distribution Tr-rs (MVA) ***	**Total Length of Lines and Cables (Km)**	**Tr-rs Loading (%)**	**Load (%)**	**Installed Capacity of Distribution Tr-rs (%)**
Alduhdah	2	Duh-F.Hawa	3.44	2.13	7.01	10.20	58	6	6
	1	Duh-Halhul	3.28	2.04	6.39	13.10	60	6	5
	3	Duh-Mazroq	4.17	2.59	11.20	11.50	44	8	9
	4	Duh-R.Jorah	3.54	2.19	8.63	7.00	48	7	7
Total1			**14.43**	**8.95**	**33.23**	**41.80**	**51**	**27**	**27**
Alfahs	14	Fah-B.Tarseep	6.02	3.74	17.33	5.59	41	11	14
	15	Fah-Berin	2.49	1.55	6.89	2.22	43	5	5
	12	Fah-J.Johar	4.7	2.92	8.34	4.16	66	9	7
	13	Fah-O.Dalyeh	5.54	3.45	17.9	12.00	36	10	14
Total2			**18.75**	**11.66**	**50.46**	**23.97**	**44**	**35**	**40**
Alharayek	10	Har-Hawoz1	3.82	2.31	7.26	13.00	62	7	6
	9	Har-W.Hariyya	3.41	2.11	2.02	8.45	46	6	2

	11	Har-Hawoz2	1.70	1.05	8.96	4.10	22	3	7
Total3			**8.93**	**5.47**	**18.23**	**25.55**	**58**	**17**	**15**
Alras	7	Ras-B.Zawyeh	4.14	2.57	8.68	7.00	56	8	7
	6	Ras-Husein	3.39	2.11	8.75	6.50	46	6	7
	8	Ras-K.Hadoor	0.28	0.18	0.83	1.20	40	1	1
	5	Ras-O.Farah	3.08	1.91	6.72	18.30	54	6	5
Total4			**10.89**	**6.77**	**24.90**	**33.00**	**51**	**21**	**20**
Total			**53.00**	**32.85**	**126.81**	**124.30**	**50**	**100**	**100**

* Tr-rs: Transformers

The next figures represent the load, distribution transformers capacity and transformers loadings for each zone in the system.

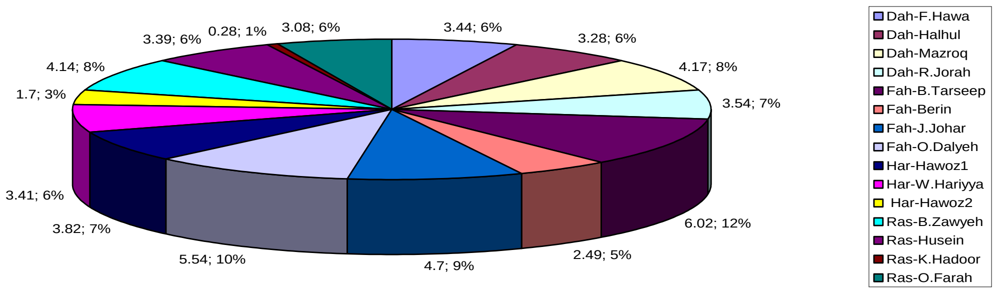


Fig 5. 1: Zones (Feeders) Loads MW and % of Total.

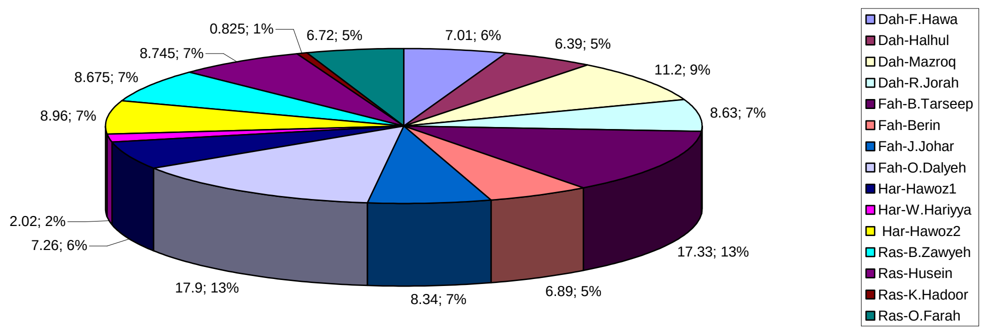


Fig 5. 2: Installed Distribution Transformers MVA per Zone (Feeder).

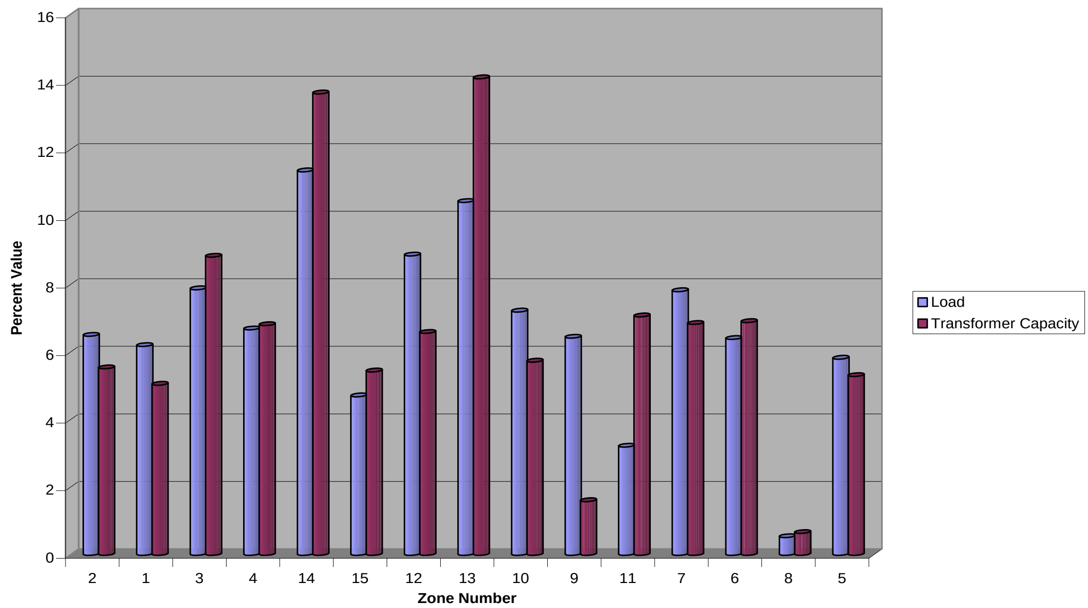


Fig 5. 3: Zones Load % and Installed Capacity %.

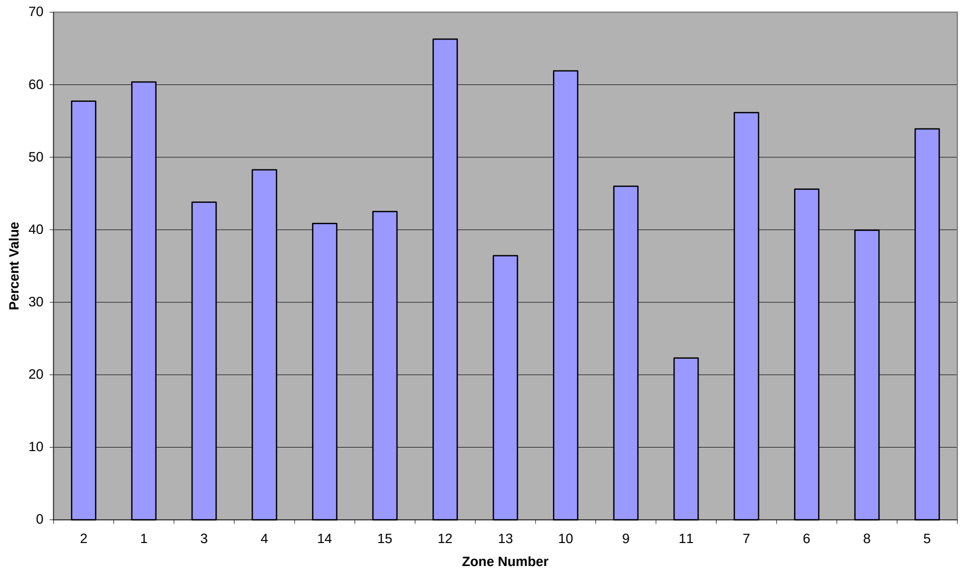


Fig 5. 4: Transformers Loading%.

It is noticed that the loading of the transformers in Hebron network ranges from **22%** in zone 11 (feeder Har-Hawoz2) to **66%** in zone 12 (feeder Fah-J.Johar), the total average loading of the network transformers is **50%**.

5.3.2 Load Factor of the System (L.F.):

The yearly Load Factor is defined as the relationship between the average demand and the maximum demand over the period of one year. It is given by:

$$\frac{(\text{Total energy} / 8760)}{\text{Maximum Demand}} \quad \ldots\ldots(5.1)$$

The load factor is usually expressed as a percentage. Thus if the maximum demand and the Load Factor are known then the average load can be calculated.

To calculate the L.F. for Hebron system :

Total energy = 194.3GWh

Maximum Demand = 53MW

By using (5.1)

L.F. = 42%

5.3.3 Loss Load Factor (L.L.F.):

Whilst the annual energy supplied by a feeder can be calculated using the Load Factor, the energy losses of that feeder will vary with the square of the load on the feeder. *The yearly energy losses can clearly not be calculated by simply multiplying the power loss at average load by 8760 hours for one year*. The Loss Load Factor (L.L.F.) relates the annual energy losses to the peak power losses as follows:

Annual Energy Losses = Loss Load Factor x Peak Power Losses x 8760 ....(5.2)

The relationship between load factor and loss load factor has been widely studied and the following empirical formula is widely accepted:

$$\mathbf{L.L.F. = 0.3\,LF + 0.7\,LF^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.3)$$

From the (5.3) we found the L.L.F. for Hebron system = ***25%***.

5.3.4 Load Flow Results and Losses Calculations:

All data has been entered to the load flow program to derive the losses for each system component, and the results are illustrated in the following tables.

Table 5. 2: Existing Power Losses for Each Component in the System

System Component	Power Losses (MW)	% Of Total Power Losses	Energy Losses (MWh)	% Of Total Energy Losses
Losses in 6.6KV Lines & Cables	7.190	84.00	15,746.1	77.9
Transformers Losses	1.140	13.30	2,496.6	12.3
Transformers No Load Losses	0.226	2.64	1,979.8	9.8
Total Losses	8.556	100.00	20,222.5	100.0
Total Peak at the Connection Points (MW)	61			
Total Load (MW)	53			
Losses as % of Peak	14			
Losses as % of Load	16.1			
Total Purchase (GWh)	194.3			
Losses as % of Purchase	10.4			

The substations and feeders share of power and energy losses is illustrated in the next two tables.

Table 5. 3: Power Losses (MW) in Each Zone for Each Component Type

Zone Number	Zone Name	Losses in 6.6KV Lines and Cables	6.6/0.4KV D.T.* Losses	33/6.6KV P.T. ** Losses	Total Losses (MW)	Total Load (MW)
2	Duh-F.Hawa	0.195	0.048		0.243	
1	Duh-Halhul	0.450	0.054		0.504	
3	Duh-Mazroq	3.734	0.126		3.860	
4	Duh-R.Johar	0.166	0.040		0.206	
	Total Duhdah	**4.545**	**0.268**	**0.134**	**4.947**	**14.42**
14	Fah-B.Tarseep	0.268	0.049		0.317	
15	Fah-Berin	0.015	0.021		0.036	
12	Fah-J.Johar	0.109	0.073		0.182	
13	Fah-O.Dalyeh	0.219	0.046		0.265	
	Total Fahs	**0.611**	**0.189**	**0.143**	**0.943**	**18.75**
10	Har-Hawoz1	0.639	0.075		0.714	
9	Har-W.Hariyya	0.524	0.039		0.563	

11	Har-Hawoz2	0.009	0.019		0.028	
	Total Harayek	**1.172**	**0.133**	**0.082**	**1.387**	**8.93**
7	Ras-B.Zawyeh	0.069	0.051		0.120	
6	Ras-Husein	0.141	0.033		0.174	
8	Ras-K.Hadoor	0.001	0.002		0.003	
5	Ras-O.Farah	0.654	0.041		0.695	
	Total Ras	**0.865**	**0.127**	**0.066**	**1.058**	**10.89**
	Total	**7.193**	**0.717**	**0.425**	**8.335**	**53.00**

* D.T.: Distribution Transformer.

** P.T.: Power Transformer.

Fig (5.5) shows the sharing of each system component in power losses (MW & %) and Fig (5.6) shows the distribution of losses and load among the four substations.

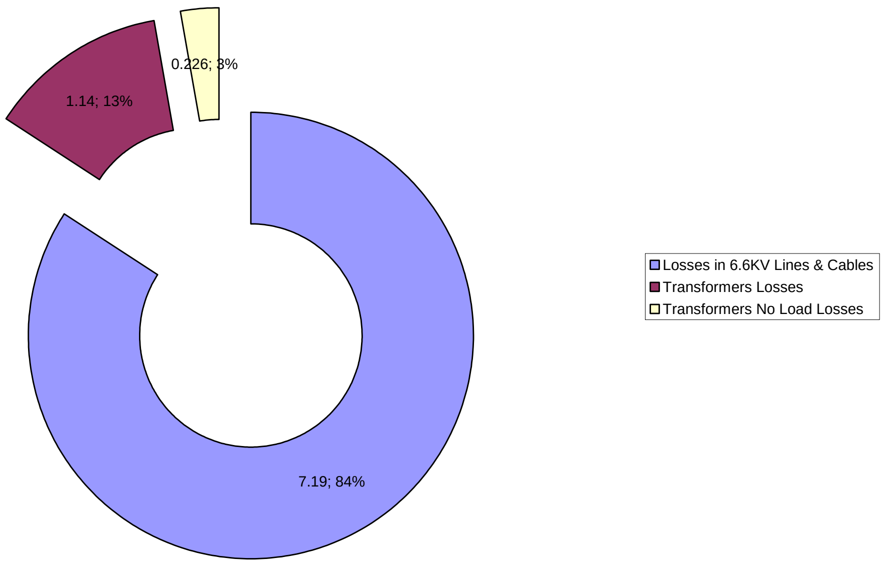


Fig 5. 5: Losses per Component Type (MW, %).

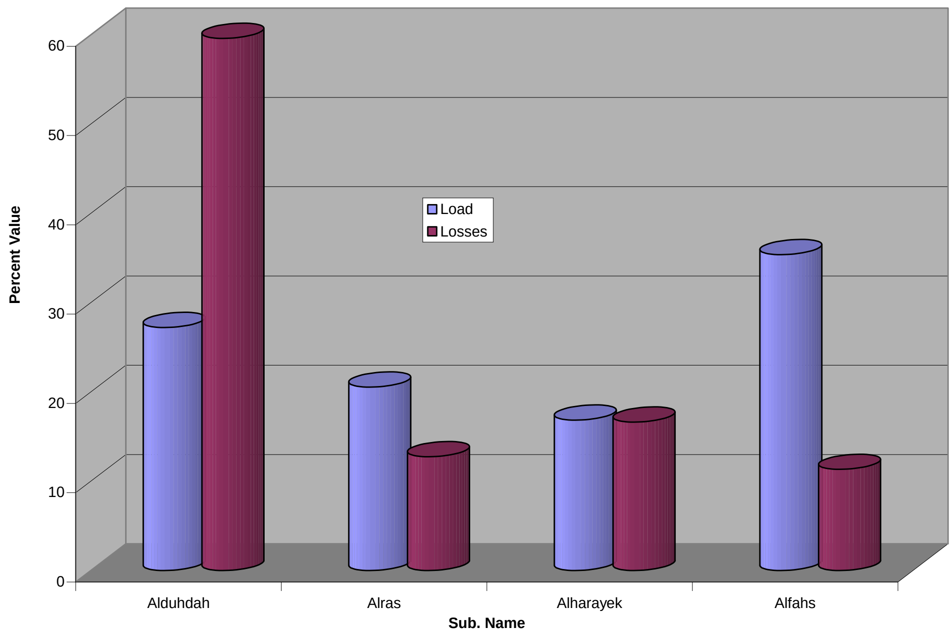


Fig 5. 6: Losses % & Load % for each Substation.

This figure indicates that **Alduhdah substation** has **58%** of the system losses while it has only about **27%** of the system load.

Table 5. 4: Energy Losses (MWh) in Each Zone for Each Component Type

Zone No.	Zone Name	Losses in 6.6KV Lines and Cables(MWh)	6.6/0.4KV D.T. Losses(MWh)	33/6.6KV P.T. Losses(MWh)	Total Losses (MWh)	Total Consumed Energy (MWh)
2	Duh-F.Hawa	427.05	105.12		532.17	
1	Duh-Halhul	985.50	118.26		1,103.76	
3	Duh-Mazroq	8,177.46	275.94		8,453.40	
4	Duh-R.Johar	363.54	87.60		451.14	
	Total Duhdah	**9,953.55**	**586.92**	**293.46**	**10,833.93**	**53,054.1**
14	Fah-B.Tarseep	586.92	107.31		694.23	
15	Fah-Berin	32.85	45.99		78.84	
12	Fah-J.Johar	238.71	159.87		398.58	
13	Fah-O.Dalyeh	479.61	100.74		580.35	

	Total Fahs	**1,338.09**	**413.91**	**313.17**	**2,065.17**	**68,985.6**
10	Har-Hawoz1	1,399.41	164.25		1,563.66	
9	Har-W.Hariyya	1,147.56	85.41		1,232.97	
11	Har-Hawoz2	19.71	41.61		61.32	
	Total Harayek	**2,566.68**	**291.27**	**179.58**	**3,037.53**	**32,855.3**
7	Ras-B.Zawyeh	151.11	111.69		262.8	
6	Ras-Husein	308.79	72.27		381.06	
8	Ras-K.Hadoor	1.10	4.38		5.475	
5	Ras-O.Farah	1,432.26	89.79		1,522.05	
	Total Ras	**1,894.35**	**278.13**	**144.54**	**2,317.02**	**40,066.5**
	Total	**15,752.67**	**1,570.23**	**930.75**	**18,253.65**	**194,997.6**

Fig (5.7) shows the sharing of each substation in consumed energy and energy losses (MWh & %).

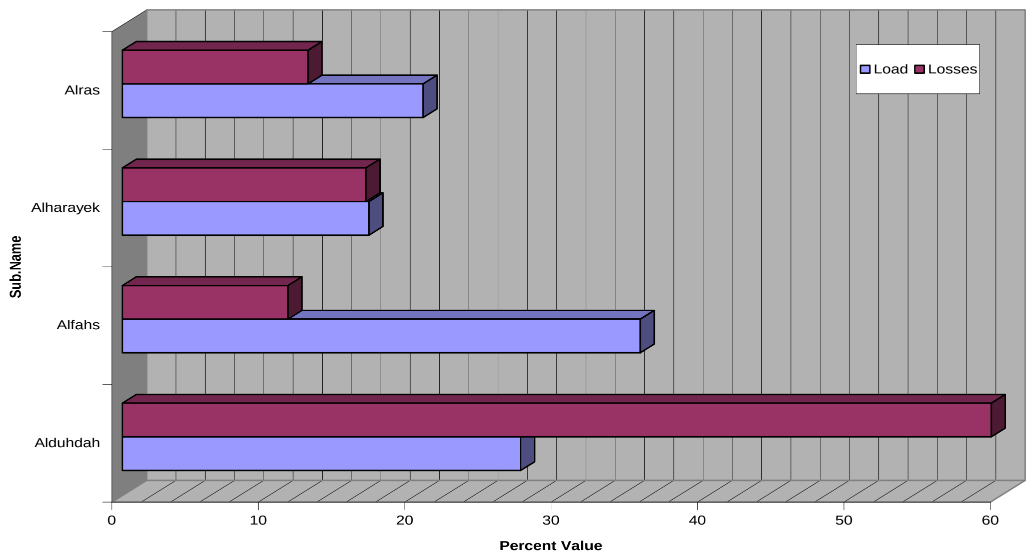


Fig 5. 7: Losses % & Load % for each Substation.

5.3.5 System Voltage Profile:

The load flow results show that the following zones suffer from voltage drop, which are 1, 3, 4, 5, 9 and 10 where most of the buses in each zone have voltage less than the nominal voltage; the next graph represents a color contouring of the voltage.

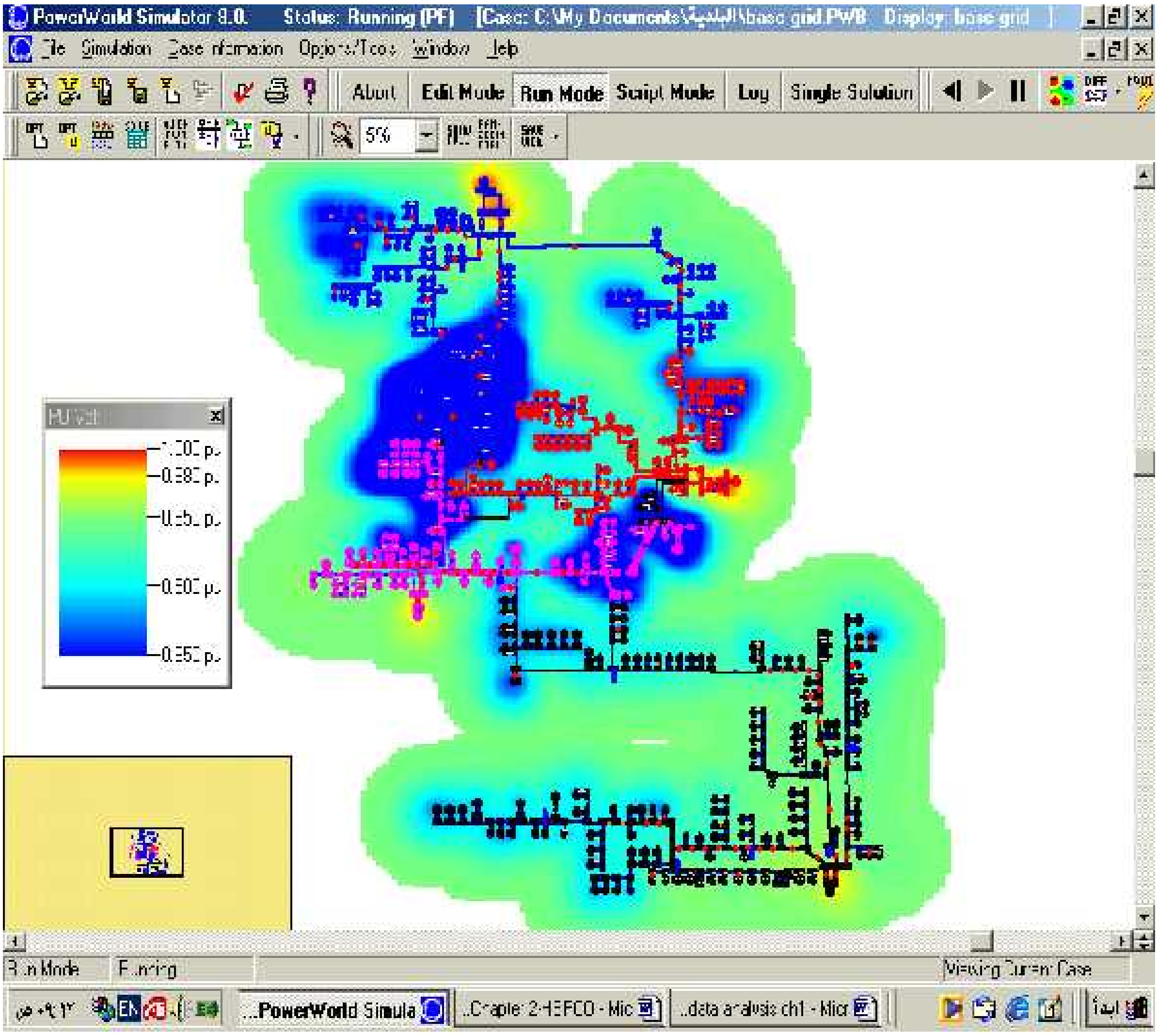


Fig 5. 8: Voltage Contouring of the System.

5.3.6 Lines and Cables Loadings:

The percentage of the lines loadings indicates if the system is relieved or not, the ability of the system to connect new loads without causing technical problems.

The load flow results show the following average loadings for each conductor type.

Table 5. 5: Lines and Cables Loadings

Conductors Type	Total Length (Km)	Average Loading (%)	Total Length above 100% Loading (Km)	Total Length between 80% and 100% Loading (Km)
6.6KV ACSR, 50mm^2	15.50	41.8	0.10	0.60
6.6KV ACSR, 70mm^2	4.69	42.3	1.50	0.23
6.6KV ACSR, 95mm^2	48.67	53.1	10.80	1.90
6.6KV ACSR, 120mm^2	20.40	61.6	5.50	0.80
6.6KV ACSR, 150mm^2	14.36	49.6	2.20	0.00
6.6.KV Cu, 35mm^2	1.50	123.0	1.50	0.00
6.6KV XLPE Cu 3c, 50mm^2	4.60	12.2	0.00	0.00
6.6KV XLPE Cu 3c, 95mm^2	0.30	29.2	0.00	0.00
6.6kV XLPE Cu 3c, 120mm^2	13.50	39.7	3.20	0.30
6.6KV XLPE Cu 3*1c, 150mm^2	0.20	152.9	0.20	0.00
6.6KV XLPE Cu 3*1c, 300mm^2	0.60	64.0	0.00	0.20
Total	**124.32**	**60.9**	**25**	**4.03**

As clearly indicated in this table, it is immediately recommended to re-conduct all the overloaded conductors and cables with a total length of **25Km**. Also it is recommended to *re-conduct* all the conductors and cables that have loading above 80%, as they will be overloaded in 3 years assuming an average yearly growth of 7%.

5.4 Loss Reduction Proposed Projects:

5.4.1 Scenario 1: Re-conductoring:

This scenario aims to see the effect of re-conductoring the overloaded conductors with an overall length of 25Km.

5.4.1.1 Re-conduct the Overloaded Lines and Cables:

The adopted criteria for choosing the new size of the overloaded line or cable is as the following:

a- 6.6KV ACSR, $50mm^2$ Re-conduct to ACSR, $150mm^2$.
b- 6.6KV ACSR, $70mm^2$: Re-conduct to ACSR, $150mm^2$.
c- 6.6KV ACSR, $95mm^2$: Re-conduct to ACSR, $150mm^2$.
d- 6.6KV ACSR, $120mm^2$: Re-conduct to ACSR, $150mm^2$.
e- 6.6KV ACSR, $150mm^2$: Re-conduct to ACSR, $185mm^2$.
f- 6.6KV Cu, $35mm^2$: Re-conduct to Cu, 65 mm^2.
g- 6.6KV XLPE Cu 3c, $120mm^2$: Re-conduct to 6.6KV XLPE Cu 3*1c, $185mm^2$.
h- 6.6KV XLPE Cu 3c, $150mm^2$: Re-conduct to 6.6KV XLPE Cu 3*1c, $185mm^2$.
i- The main Feeders Cables: Re-conduct to XLPE Cu3*1c, $300mm^2$.

By adopting this criteria, it is found that:

1- 0.1Km of ACSR, $50mm^2$ has to be re-conducted to ACSR, $150mm^2$.
2- 1.5Km of ACSR, $70mm^2$ has to be re-conducted to ACSR, $150mm^2$.

3- 10.8Km of ACSR, 95mm^2 has to be re-conducted to ACSR, 150mm^2.

4- 5.5Km of ACSR, 120mm^2 has to be re--conducted to ACSR, 150mm^2.

5- 5.5Km of ACSR, 150mm^2 has to be re-conducted to ACSR, 185mm^2.

6- 1.5Km of Cu, 35mm^2 has to be re-conducted to Cu, 65mm^2.

7- 3.2Km of XLPE Cu 3c, 120mm^2 has to be re-conducted to XLPE Cu 3*1c, 185mm^2.

8- 0.2Km of XLPE Cu 3c, 150mm^2 has to be re-conducted to XLPE Cu 3*1c, 185mm^2.

9- 1.02Km Re-conduct to XLPE Cu 3*1c, 300mm^2.

The effect of re-conductoring on the overloaded lines and cables is:

Table 5. 6: Effect of Reconductoring on the Overloaded Lines and Cables

System Component	Power Losses (MW)	% Of Total MW Losses	Energy Losses (MWh)	% Of Total MWh Losses
Losses in 6.6KV Lines & Cables	3.039	71.60	6,655.41	61.8
Transformers Losses	0.978	23.00	2,141.82	19.9
Transformers No Load Losses	0.226	5.30	1,979.76	18.4
Total Losses	4.246	100.00	10,777.00	100.0
Total Peak at the Connection Points (MW)	56.9			
Total Load (MW)	53			
Losses as % of Peak	7.5			
Losses as % of Load	8			
Total Purchase (GWh)	194.3			
Losses as % of Purchase	5.5			

The savings achieved by re-conductoring the overloaded lines and cables are **9,445.5MWh** *and* **4.31MW** also removing the overloading from **25Km** of lines and cables. The maximum voltage drop is reduced to **10%.**

5.4.2 Scenario 2: Voltage Upgrading from 6.6KV to 11KV:

As mentioned before, the electric power is distributed through the city via 6.6KV. In this scenario the 6.6KV is upgraded to 11KV so to reduce the losses on the 6.6KV lines, where it represents **84%** of the total power losses and **77.9%** of the total system energy losses and also to increase the power capacity of these lines.

The effect of the voltage upgrading on each component of the system losses is shown in the following tables:

Table 5. 7: Effect of Voltage Upgrading Scenario

System Component	Power Losses (MW)	% of Total MW Losses	Energy Losses (MWh)	% of Total MWh Losses
Losses in 11 KV Lines & Cables	1.395	65.90	3,055.10	49.8
Transformers Losses	0.500	23.60	1,0950	17.9
Transformers No Load Losses	0.226	10.60	1,979.80	32.3
Total Losses	2.116	100.00	6,129.90	100.0
Total Peak at the Connection Points (MW)	54.9			
Total Load (MW)	53			
Losses as % of Peak	3.85			
Losses as % of Load	4			
Total Purchase (GWh)	194.3			
Losses as % of Purchase	3.2			

From this table it is noticed that *the total power losses is reduced from* **16.1%** *to* **4%** which means a saving of **6.44MW**, and *the power losses on the 11KV lines represents* **65.9%** *instead of* **84%** *on the 6.6KV lines*. Also *the energy losses have been reduced* to **6,129.90MWh** *from* **20,222.50MWh**.

The substations and feeders share of power and energy losses at 11KV is illustrated in the next two tables.

Table 5. 8: Power Losses (MW) in each Zone for each Component Type after Voltage Upgrading

Zone No.	Zone Name	Losses in 11KV Lines and Cables (MW)	11/0.4KV D.T Losses (MW)	33/11KV P.T. Losses (MW)	Total Losses (MW)	Total Load (MW)
2	Duh-F.Hawa	0.060	0.015		0.075	
1	Duh-Halhul	0.116	0.016		0.132	
3	Duh-Mazroq	0.404	0.015		0.419	
4	Duh-R.Jora	0.050	0.012		0.062	
	Total Duhdah	**0.630**	**0.058**	**0.078**	**0.766**	**14.45**
14	Fah-B.Tarseep	0.085	0.016		0.101	
15	Fah-Berin	0.005	0.007		0.012	
12	Fah-J.Johar	0.055	0.024		0.079	
13	Fah-O.Dalyeh	0.070	0.015		0.085	
	Total Fahs	**0.215**	**0.062**	**0.131**	**0.408**	**18.80**
10	Har-Hawoz1	0.151	0.018		0.169	
9	Har-W.Hariyya	0.138	0.011		0.149	
11	Har-Hawoz2	0.003	0.006		0.009	
	Total Harayek	**0.292**	**0.035**	**0.060**	**0.387**	**8.93**
7	Ras-B.Zawyeh	0.020	0.015		0.035	
6	Ras-Husein	0.042	0.010		0.052	
8	Ras-K.Hadoor	0.0001	0.001		0.001	
5	Ras-O.Farah	0.014	0.012		0.026	
	Total Ras	**0.076**	**0.038**	**0.039**	**0.153**	**10.84**
	Total	**1.213**	**0.193**	**0.308**	**1.714**	**53.000**

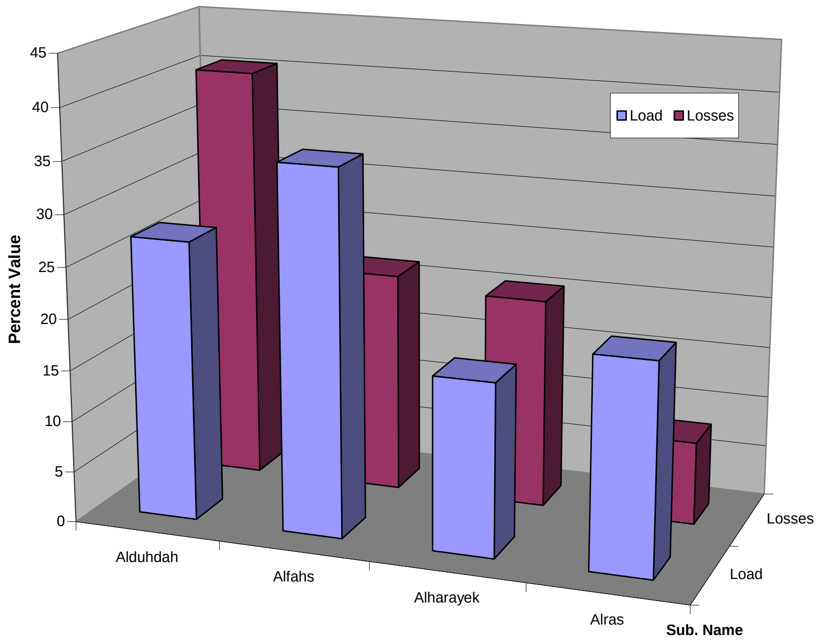


Fig 5. 9: Losses % & Load % for each Substation.

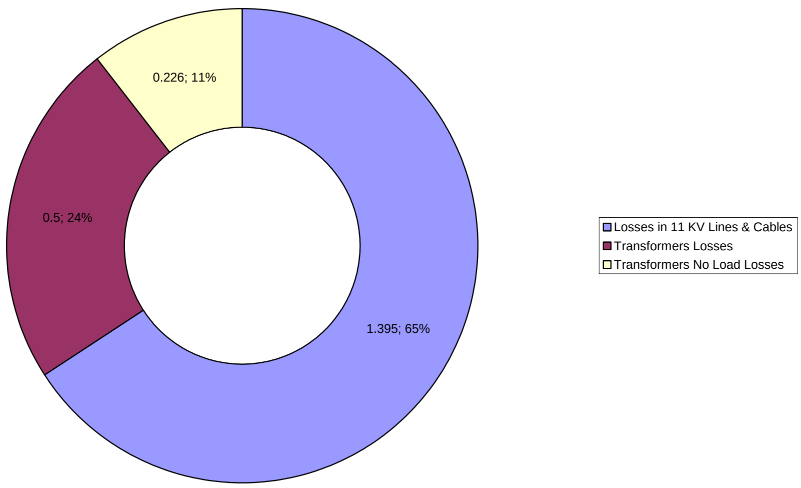


Fig 5. 10: Power Losses per Component Type (MW, %).

Table 5. 9: Energy Losses (MWh) in each Zone for each Component Type

Zone No.	Zone Name	Losses in 11KV Lines and Cables (MWh)	11/0.4KV D.T Losses (MWh)	33/11KV P.T. Losses (MWh)	Total (MWh)	Total Consumed Energy (MWh)
2	Duh-F.Hawa	131.4	32.85		164.3	
1	Duh-Halhul	254.04	35.04		289.1	
3	Duh-Mazroq	884.76	32.85		917.6	
4	Duh-R.Jora	109.5	26.28		135.8	
	Total Duhdah	**1379.7**	**127.02**	**170.82**	**1,677.50**	**53,054.1**
14	Fah-B.Tarseep	186.15	35.04		221.2	
15	Fah-Berin	10.95	15.33		26.3	
12	Fah-J.Johar	120.45	52.56		173	
13	Fah-O.Dalyeh	153.3	32.85		186.2	
	Total Fahs	**470.85**	**135.78**	**286.89**	**893.5**	**68,985.6**
10	Har-Hawoz1	330.69	39.42		370.1	
9	Har-W.Hariyya	302.22	24.09		326.3	
11	Har-Hawoz2	6.57	13.14		19.7	
	Total Harayek	**639.48**	**76.65**	**131.4**	**847.5**	**32,855.3**
7	Ras-B.Zawyeh	43.8	32.85		76.7	
6	Ras-Husein	91.98	21.9		113.9	
8	Ras-K.Hadoor	0.26	1.314		1.6	
5	Ras-O.Farah	30.66	26.28		56.9	
	Total Ras	**166.44**	**83.22**	**85.41**	**335.1**	**40,066.5**
	Total	**2,656.48**	**422.67**	**674.52**	**3,753.70**	**194,997.6**

The next figure shows the total consumed energy of each substation and its losses as a percentage of the total energy and losses.

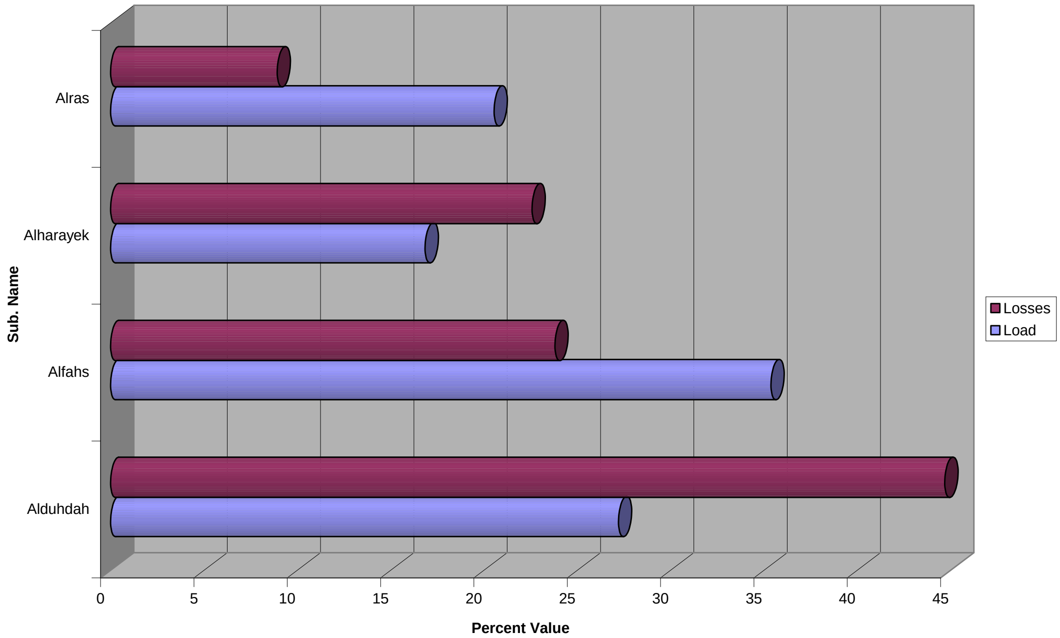


Fig 5. 11: Consumed Energy % and Energy Losses % for each Substation.

5.4.2.1 System Voltage Profile:

It is noticed that when upgrading the system to 11KV, there will few transformers suffer from low voltage; in fact the lowest voltage will be 0.94 P.U..

As clearly shown in the next voltage-contouring graph, there is no Dark Blue color that represents the voltage in the range less than 0.85 P.U..

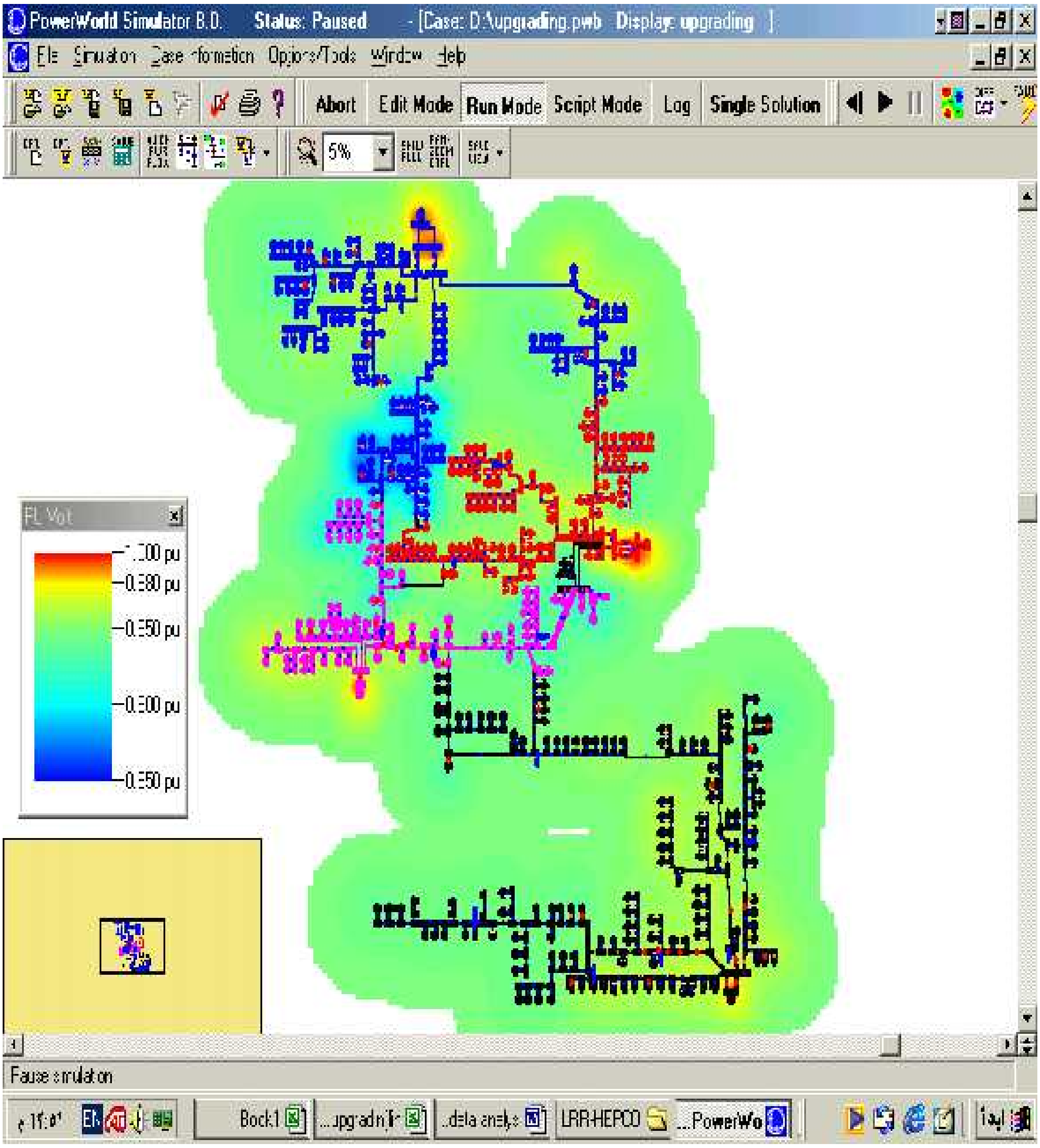


Fig 5. 12: Voltage Contour after Upgrading.

5.4.2.2 Lines and Cables Loadings:

The load flow results show the following average loadings for each conductor type.

Table 5. 10: Lines and Cables Loading

Conductors Type	Total Length (Km)	Average Loading (%)	Total Length above 100% Loading (Km)	Total Length between 80% and 100% Loading (Km)
11KV ACSR, 50mm^2	15.50	10.6	0.00	0.10
11KV ACSR, 70mm^2	4.69	23.9	0.00	0.00
11KV ACSR, 95mm^2	48.67	30.0	1.10	2.30
11KV ACSR, 120mm^2	20.40	30.9	0.00	2.00
11KV ACSR, 150mm^2	14.36	31.4	0.43	0.20
11KV Cu, 35mm^2	1.50	68.7	0.00	0.00
11KV XLPE Cu 3c, 50mm^2	4.60	7.1	0.00	0.00
11KV XLPE Cu 3c, 95mm^2	0.30	17.0	0.00	0.00
11KV XLPE Cu 3c, 120mm^2	13.50	19.2	0.00	0.40
11KV XLPE Cu 3*1c, 150mm^2	0.20	81.0	0.00	0.20
11KV XLPE Cu 3*1c, 300mm^2	0.60	35.4	0.00	0.00
Total	**124.32**	**32.3**	**1.53**	**5.20**

The average loading of the lines at 11KV voltage level is about **32.3%** reduced from **60.9%**. The total length of the overloaded conductors is only **1.53Km** instead of **25Km.**

5.4.2.3 Comparison between 6.6KV and 11KV Systems:

The following table illustrates the savings and differences between running the system at the current 6.6KV voltage level and upgrading it to 11KV voltage level.

Table 5. 11: Comparison between 6.6KV and 11KV Systems

	6.6KV System	11KV System	Difference
Power Losses (MW)	8.56	2.12	6.44
Energy Losses (MWh)	20,222.50	6,129.90	14,092.60
Average Line Loadings (%)	60.84	32.28	28.56
Length of Over Loaded Lines and Cables (Km)	25.00	1.53	23.47
Maximum Voltage Drop (%)	20.00	10.00	10.00

5.4.3 Scenario 3: Power factor Improvement:

In this scenario, the total power factor of the system is improved from by 8%. This can be done by:

1. Forcing the consumers to take care of their power factor.
2. Installing capacitor banks.
3. Mixed of the above two options.

Table 5. 12: Effect of Power Factor Improvement Scenario

System Component	Power Losses (MW)	% Of Total MW Losses	Energy Losses (MWh)	% Of Total MWh Losses
Losses in 6.6KV Lines & Cables	3.751	76.10	8,214.70	67.0
Transformers Losses	0.947	19.20	2,074.00	17.0
Transformers No Load Losses	0.226	4.60	1,979.80	16.0
Total Losses	4.930	100.00	12,268.50	100.0
Total Peak at the Cconnection Points (MW)	57.3			
Total Load (MW)	53			
Losses as % of Peak	8.6			
Losses as % of Load	9.3			
Total Purchase (GWh)	194.3			
Losses as % of Purchase	6.3			

In this scenario it is assumed that the utility will improve the power factor by installing capacitors at the network. The improvements in the system is shown in the next table:

Table 5. 13: Effect of Improving Power Factor by 8% on Hebron System

Needed Capacitors (Mvar)	11
Reduction on Power Losses (MW)	3.6
Reduction on Energy Losses (MWh)	7,954

5.4.4 Other Scenarios:

5.4.4.1 Adding New Substations:

Hebron Municipality engineers plan to improve the network by adding a new two substations, which are:

- Alhusain Substation.
- The West Substation.

Alhusain Substation which includes two power transformers each one has a capacity of (10MVA), also the West Substation which includes two power transformers each one has a capacity of (10MVA).

And now we will compare the status of the network before and after adding these two substations from many sides such as losses, voltage drop, and other sides.

1. Network Losses:

Table 5. 14: Effect of Adding New Substations

System Component	Power Losses (MW)	% Of Total MW Losses	Energy Losses (MWh)	% Of Total MWh Losses
Losses in 6.6KV Lines & Cables	1.516	61.90	3,320.04	48.5
Transformers Losses	0.708	28.00	1,551.00	28.9
Transformers No Load Losses	0.226	9.20	1,979.76	28.9
Total Losses	2.450	100.00	6,850.80	100.0
Total Peak at the Connection Points (MW)	50.5			
Total Load (MW)	48.2			
Losses as % of Peak	4.9			
Losses as % of Load	5.1			
Total Purchase (GWh)	194.3			
Losses as % of Purchase	3.5			

Table 5. 15 Comparison between 4-Substations and 6-Substations Scenarios

Scenario	Total Losses	Conductors Losses		Transformers Load Losses	
	(MW)	(MW)	(MWh)	(MW)	(MWh)
4-Substations	8.556	7.19	15,746.1	1.14	2,496.6
6-Substations	2.450	1.52	3,320.0	0.71	1,550.5
Difference	6.106	5.67	12,426.1	0.43	946.1

2. Network Voltage Drop:

The following figure of the network contouring shows the network status after adding the two substations, and their effect on the network voltage.

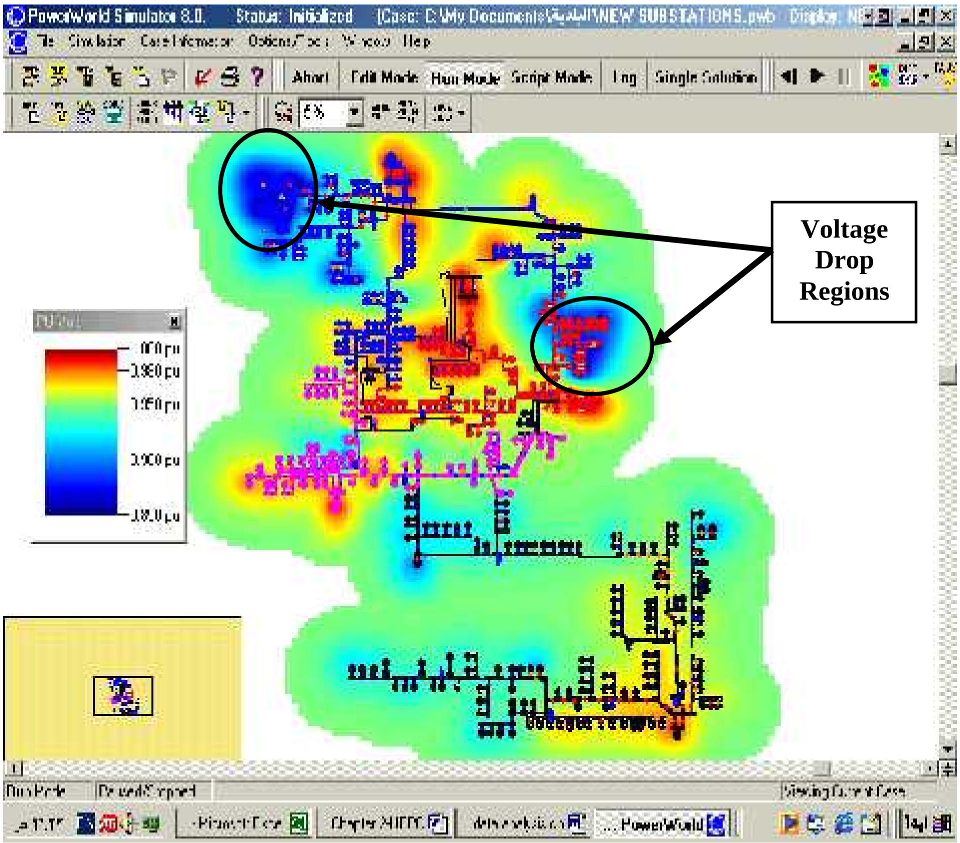


Fig 5. 13: Contouring Map of the New Substations Scenario.

From the contouring figure of the network and after comparing it with the base grid, we see that most of the voltage drop disappeared, but it can be seen at specific regions on the network with small values.

And to solve the problem of voltage drop at the framed regions shown on the previous figure, we take the following scenario.

5.4.4.2 Voltage Drop Problem Solving Scenario:

We solved the voltage drop problem at the specified regions by fed each region by a new feeder from its substation. And the following figure shows the effect of this solution on the network.

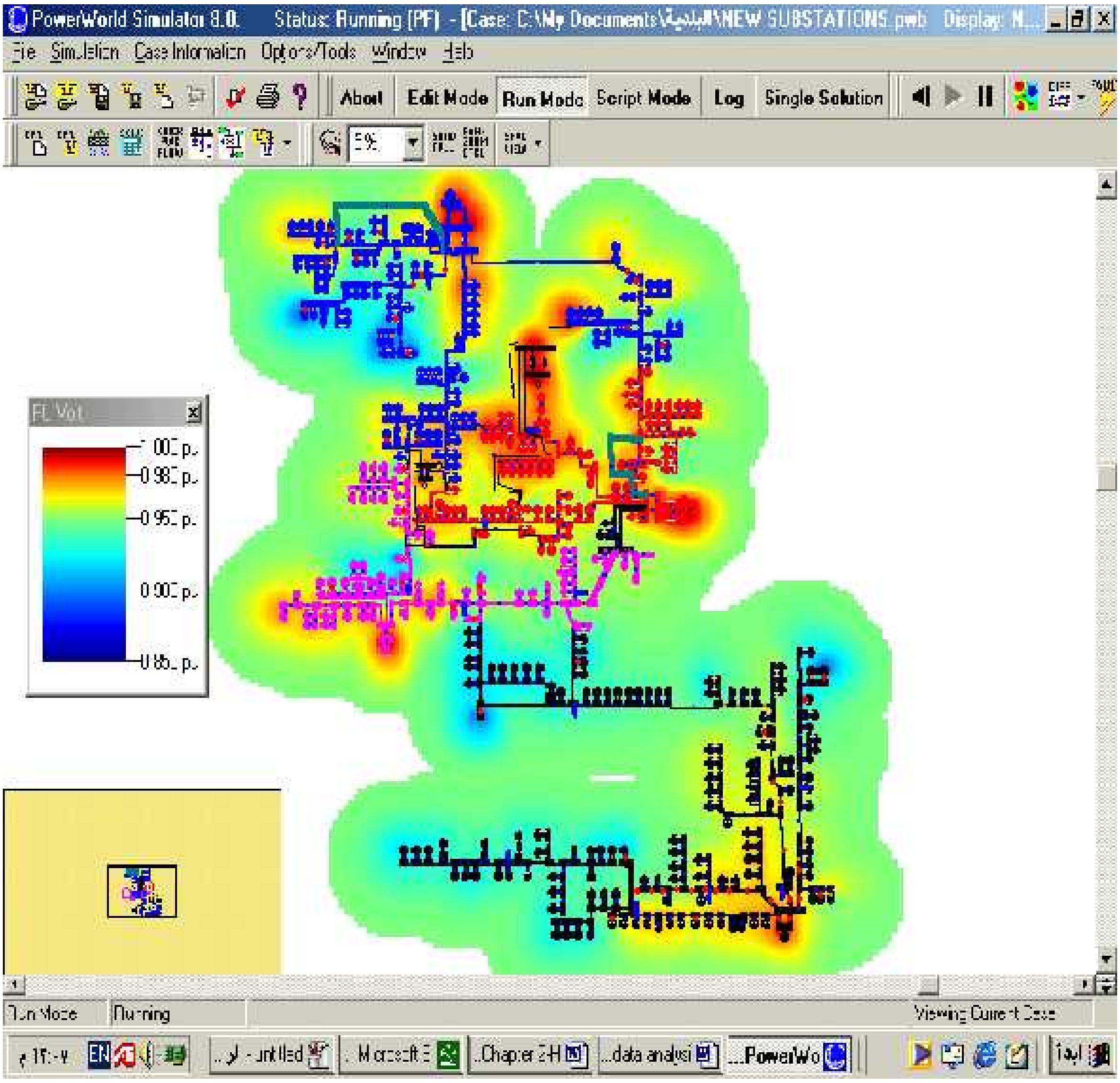


Fig 5. 14: Contouring Map of the New Substations Scenario after Adding New Feeders.

5.4.4.3 Upgrading the Overloaded Transformers Scenario:

Table 5. 16: Over Loaded Transformers

Feeder Name	Number of Over Loaded Transformers	Transformer Apparent Power (KVA)					
		100	250	315	400	500	630
Duh-F.Hawa	3			1	2		
Duh-Halhul	5	2	3				
Duh-Mazroq	2		1	1			
Duh-R.Jora	3		2		1		
Ras-B.Zawyeh	3				2	1	
Ras-Husein	2		2				
Ras-K.Hadoor	0						
Ras-O.Farah	2		2				
Har-Hawoz1	6		3		1	1	1
Har-Hawoz2	0						
Har-W.Hariyya	3		2				1
Fah-B.Tarseep	1		1				
Fah-Berin	2		1			1	
Fah-J.Johar	3		1		2		
Fah-O.Dalyeh	3	1	1	1			
Total	**38**	**3**	**19**	**3**	**8**	**3**	**2**

- 2-Transformers of 100KVA must be upgraded to 250KVA.
- 1-Transformer of 100KVA must be upgraded to 315KVA.
- 13-Transformers of 250KVA must be upgraded to 315KVA.
- 4-Transformers of 250KVA must be upgraded to 400KVA.
- 1-Transformer of 250KVA must be upgraded to 500KVA.
- 1-Transformer of 250KVA must be upgraded to 630KVA.
- 2-Transformers of 315KVA must be upgraded to 400KVA.
- 1-Transformer of 315KVA must be upgraded to 500KVA.
- 1-Transformer of 315KVA must be upgraded to 630KVA.
- 4-Transformers of 400KVA must be upgraded to 500KVA.
- 2-Transformers of 400KVA must be upgraded to 630KVA.

- 1-Transformer of 400KVA must be upgraded to 1000KVA.
- 2-Transformers of 500KVA must be upgraded to 630KVA.
- 1-Transformer of 500KVA must be upgraded to 800KVA.
- 2-Transformers of 630KVA must be upgraded to 800KVA.

5.5 Comparison between the Scenarios:

Table 5. 17: Comparison between the Scenarios

No.	Scenario	Losses	Conductor Losses		Transformer Losses		Max. Voltage Drop	Power Factor
		(MW)	(MW)	(MWh)	(MW)	(MWh)	(%)	(%)
1	**Base Grid**	8.556	7.190	15746.1	1.140	2496.6	15	85
2	**Reconductoring**	4.246	3.039	6655.4	0.978	2141.8	10	85
3	**Voltage Upgrading**	2.116	1.395	3055.1	0.500	1095.0	6	85
4	**Power Factor Correction**	4.926	3.751	8214.7	0.947	2073.9	10	93
5	**Adding New Substations**	2.45	1.516	3320.0	0.708	1550.5	9	90

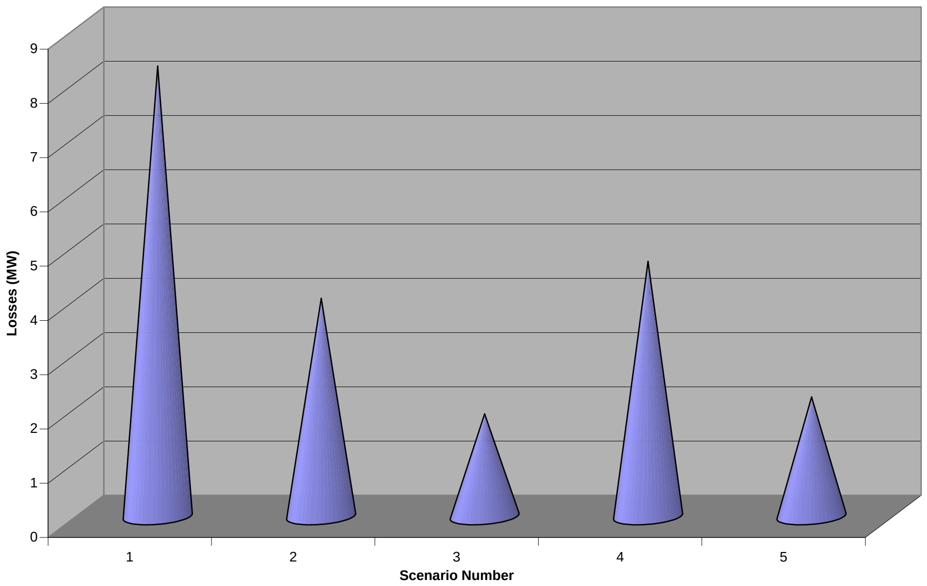


Fig 5. 15: Scenarios Power Losses (MW).

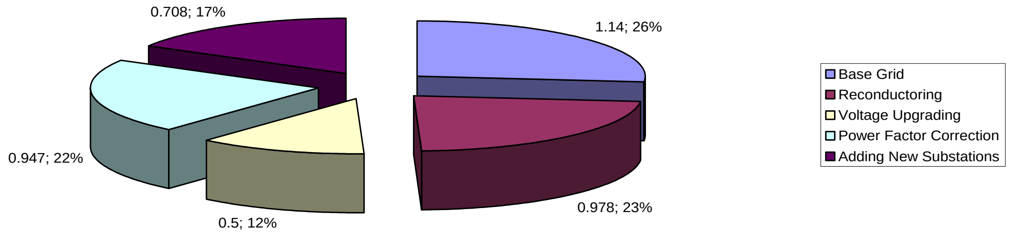


Fig 5. 16: Transformer Load Losses for each Scenario.

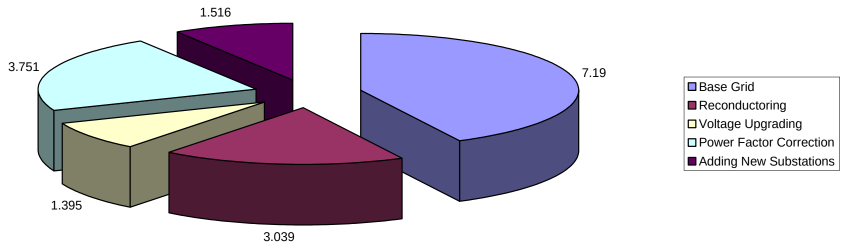


Fig 5. 17: Conductor Losses for each Scenario.

Chapter Six

Conclusions and Recommendations

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Conclusions:

❖ **Network Problems:**

The project conclusions can be summarized as follow:

- **Hebron medium voltage electric power network has high Losses:**

  The load flow results of Hebron city electric power network show that it has a high level of power losses nearly 8.56MW (16%) of the total load and energy losses 20.2GWh

- **Hebron medium voltage electric power network has a range of Power Factor (0.85-0.9):**

  Also the load flow results show that the Power Factor of the most regions of the network nearly 0.85 and in the other regions varies between 0.85 and 0.9.

- **Hebron medium voltage electric power network has voltage drop:**

  The contouring capability of the Simulator program shows the specific regions of Hebron city where the voltage is under the nominal voltage, and the average voltage drop in the network nearly 15%.

- **Hebron medium voltage electric power network has unbalanced loads distribution:**

  This problem causes other new problems such as voltage drop, losses and electricity cut off problem.

- **Hebron medium voltage electric power network has overloaded conductors and transformers:**

  The load flow also shows that the network has 25Km of overloaded conductors (overhead lines and cables) with a specific length; also the network has 38 of overloaded transformers.

❖ **<u>Problems Solutions:</u>**

- Low Power Factor problem solved by Power Factor improvement scenario.

- Voltage drop problem solved by voltage upgrading and re-conductoring scenarios.

- Unbalanced loads distribution problem solved by adding new two substations scenario.

- Each scenario reduces the network losses, mainly the voltage upgrading scenario.
- Also each scenario affects on the network operation and stability.

This project contributes in describing the present status of Hebron medium voltage electric power network, and in solving its problems, also it contributes in developing and improving this network and its operation.

When the results and solutions of this project are adopted; the following advantages can be gotten:

- The network losses will be reduced to adequate level.

- The Power Factor of the network will increase to a value as near as to a unity Power Factor.

- The problem of voltage drop will be eliminated.

- The loads will be distributed in a balanced way.
- The electricity cut off problem which results from the bad distribution of loads will be eliminated.

- There will be no overloaded conductors or transformers.

Recommendations:

- **Recommendations for Hebron Municipality:**

  - ✓ Use the Power World Simulator program to study and develop the network.
  - ✓ Make suitable archives for data of each element in the network.
  - ✓ Work hard to get SCADA system and apply it on the network.
  - ✓ When the municipality purchases new elements, it must sure that they can work with any new system.

- **Recommendations for the Future Studies:**

  - ✓ Make financial evaluations for the scenarios of this project.
  - ✓ Make studies for low voltage electric power network of Hebron city.
  - ✓ Make researches to apply SCADA system on Hebron city grid.
  - ✓ Use the Simulator program to analyze other networks for various cities and regions.

- **Recommendations for our university:**

  - ❖ Make relationships with the establishments that concern with the electric power field (Palestinian Energy Authority, Hebron Municipality).
  - ❖ Make it easy for any student who interests in the Simulator Program to use it.

By adopting this project and applying it in the practical life, the operation of Hebron electric power network will be improved, and the network problems will be eliminated, and by using SCADA System, the network will be efficiently and easily controllable.