Load flow calculation and Network planning for medium voltage networks

Master's Thesis

Institute of Electrical Power Systems
Graz University of Technology

Supervisor: Univ.-Prof. DI Dr.techn. Lothar Fickert
Assistant: DI Beti Trajanoska

Author: Amina Mohiden

Head of Institute: Univ.-Prof. DI Dr.techn. Lothar Fickert

A - 8010 Graz, Inffeldgasse 18-I
Telefon: (+43 316) 873 – 7551
Telefax: (+43 316) 873 – 7553
http://www.ifea.tugraz.at
http://www.tugraz.at

Graz / July - 2008

Acknowledgments

I would like to express my gratefulness to: My dear supervisor Prof. Lothar Fickert, for his continuous helping by providing references, encouragement guiding and useful comments, also for his full meaning support words. I appreciate my dear husband for his full cooperation and support during my study time. I also appreciate Dr. Sumereder Christof's effort, who taught me in my thesis, and guide me through his friendly supports and gave me references. I appreciate DI Trajanoska Beti for her effort and full support in my thesis also for giving references and her best cooperation during the work time. I appreciate all those who helped me even by a word and become an encouragement for my thesis.

Dedicate

I would like to dedicate my thesis to:

- My dear Parents
- My dear supervisor
- My dear husband
- My dear daughter
- My friends
- All those who help me to write this thesis.

Abstract

Title: Load flow calculation and network planning for medium voltage networks

The aim of this thesis is to analyse a 10 kV distribution network in South-East Europe and to report an investigation of load flow calculation thereof. Using the available data, the distribution network was modeled in the network analaysing program NEPLAN®, where all the calculations were carried out. The load flow analysis shows a progressive overload of the 10 kV network and busbar voltages problems. Because of the above congestion and the future network expansion a new substation is proposed.

Keywords: medium voltage network, network planning, power quality, load flow calculation, and simulation.

Kurzfassung

Titel: Lastfluss Berechnung und Netzplanung für ein Mittelspannungsnetz

Das Ziel dieser Diplomarbeit ist es, die Netzsituation eines 10-kV-Verteilnetzes in Süd-Ost Europa zu analysieren. Anhand der zur Verfügung gestellten Daten wurde das Netz im Netzanalyseprogramm NEPLAN® modelliert, um Lastflussberechnungen durchzuführen.

Die Lastflussanalyse ergibt eine fortschreitende Überlastung des 10-kV-Netzes, die zu Stromüberlastungen und Spannungsproblemen führt. Auf Grund der genannten Überlastungen wurde einen Vorschlag für den Netzausbau zusammengestellt.

Schlüsselwörter: Mittelspannungsnetz, Netzplanung, Lastflussanalyse, Lastfluss Berechnung und Simulation.

Table of Contents

1 Symbols

U_n	nominal voltage
P_v	active power losses
ϑ	transmission angle
ϑ_{gr}	transmission angle of a high voltage overhead line
$\underline{V}_1$, $\underline{V}_2$	voltage at the beginning / end of the conductor
$\underline{I}_1$, $\underline{I}_2$	current at the beginning / end of the conductor
P_1, P_2	effective power at the beginning / end of the conductor
Q_1, Q_2	reactive power at the beginning / end of the conductor
S_1, S_2	apparent power at the beginning / end of the conductor
$\underline{Z}_L$	conductor impedance
$\underline{Z}_B$	load impedance
pf	Power factor
SAOD	System Average Outage Duration time
OECD	Organization for Economic Co-operation and Development
p.u.	per unit
OHL	Overhead line
NEPLAN®	fully integrated Power System Analysis Software for Electrical Transmission, Distribution and Industrial Networks, including Optimal Power Flow, Transient Stability, Reliability Analysis and much more.
flicker	Random or repetitive variations in the RMS voltage between 90 and 110% of nominal can produce a phenomena known as "flicker" in lighting equipment. Flicker is the impression of unsteadiness of visual sensation induced by a light stimulus on the human eye.
dip	(in British English) or “sag" (in American English - the two terms are equivalent) is the opposite situation: the RMS voltage is below the nominal voltage by 10 to 90% for 0.5 cycles to 1 minute.
Undervoltage	occurs when the nominal voltage drops below 90% for more than 1 minute. The term "brownout" is an apt description for voltage drops somewhere between full power (bright lights) and a blackout (no power

	- no light). It comes from the noticeable to significant dimming of regular incandescent lights, during system faults or overloading etc., when insufficient power is available to achieve full brightness in (usually) domestic lighting. This term is in common usage has no formal definition but is commonly used to describe a reduction in system voltage by the utility or system operator to decrease demand or to increase system operating margins.
Overvoltage	occurs when the nominal voltage rises above 110% for more than 1 minute.

2 List of Tables

3 List of Figures

4 Summary

4.1 Objective

The objectives of this thesis are

- to analyse 10 kV (medium-voltage-network) distribution network
- to build network plans with data for the network elements
- Load flow calculation
- Identification of the voltage quality
- Identification of the busbar
- to propose a solution for both conductors and busbars

4.2 Method

Based on the available data (a winter record of maximum load), the network was modeled in a network analyzing program NEPLAN® 5.3.4 to conduct load flow calculations and to review (n-1) secure operation thereof. This is necessary in order to ensure the final secure future supply to the customers. Particular focus will be the utilization of operational equipment and voltages quality, as these variables represent the state of the network.

4.3 Results

After the calculation of load flow for the existing network, it is noticed that:

- Some voltage problems in busbars exist
- Some lines become overloaded

4.4 Conclusions

As the load flow calculation in the distribution system shows, the voltage at the load end tends to get lower due to the lack of reactive power. In the case of long transmission lines, their active power available at the end of the line during peak load conditions is small and hence according to the system connection and future need of the network, solution should be made by changing conductor type or by inserting a new substation.

5 Introduction

Power systems typically operate under slowly changing conditions, which can be analyzed using steady-state analysis. Power flow analysis provides the starting point for most other analyses. For example, disturbances resulting in instability under heavily loaded system conditions may not have any adverse effects under lightly loaded conditions.

Power flow analysis is fundamental to the study of power systems; in fact, power flow forms the core of power system analysis. A power flow study is valuable for many reasons. For example, power flow analyses play a key role in the planning of additions or expansions to transmission and generation facilities. A power flow solution is often the starting point for many other types of power system analyses. In addition, power flow analysis and many of its extensions are an essentially ingredient of the studies performed in power system operations. It is at the heart of contingency analysis and the implementation of real-time monitoring systems. The power flow problem (popularly known as the load flow problem) can be stated as follows:

For a given power network, with known complex power loads and some set of specifications or restrictions on power generations and voltages, solve for the unknown bus voltages and unspecified generation and finally for the complex power flow in the network components. Additionally, the losses in individual components and the total network as a whole are usually calculated. Furthermore, the system is often checked for component overloads and voltages outside allowable tolerances. Three-phase balanced operation is assumed for the most power flow studies. Consequently, the positive sequence network is used for the analysis. In the solution of the power flow problem, the network element values are almost always taken to be in per-unit. Like wise, the calculations within the power flow analysis are typically in per-unit. However, the solution is usually expressed in a mixed format. Solution voltages are usually expressed in per-unit; powers are most often given in kVA or MVA. The ‘‘given network’’ may be in the form of a system map and accompanying data tables for the network components. More often, however, the network structure is given in the form of an one-line diagram such as shown in Figure (5-1). Regardless of the form of the given network and how the network data is given, the steps to be followed in a power flow study can be summarized as follows:

1. Determine the element values for passive network components.
2. Determine the locations and values of all complex power loads.
3. Determine the generation specifications and constraints.
4. Develop a mathematical model describing power flow in the network.
5. Check for constraint violations. [1]
6. Computation of the voltages at all system buses
7. Determination of the real and reactive power flows in the transmission lines of a system [8]

The figure below shows the single line diagram of a power system.

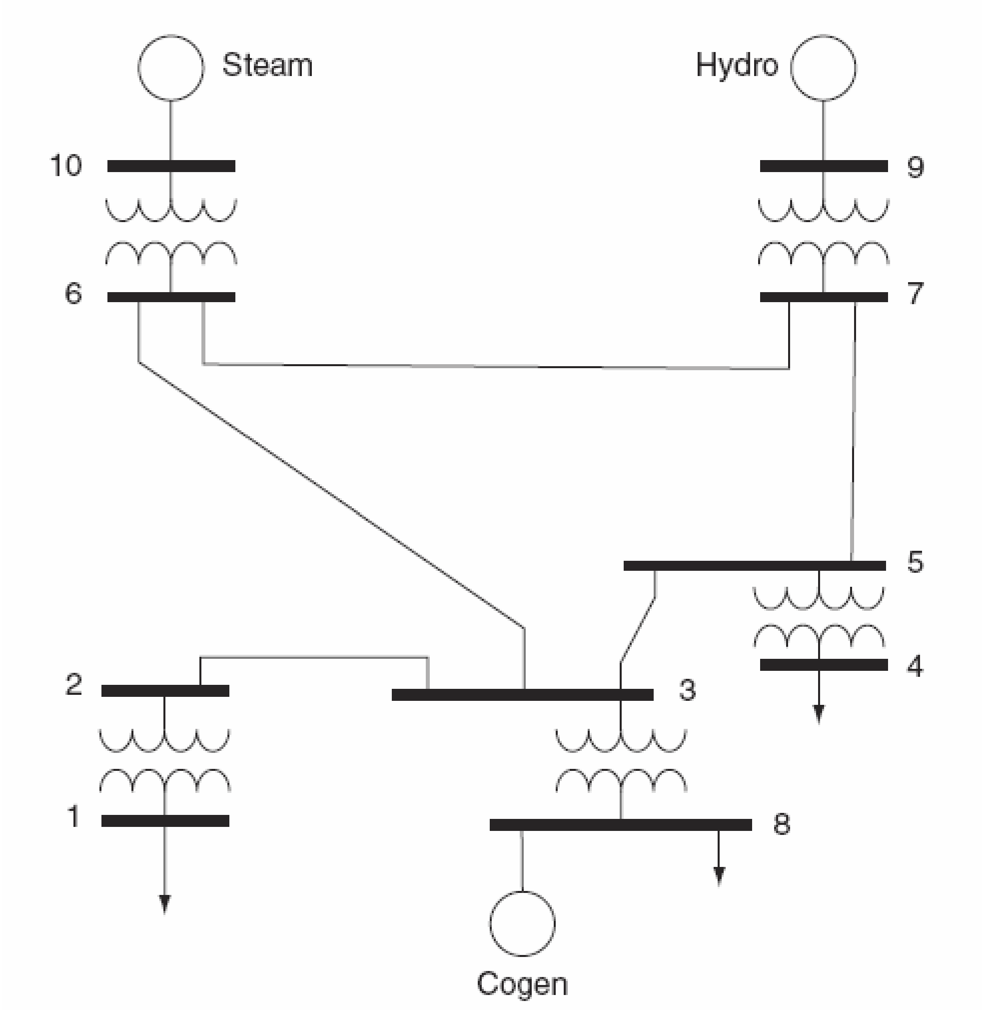


Figure 5-1; One-line diagram of a power system [1]

6 Methods

6.1 Load Flow

A load-flow study is carried out to determine the steady-state bus voltages, active and reactive power flows, transformer tap settings, component or circuit loading, generator exciter regulator voltage set points, system performance under contingency or emergency operations, and system losses. Load flow can also be used to determine the voltage profile at the time of starting a large motor. Two algorithms, Gauss-Seidel and Newton-Raphson, are used to solve the load-flow equations. Both are options in commercially available programs. The Gauss-Seidel method gives a simple and stable solution and works well up to 100 buses. The solution iterates one bus at a time, corrects that bus voltage to the specified value, and continues until an error is detected. The solution may not converge for the following reasons:

- Error in the input data
- System is too weak to carry the load
- Insufficient VAR in the system to support the voltage

In the Newton-Raphson method, the n quadratic equations are first linearized by forming a Jacobian matrix. The present value of the bus voltage is then calculated, and then n linear equations are solved in steps. The number of iterations is small, between five and ten. [4]

6.1.1 Analysed Sample Network

The System Model used is a capital in South-East Europe with more than 600,000 inhabitants. The supplied energy for the model consists of 2x (400/110) kV Substations with (2 x 300) MVA Transformers and 1x 220/110 kV Substation with (3x150) MVA Transformers. The medium voltage network in question consists of the following elements:

10 x Substations 110/x kV, (x= 35 kV or 10 kV)

17 x Substations 35/10 kV

9 x 110 kV, (OHL type with total length=37, 5 km)

33 x 35 kV, (OHL type with total length=144 km and Cable with total length=31 km)

The complete network representation of the capital city is shown in Figure (6-1).

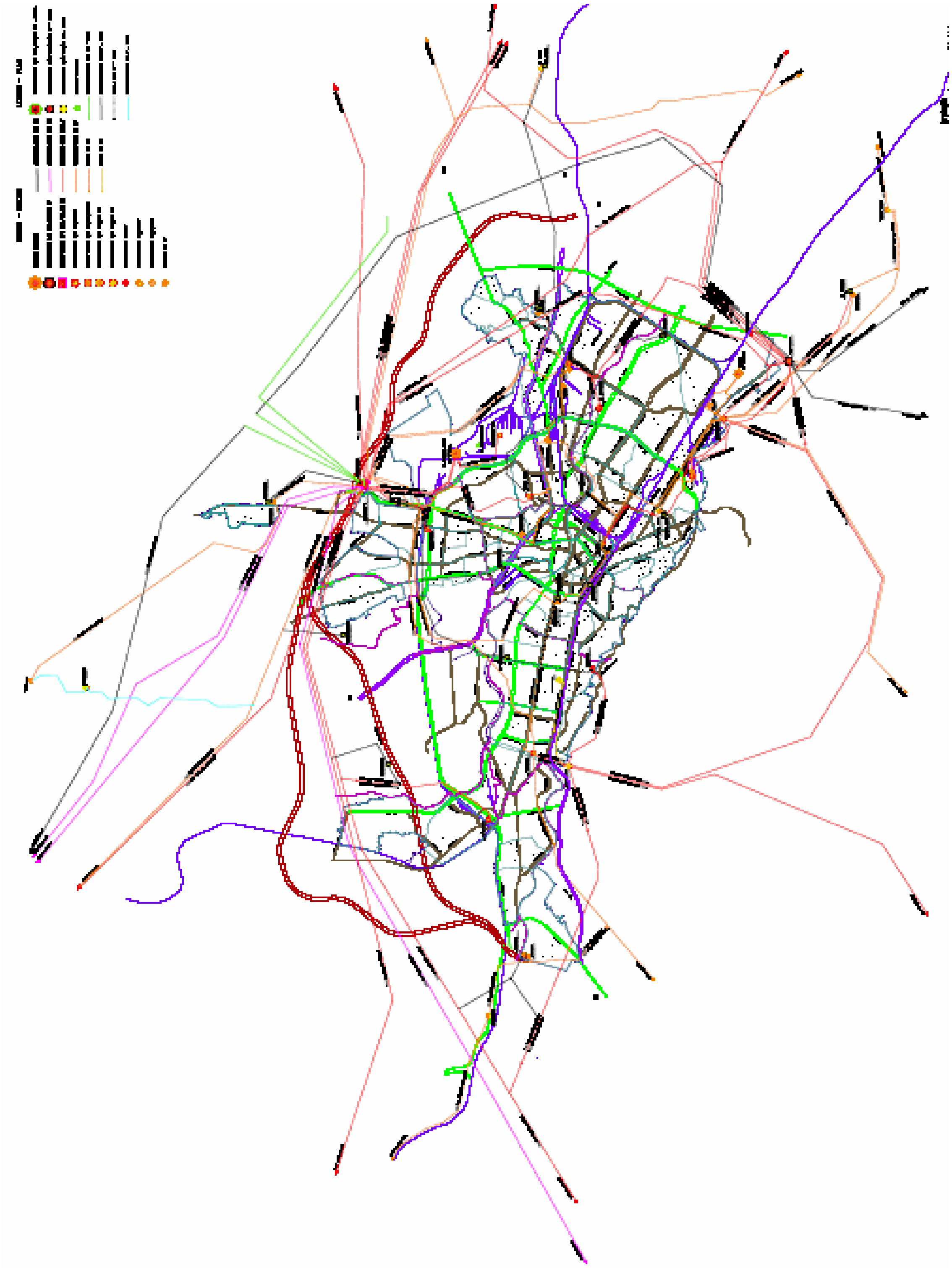


Figure 6-1; Complete network of the capital city

The single line diagram of the existing network for the capital city is shown in Figure (6-2).

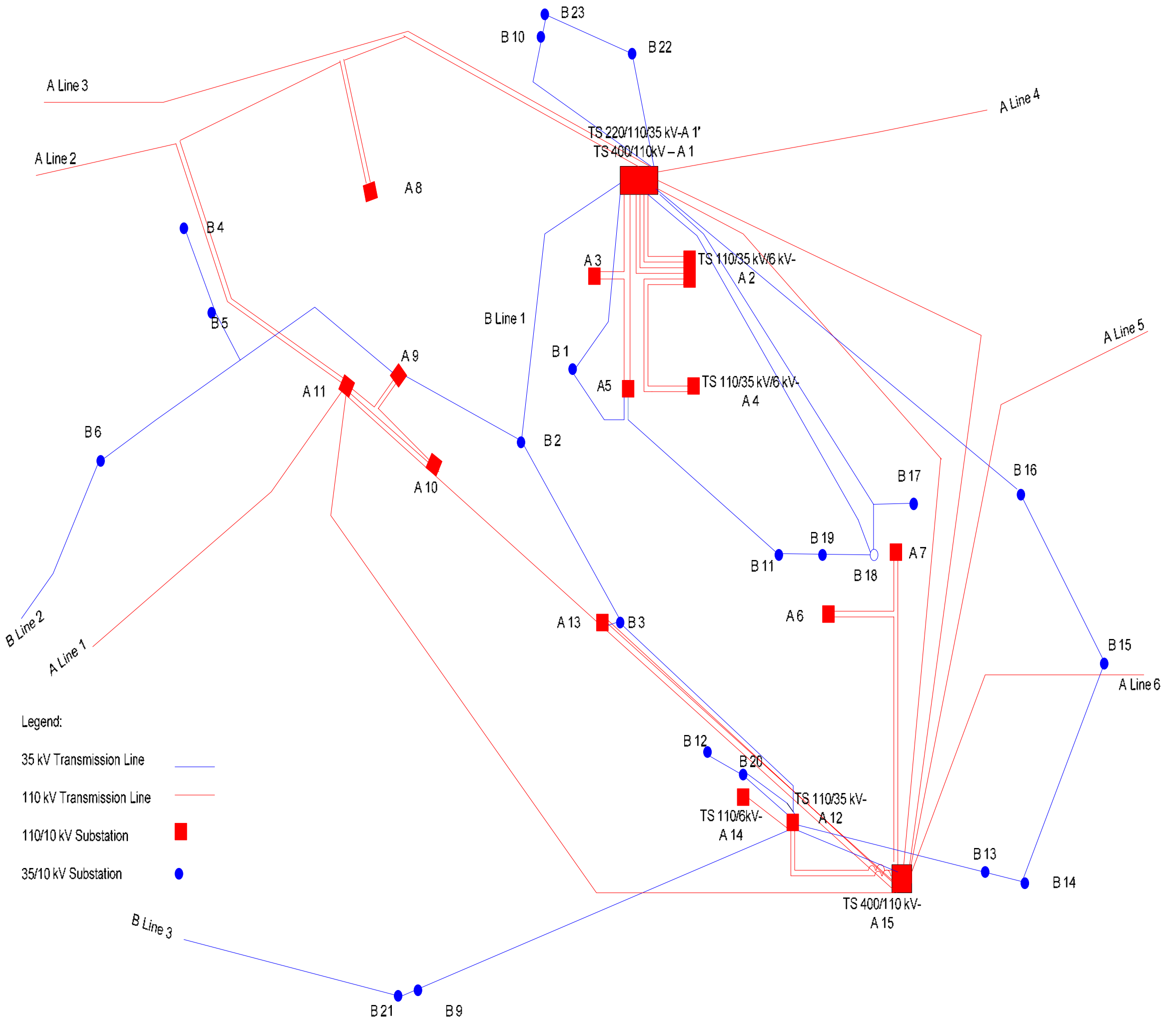


Figure 6-2; Single line diagram of the existing network for the Capital city

6.1.2 Description

The load flow calculations are carried out in order to keep the system running in a stable and safe state and are used to determine possible or optimal choice of the grid's components (transformers' voltage regulators, automatic control settings of the machine regulators). The determining inputs are usually the voltages and/or currents and/or the active/reactive power at the consumer's port or at the generator's port.

Lines - overhead lines and cables – are important elements. In order to carry out grid calculations in a simple way, it is common practice to use as few circuit elements as is possible for the given task. In the case of low voltage lines in most cases an ohmic resistance will do and even for high voltage lines in most cases the longitudinal impedance is taken into consideration. For long lines one must also take the capacitive components into account [7]

To classify the equipment overload and busbar voltages the following limit values together with network operator are defined:

Network equipment description	Degree of loading
-	%
rated load	< 80
heavy load	≥ 80, < 100
over load	≥ 100

Voltage level description	The Voltage is more than % of Nominal Voltage
-	%
busbar voltage is ok	≥ 94, ≤ 106
busbar voltage is to low	< 94

Table 6-1 Classification of busbar voltage and overloaded element [14]

According to the Europe Standard EN 50160 for medium-voltage-supply the supply voltage variations are characterized as:

Under normal operating conditions excluding voltage interruptions, during each period of one week, 95 % of the 10 min mean r.m.s. values of the supply voltage shall be within the range of Uc ± 10 %.[15]

6.1.3 Load-Flow Explanation

System and equipment data are common for load-flow and short-circuit studies, with the exception of the tolerance given in the standards. Apply positive tolerance for load flow and negative tolerance for short circuit. Suggested guide lines to help avoid errors are:

- Enter the data with care, especially with units. This is the most common cause of error.
- Start with a small system, for example a 10-bus network, and expand the system as the solution is found.
- Do not use very small impedances for ties and feeders.
- Add a dummy capacitor or a synchronous condenser for voltage support if the solution does not converge. [4]

6.1.4 Single Line Diagram

A one-line diagram is a simplified notation for representing a three-phase power system. The one-line diagram has its largest application in power flow studies. Electrical elements such as circuit breakers, transformers, capacitors, busbars and conductors are shown by standardized schematic symbols. Instead of representing each of three phases with a separate line or terminal, only one conductor is represented see figure (6.3). The theory of three-phase power systems tells us that as long as the loads on each of the three phases are balanced and the lines, transformers and busbars are symmetrical, we can consider each phase separately. In power engineering, this assumption is usually true (although an important exception is the asymmetric fault), and to consider all three phases requires more effort with very little potential advantage. A one-line diagram is usually used along with other notational simplifications, such as the per-unit system. A secondary advantage to using a one-line diagram is that the simpler diagram leaves more space for non-electrical, such as economic, information to be included. A presentation of a single line diagram of an 11-kV Switchgear as an example in Asian country (Iraq) is shown bellow in Figure (6-3), and a typical electricity power system in the same country is shown in Figure (6-4).

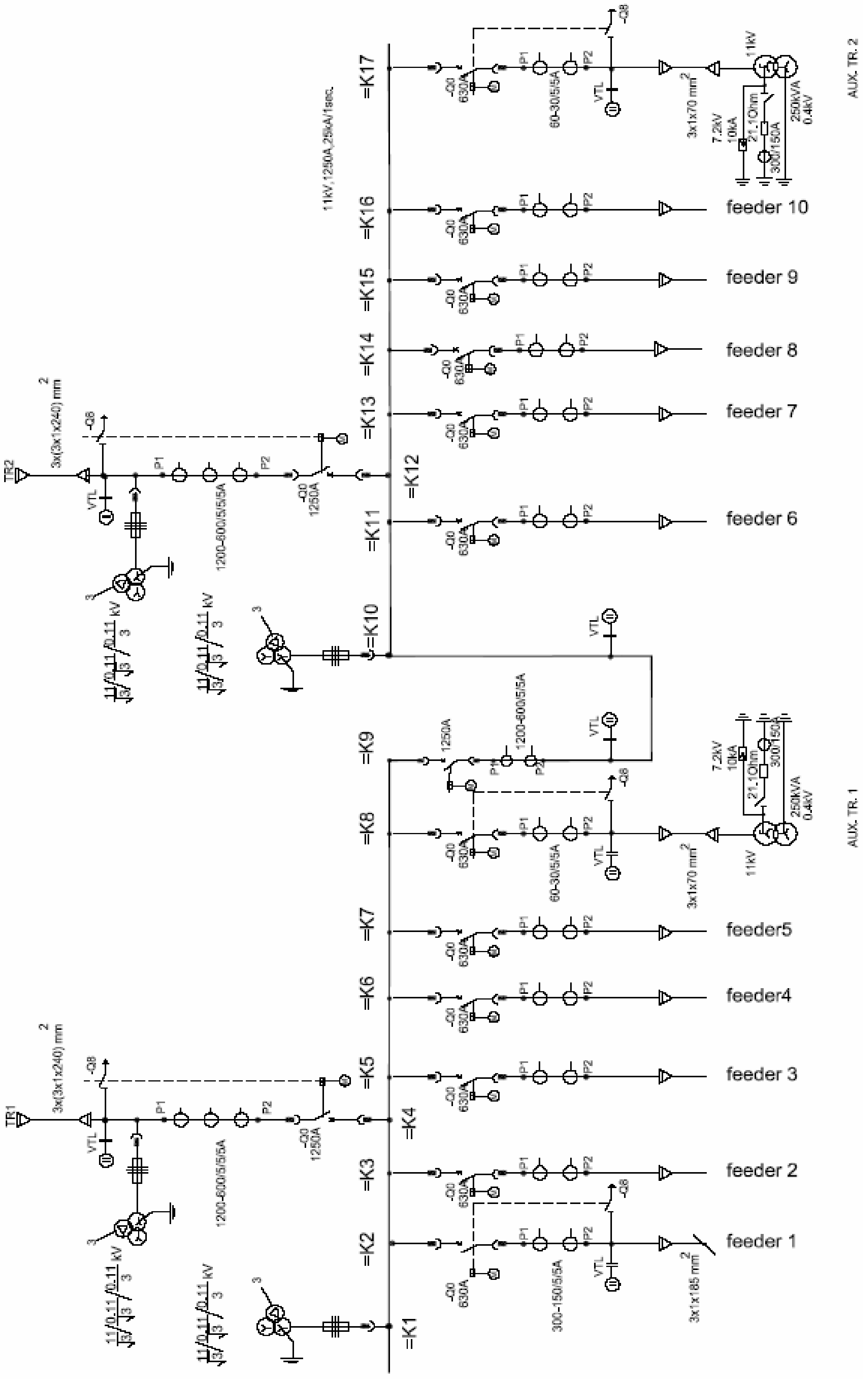


Figure 6-3; Single line diagram of 11 kV switchgear

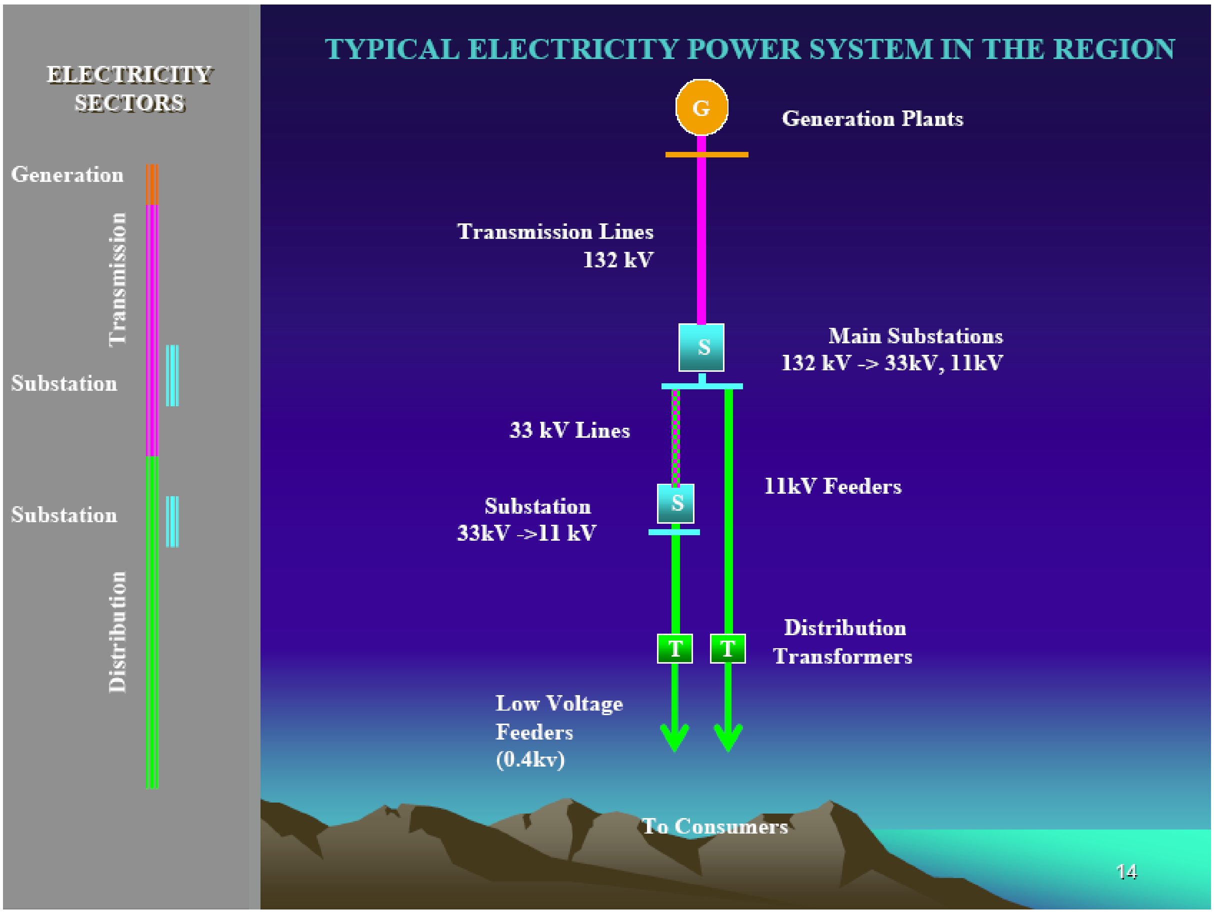


Figure 6-4; Typical electricity power system in an Asian country [17]

6.2 Power Quality

Classification of Power system disturbances:

To make the study of Power Quality problems useful, the various types of disturbances need to be classified by magnitude and duration. This is especially important for manufacturers and users of equipment that may be at risk. The principal standards in this field are IEC 61000, EN 50160, and IEEE 1159. Standards are essential for manufacturers and users alike, to define what is reasonable in terms of disturbances that might occur and what equipment should withstand. [9]

The following definition has been worked out by the IEC - TC77A / WG09 "Power Quality Measurement Methods" in the course of the standard 61000-4-30 task force: Power Quality: The characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters. The following parameters are relevant for the power quality corresponding the European standard EN 50160:

- Voltage level, slow voltage deviation
- Voltage dips (short, long)

- Voltage drop
- Rapid voltage deviation, flicker
- Unbalance
- Voltage distortion (harmonics, signal, voltage)
- Transient and mains frequency overvoltage
- Frequency [12]

6.3 Load Flow Calculation Method

The goal of a power flow study is to obtain the complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance.

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus.

- A bus without any generators connected to it is called a Load Bus.
- With one exception, a bus with at least one generator connected to it is called a Generator Bus.
- The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the Slack Bus. [6]
- Slack Bus at which:

$$P = \infty$$
$$Q = \infty$$
$$V = \text{constant}$$

Type	Known variables	unknown variables
1. SL, Slack	**V,theta**	**Pg,Qg**
2. PV, Voltage controlled bus	**Pg,V**	**Qg, theta**
3. PQ, Load bus	**Pg, Qg, Pd, Qd**	**V, theta**

Table 6-2 Classification of load flow busses [16]

V =voltage magnitude
Theta =voltage angle
Pg, Qg =MW, MVar generation
Pd, Qd =MW, MVar demand [16]

Either the bus self and mutual admittances which compose the bus admittances matrix Y bus may be used in solving the load flow problem. We shall confine our study to methods using admittances. Operating conditions must always be selected for each study. [18]

In the power flow problem, it is assumed that the absorbed real power P_d and reactive power Q_D at each Load Bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real power generated P_g and the voltage magnitude *V* are known. For the Slack Bus, it is assumed that the voltage magnitude *V* and voltage angle are known. Therefore, for each Load Bus, both of the voltage magnitude and angle are unknown and must be solved for; for each Generator Bus, the voltage angle and Q must be solved. In a system with *N* buses and R generators, there are then 2(N − 1) − (R − 1) unknowns. In order to solve the 2(N − 1) − (R − 1) unknowns, there must be 2(N − 1) − (R − 1) equations that do not introduce any new unknown variables. The possible equations to use are power balance equations, which can be written for real and reactive power for each bus, for the bus k is given. The real power balance equation is:

$$0 = -P_i + \sum_{k=1}^{N} V_i V_k \left(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik} \right)$$

Pi = net power injected at bus i
Gik = real part of the element in the Y_{bus} corresponding to the i^{th} row and k^{th} column,
Bik = imaginary part of the element in the Y_{bus} corresponding to the i^{th} row and k^{th} column
θik = difference in voltage angle between the ith and kth buses.
Qi = net reactive power injected at bus i.
N = total number of buses
Vi = voltage at bus i
Vk = voltage at bus k
k = varying index
V = voltage magnitude

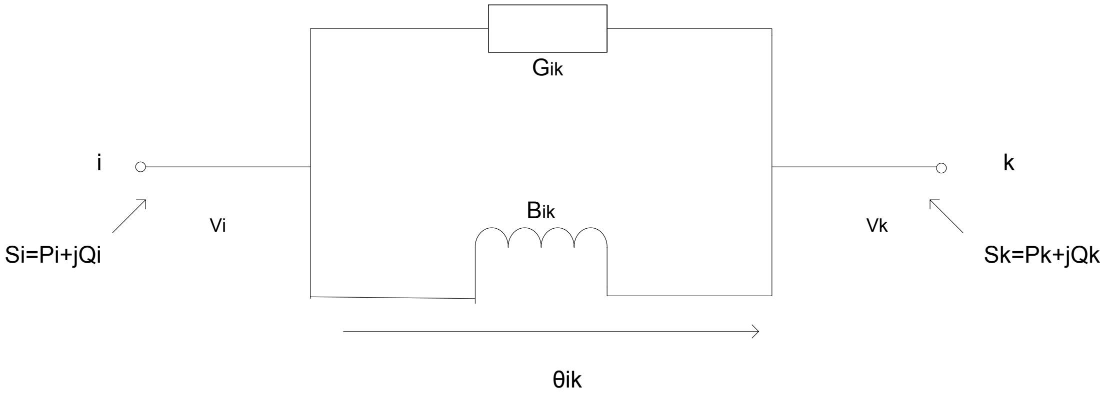


Figure 6-5; Typical scheme of load flow characteristic

where P_i is the network power injected at bus i, G_{ik} is the real part of the element in the Y_{bus} corresponding to the i^{th} row and k^{th} column, B_{ik} is the imaginary part of the element in the Y_{bus} corresponding to the i^{th} row and k^{th} column and θ_{ik} is the difference in voltage angle between the ith and kth buses. The reactive power balance equation is:

$$0 = -Q_i + \sum_{K=1}^{N} V_i V_k \left(G_{ik} \sin\theta_{ik} + B_{ik} \cos\theta_{ik} \right)$$

where Q_i is the netork reactive power injected at bus i. Equations included are the real and reactive power balance equations for each Load Bus and the real power balance equation for each Generator Bus. Only the real power balance equation is written for a Generator Bus because the network reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the Slack Bus. [6]

6.4 Power Flow Methods

The method of load flow calculation with NEPLAN® 5.3.4 program is used. Load flow can be calculated with

- Extended Newton-Raphson
- Power iteration method
- Newton-Raphson
- DC flows

6.4.1 Newton's Method

In numerical analysis, Newton's method (also known as the Newton–Raphson method or the Newton–Fourier method) is perhaps the best known method for finding successively better approximations to the zeros (or roots) of a real-valued function.

Unlike Gauss-Seidel, (GS) which updates the bus voltage one at a time, Newton Raphson, (NR) solves a voltage correction for all the buses and updates them. Comparing NR with GS, GS has problems when the system becomes large. One reason is the presence of negative impedances as a result of 3-winding transformer representation. GS tends to increase in iteration count and is slow in computer time. [16]

Most production-type power-flow programs use the power equation form with polar coordinates, for any bus k we have:

$$\tilde{S}_k = P_k + jQ_k = \tilde{V}_k \tilde{I}^*_k \text{ .... (1)}$$

$$\text{Since } \tilde{I}_k = \frac{P_k - jQ_k}{\tilde{V}^*_k}$$

$$I_k = Y_k \cdot V_k$$

$$V_k^{*-1}\left(P_k - jQ_k\right) = Y_k \cdot V_k$$

$$\tilde{I}_k = \sum_{m=1}^{n} \tilde{Y}_{km} \tilde{V}_m \text{ .... (2)}$$

Substitution of $\tilde{I}_k$ given by Equation (2) in Equation (1) yields

$$P_k + jQ_k = \tilde{V}_k \sum_{m=1}^{n} \left(G_{km} - jB_{km}\right) \tilde{V}^*_m$$

n = unknown
ki = bus
V = Voltage vector
P = Power
Q = reactive power
θ = phase angel
$\tilde{V}_k$ =is the phasor voltage to ground at node i
$\tilde{I}_k$ = is the phasor current flowing into the network at node i

The product of phasors $\tilde{V}_k$ and $\tilde{V}^*_m$ may be expressed as

$$\tilde{V}_k \tilde{V}^*_m = \left(V_k^{e^{j\theta_k}}\right)\left(V_m^{e^{-j\theta_m}}\right) = V_k V_m^{e^{j(\theta_k - \theta_m)}}$$

$$= V_k V_m \left(\cos\theta_{km} + j\sin\theta_{km}\right) \qquad \left(\theta_{km} = \theta_k - \theta_m\right)$$

Therefore, the expressions for P_k and Q_k may be written in real form as follows:

$$P_k = V_k \sum_{m=1}^{n} \left(G_{km} V_m \cos\theta_{km} + B_{km} V_m \sin\theta_{km} \right)$$

$$Q_k = V_k \sum_{m=1}^{n} \left(G_{km} V_m \sin\theta_{km} - B_{km} V_m \cos\theta_{km} \right)$$

Thus, P and Q at each bus are functions of voltage magnitude *V* and angle θ of all buses. [20]

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equations are below a specified tolerance. A rough outline of solution of the power flow problem is:

- Make an initial guess of all unknown voltage magnitudes and angles. It is common to use a "flat start" in which all voltage angles are set to zero and all voltage magnitudes are set to 1.0 p.u.
- Solve the power balance equations using the most recent voltage angle and magnitude values.
- linearize the system around the most recent voltage angle and magnitude values
- solve for the change in voltage angle and magnitude
- update the voltage magnitude and angles
- Check the stopping conditions, if met then terminate. [6]

6.4.2 Gauss-Seidel Method

The Gauss-Seidel method is a technique used to solve a linear system of equations. The method is named after the German mathematicians Carl Friedrich Gauss and Philipp Ludwig von Seidel. The method is an improved version of the Jacobi method. It is defined on matrices with non-zero diagonals, but convergence is only guaranteed if the matrix is either diagonally dominant or symmetric and positive definite. A method Gauss-Seidel can solve the unknown voltage. [6]

Form equations $\tilde{I}_k = \frac{P_k - jQ_k}{\widetilde{V^*}_k} = \tilde{V}_k \tilde{I}_k$ for the kth bus we can write

$$\frac{P_k - jQ_k}{\tilde{V}^*_k} = Y_{kk} \tilde{V}_k + \sum_{\substack{i=1 \\ i \neq k}}^{n} Y_{ki} \tilde{V}_i \text{ .... } (1)$$

from which the voltage $\tilde{V}_k$ may be expressed as

$$\widetilde{V}_k = \frac{P_k - jQ_k}{\widetilde{V}^*_k Y_{kk}} - \frac{1}{Y_{kk}} \sum_{\substack{i=1 \\ i \neq k}}^{n} Y_{ki} \widetilde{V}_i \quad .... (2)$$

I = Current vector
Yii = admittance matrix
U = Voltage vector
P = Power
Q = reactive power
θ = phase angel
n = total number of nodes
$\widetilde{V}_k$ =is the phasor voltage to ground at node i
$\widetilde{I}_k$ = is the phasor current flowing into the network at node i

Equation (1) is the heart of the iterative algorithm. The iterations begin with an informed guess of the magnitude and angle of the voltages at all load buses, and of the voltage angle at all generator buses. For load bus, P and Q are known, and Equation (2) is used to compute the voltage $\widetilde{V}_k$ by using the best available voltages for all the buses. [20]

6.5 Electrical Power Industry

The electrical power industry provides the production and delivery of electrical power (electrical energy), often known as power, or electricity, in sufficient quantities to areas that need electricity through a grid. Many households and businesses need access to electricity, especially in developed nations, the demand being scarcer in developing nations. Demand for electricity is derived from the requirement for electricity in order to operate domestic appliances, office equipment, industrial machinery and provide sufficient energy for both domestic and commercial lighting, heating, cooking and industrial processes. Because of this aspect of the industry, it is viewed as a public utility as infrastructure.

The electrical power industry is commonly split up into four processes. These are electricity generation such as a power station, electric power transmission, electricity distribution and electricity retailing.

6.5.1 Transmission of Power

Power is the rate of flow of energy past at a given point. In alternating current circuits, voltage and current only remain in phase if the load is purely resistive. When this happens the power is said to be 'real power'. If instead the load is purely reactive (either capacitive or inductive), all of the power is reflected back to the generator as the phase cycles. The load is said to draw zero real power, instead it draws only 'reactive power'. If a load is both resistive and reactive, it will have both real and reactive power, resulting in total amount of power called the 'apparent power'.

The portion of power flow averaged over a complete cycle of the AC waveform that results in net transfer of energy in one direction is known as real power. The portion of power flow due to stored energy which returns to the source in each cycle is known as reactive power. [19]

Effect of Voltage on Transmission Efficiency:

Let us suppose that a power of (W) Watt is to be delivered by a 3- phase transmission line at a line voltage of V and power factor cos φ.

The line current $I = \frac{W}{\sqrt{3}V^{*}\cos\varphi}$

Then $A = \frac{I}{\sigma} = \frac{W}{\sqrt{3}\cdot V\cdot\sigma\cdot\cos\varphi}$

l=length of the line conductor
σ=current density in ampere/m²
A=cross-section of conductor

Now $R = \frac{\rho l}{A} = \frac{\sqrt{3}\sigma\rho l V\cos\varphi}{W}$

ρ= specific resistance of conductor material

Line loss = 3 x loss per conductor $= 3I^2R$

$$= 3\frac{W^2}{3V^2\cos^2\varphi}\times\frac{\sqrt{3}\sigma\rho l V\cos\varphi}{W} = \frac{\sqrt{3}\sigma\rho l W}{V\cos\varphi} \quad \text{.. ... (1)}$$

Line intake or input $= \text{output} + \text{losses} = W + \frac{\sqrt{3}\sigma\rho l W}{V\cos\varphi} = W\left(1+\frac{\sqrt{3}\sigma\rho l}{V\cos\varphi}\right)$

Efficiency of transmission $= \frac{\text{output}}{\text{input}} = \frac{W}{W\left(1+\frac{\sqrt{3}\sigma\rho l}{V\cos\varphi}\right)} = \left(1-\frac{\sqrt{3}\sigma\rho l}{V\cos\varphi}\right)$ approx.……..... (2)

Voltage drop per line $= IR = \frac{\sqrt{3}\sigma l V\cos\varphi}{W}\times\frac{W}{\sqrt{3}V\cos\varphi} = \sigma\rho l$ ……………………………....... (3)

Total Volume of copper $= 3lA = \frac{3Wl}{\sqrt{3}\cdot\sigma\cos\varphi} = \frac{\sqrt{3}Wl}{\sigma V\cos\varphi}$ ……………………………...…. (4)

*** In [13] the voltage is given as E, instead that the voltage is represented with V.**

- From equation (1), line losses are inversely proportional to V. It is also inversely proportional to the power factor, cos φ.
- Transmission efficiency increases with the voltage of transmission and power factor as seen from equation (2).
- As seen from equation (3), for a given current density, the resistance drop per line is constant **(**since ρ and I have been assumed fixed in the present case**)**. Hence, percentage drop is decreased as (V) is increased.
- The volume of copper required for a transmission line is inversely proportional to the voltage and the power factor as seen from equation (4)

It is clear from the above that for long distance transmission of an AC. Power, high voltage and high power factor are essential. Economical upper limit of voltage is reached when the saving in cost of copper or aluminum is offset by the increased cost of insulation and increased cost of transformers and high-voltage switches. Usually, 650 volt per route km is taken as a rough guide for 110 kV (high voltage). [13]

6.5.2 Power Factor

The power factor has an effect on the efficiency of an AC power system. The power factor is the real power per unit of apparent power. A power factor of one is perfect, and 99% is good. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (φ) between the current and voltage sinusoid waveforms. Equipment data sheets and nameplates often will abbreviate power factor as "cosφ" for this reason.

The power factor equals 1 when the voltage and current are in phase, and is zero when the current leads or lags the voltage by 90 degrees. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle, where leading indicates a negative sign. For two systems transmitting the same amount of real power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from energy storage in the load. These higher currents in a practical system will produce higher losses and reduce overall transmission efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of real power transfer.

A lagging power factor is one in which the current is lagging behind the voltage and is characteristic of an inductive load. A leading power factor is one in which the current is leading the voltage and is characteristic of a capacitive load.

The Lagging Power Factor: Consider an inductive load as shown in Figure (6-6). In this circuit, both watts and VARs are delivered from the source. The corresponding phasor diagram is shown in figure (6-6). The power factor angle in this case is negative, and therefore the power factor is lagging.

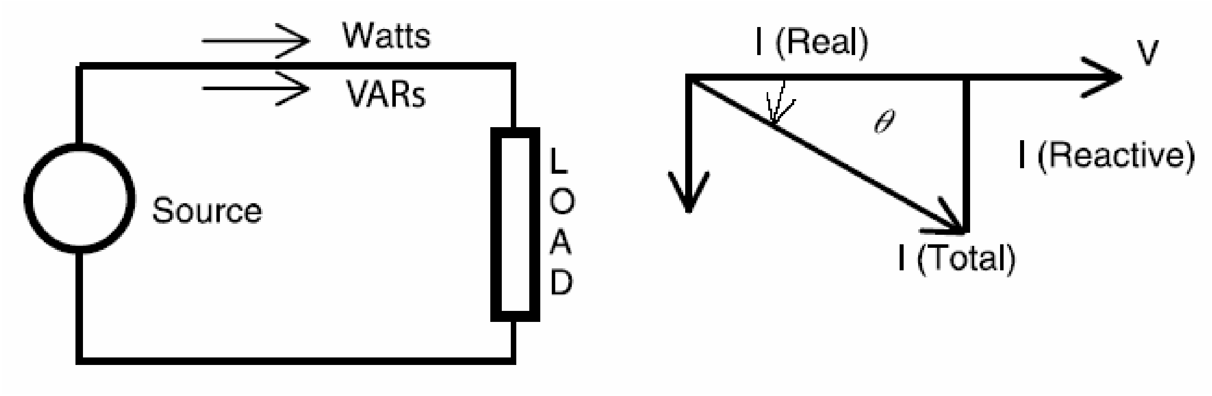


Figure 6-6; The concept of lagging power factor [3]

The Leading Power Factor: Consider a capacitive load as shown in Figure (6-7). In this circuit, the watts are delivered from the source. The reactive power (VARs) is delivered from the load to the source. The corresponding phasor diagram is shown in figure (6-7). The power factor angle in this case is positive, and therefore the power factor is leading.

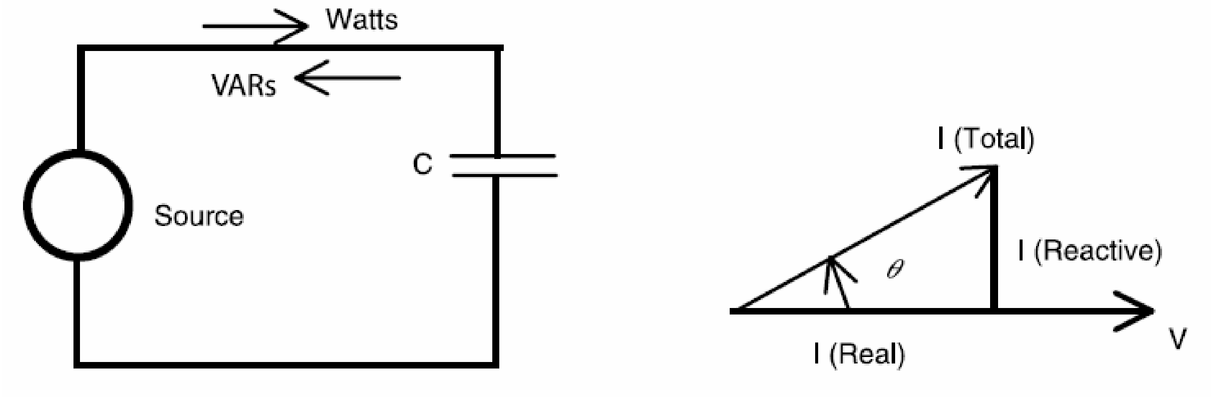


Figure 6-7; The concept of leading power factor [3]

Purely capacitive circuits cause reactive power with the current waveform leading the voltage wave by 90 degrees, while purely inductive circuits cause reactive power with the current waveform lagging the voltage waveform by 90 degrees. The result of this is that capacitive and inductive circuit elements tend to cancel each other out. [1]

Power Factor Improvement: Many utilities prefer a power factor of the order of 0.95. Since industrial equipment such as an induction motor operates at a much lower power factor, the overall power factor of the industrial load is low. In order to improve the power factor, synchronous condensers or capacitors are used. The synchronous machines, when operated at leading power factor, absorb reactive power and are called synchronous condensers. These machines need operator attendance and require periodical maintenance.

Power factor capacitors are static equipment without any rotating parts and require less maintenance. Therefore, shunt capacitors are widely used in power factor correction applications. The shunt capacitors provide kVAR at leading power factor and hence the overall power factor is improved. [3]

6.6 Network planning

Power system planning is the recurring process of studying and determining which facilities and procedures should be provided to satisfy and promote appropriate future demands for electricity. The electric power system as planned should meet or balance social goals. These include availability of electricity to all potential users at the lowest possible cost, minimum environmental damage, high levels of safety and reliability, etc. Plans should be technically and financially feasible. Plans also should achieve the objectives of the entity doing the planning, including minimizing risk. [1]

6.6.1 Network Planning Methodology

A traditional network planning methodology involves four layers of planning, namely:

- Business planning
- Long-term and medium-term network planning
- Short-term network planning
- Operations and maintenance

Each of these layers incorporate plans for different time horizons, i.e. the business planning layer determines the planning that the operator must perform to ensure that the network will perform as required for its intended life-span. The Operations and Maintenance layer, however, examines how the network will run on a day-to-day basis. The network planning process begins with the acquisition of external information. This includes:

Forecasts of how the new network/service will operate; the economic information concerning costs; and the technical details of the network’s capabilities. Because of the complexity of network dimensioning, this is typically done using specialized software tools. Whereas researches typically develop custom software to study a particular problem, network operators typically make use of commercial network planning software (e.g.NEPLAN®).

It should be borne in mind that planning a new network/service involves implementing the new system across the first four layers of the open system interconnection basic reference model (OSI). This means that even before the network planning process begins, choices must be made, involving protocols and transmission technologies. Once the initial decisions have been made, the network planning process involves three main steps:

- **Topological design**: This stage involves determining where to place the components and how to connect them the (topological) optimization methods that can be used in this stage come from an area of mathematics called Graph Theory. These methods involve determining the costs of transmission and the cost of switching, and thereby determining the optimum connection matrix and location of switches and concentrators.
- **Network-synthesis**: This stage involves determining the size of the components used, subject to performance criteria such as the grade of service (GoS). The method used is known as "Nonlinear Optimization", and involves determining the topology, required GoS, cost of transmission, etc., and using this information to calculate a routing plan, and the size of the components
- **Network realization**: This stage involves determining how to meet capacity requirements, and ensure reliability within the network. The method used is known as "Multicommodity Flow Optimization", and involves determining all information relating to demand, costs and reliability, and then using this information to calculate an actual physical circuit plan

These steps are interrelated and are therefore performed iteratively, and in parallel with one another. [11]

6.6.2 Planning Criteria

Planning criteria is a practical approach to select a predetermined number of the best network system, expansion, alternatives according to the given multiple criteria and accounting for uncertainty factors and proposed decision. In general case the number of optimization criteria is unlimited. They are used as a planning and design tool to protect the interests of all network users in terms of reliability and quality of supply.

6.6.3 Contingency Criteria

Contingency criteria relate to the ability of the network to be reconfigured after a fault so that the unfaulted portions of the network are restored.

- Urban High Voltage Distribution Feeders: High voltage distribution feeders in urban areas shall be planned and designed so that, for a zone substation feeder circuit or exit cable fault, the load of that feeder can be transferred to adjacent feeders by manual network reconfiguration. Where practical, the network shall be planned and designed so that, in the event of a failure of a zone substation transformer, all of the load of that transformer can be transferred to other transformers within the same zone substation and adjacent zone substations.

- Rural High Voltage Distribution Feeders: The radial nature of rural distribution feeders normally precludes the application of contingency criteria to these feeders. However, where reasonably achievable, interconnection between feeders shall be provided, and reclosers and sectionalizes shall be installed to minimize the extent of outages.
- Low Voltage Distribution Networks: Where practical, low voltage distribution networks in urban areas are constructed as open rings to provide an alternative supply to as many customers as possible.

6.6.4 Steady State Criteria

The steady state criteria define the adequacy of the network to supply the energy requirements of users within the component ratings and frequency and voltage limits, taking in to account planned and unplanned outages. The steady state criteria apply to the normal continuous behavior of a network and also cover post disturbance behavior once the network has settled. In planning a network it is necessary to assess the reactive power requirements under light and heavy load to ensure that the reactive demand placed on the generators, be it to absorb or generate reactive power, and does not exceed the capability of the generators. Network frequency will fall if there is insufficient total generation to meet demand. Although the reduction in frequency will cause a reduction in power demand, it is unlikely that this will be sufficient and loads shall be disconnected until the frequency rises to an acceptable level. In the following sub-sections, the various components of the steady state planning criteria are defined.

- Real and Reactive Generating Limits: Limits to the VAr generation and absorption capability of generators shall not be exceeded. Generators shall be capable of supplying the VArs for the associated load and also those necessary to maintain the voltage at the connection point at the level that existed prior to the connection of the generator.
- Steady State Voltage Limits:

  High Voltage

  The network shall be designed to achieve a continuous network voltage at a user's connection not exceeding the design limit of 110% of nominal voltage and not falling below 90% of nominal voltage during normal and maintenance conditions.
- Frequency Limits: Under emergency conditions the network frequency may vary between 47 - 52 Hz, until the underfrequency load shedding schemes operate to reduce the load on the network.

- Thermal Rating Limits: The thermal ratings of network components shall not be exceeded under normal or emergency operating conditions when calculated on the following basis:

  1. Transformers: Manufacturer's name plate rating.
  2. Switchgear: Manufacturer's name plate rating.
  3. Overhead Lines: Rating calculated in accordance with standard and rating temperature in winter and summer and conductor design clearance temperature.
  4. Cables: Normal cyclic rating, with maximum operating temperatures. [2]

6.7 Network Losses

To start planning any network, it is important to know if the network losses related to population density and electricity use, or do they rather depend on network design. If so, is there a large scope for improvement by changing network topology and the specification of network components such as cables and transformers.

6.8 Network Topology

Network topology is the study of the arrangement or mapping of the elements of a network, especially the physical (real) and logical (virtual) interconnections between nodes. (See Figure 6-8)

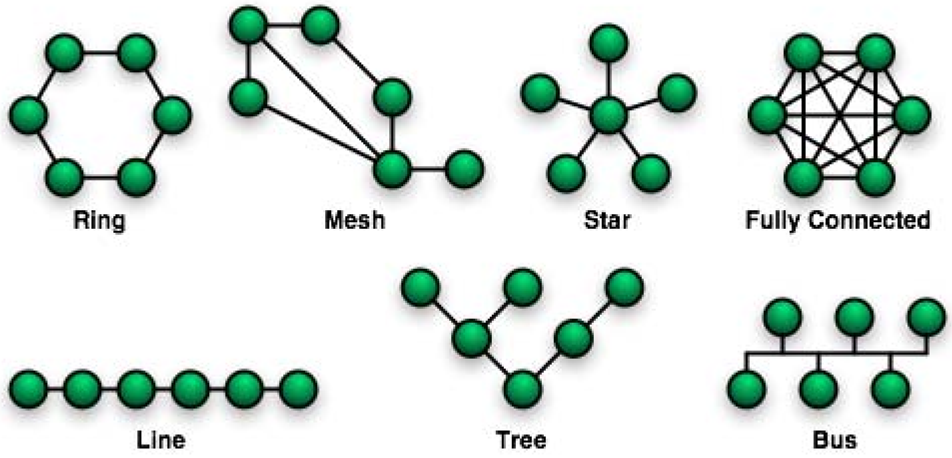


Figure 6-8; Diagram of different network topologies [10]

6.8.1 Ring Network

Ring network is a network topology in which each node connects to exactly two other nodes, forming a circular pathway for signals. (See Figure 6-9)

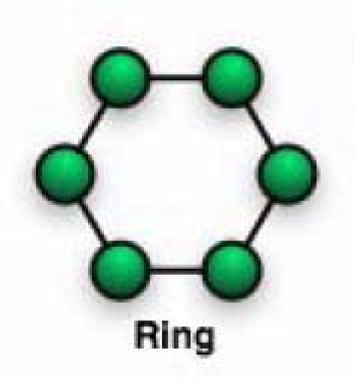


Figure 6-9; Diagram of ring type network topologies [10]

6.9 Load Flow Calculation

The ability of secure and sufficient electrical energy for consumers in a perfect condition, beside power production needs to have, enough transmission and distribution capacity of the network. With these considerations, while keeping in mind that electrical energy needs increase with time, an expansion of the network in stages is necessary, so that neither bottleneck in the supply, like by congestion of transmission connection or overload of transformers, nor uneconomical investments are made. For this reason, load flow studies in electrical network are necessary.

To classify the equipment overload and busbar voltages the following limit values together with network operator are defined:

Substation 400/110 kV	V_{operate} = 115 kV
Substation 110/35 kV	V_{operate} = 36, 75 kV
Substation 110/20 kV	V_{operate} = 21 kV
Substation 35/10 kV	V_{operate} = 10, 5 kV

The existing single line diagram of the capital city of the sampled network is shown in Figure (6-10)

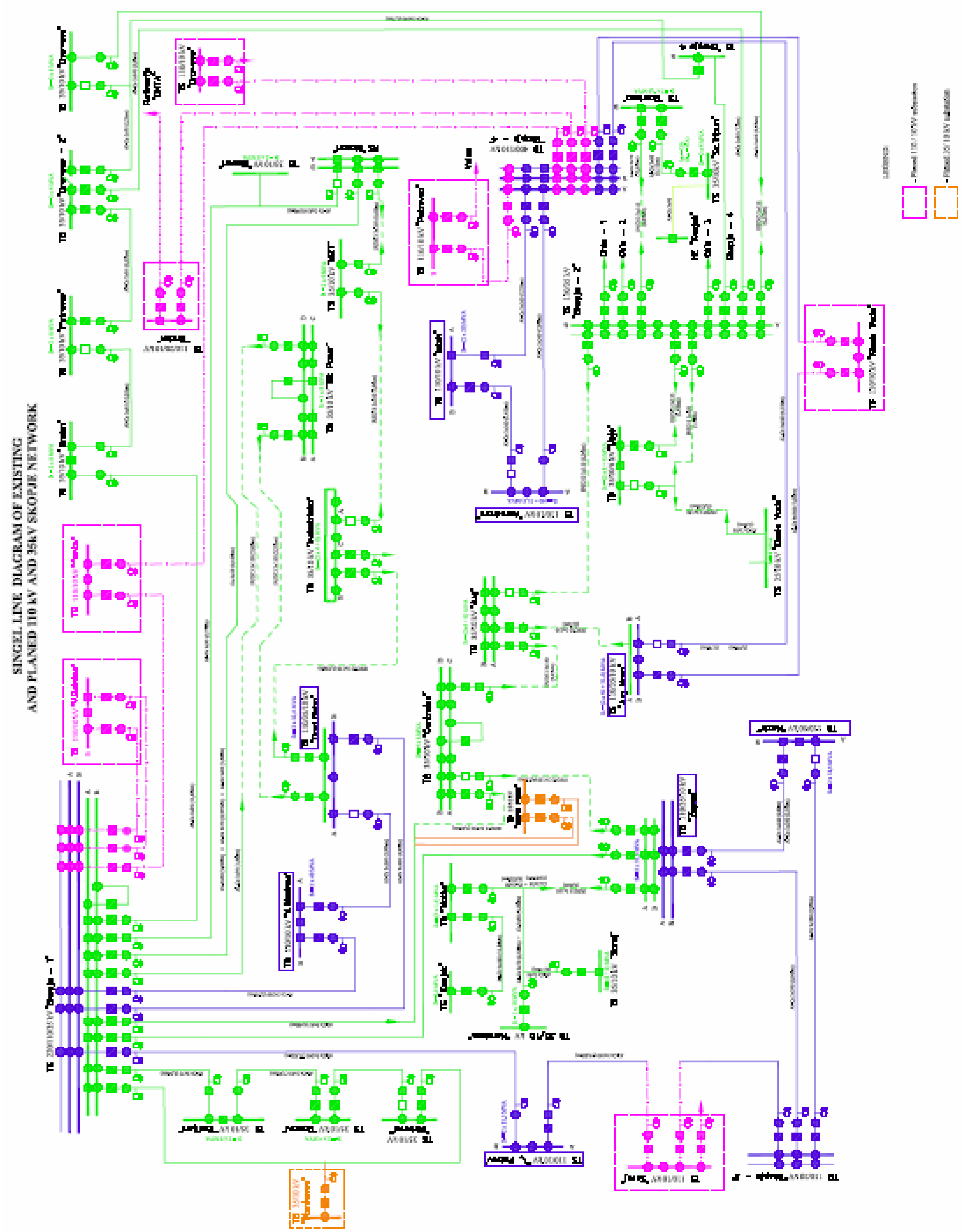


Figure 6-10; Single line diagram of existing and planed 110 kV and 35 kV for the capital city

6.9.1 Load Flow Calculation of the Sample Network

This Master's thesis work is only part of a complete 10 kV network. It reports an investigation on the load flow calculation. The drawing and analysis of the network was done with the Extended Newton-Raphson method of NEPLAN® program. The model network was a realistic model where different problems occurred during the load flow calculation. Further more the load flow calculation of a 10 kV network revealed several line overloads and busbar voltages problem and a solution for the problems is proposed.

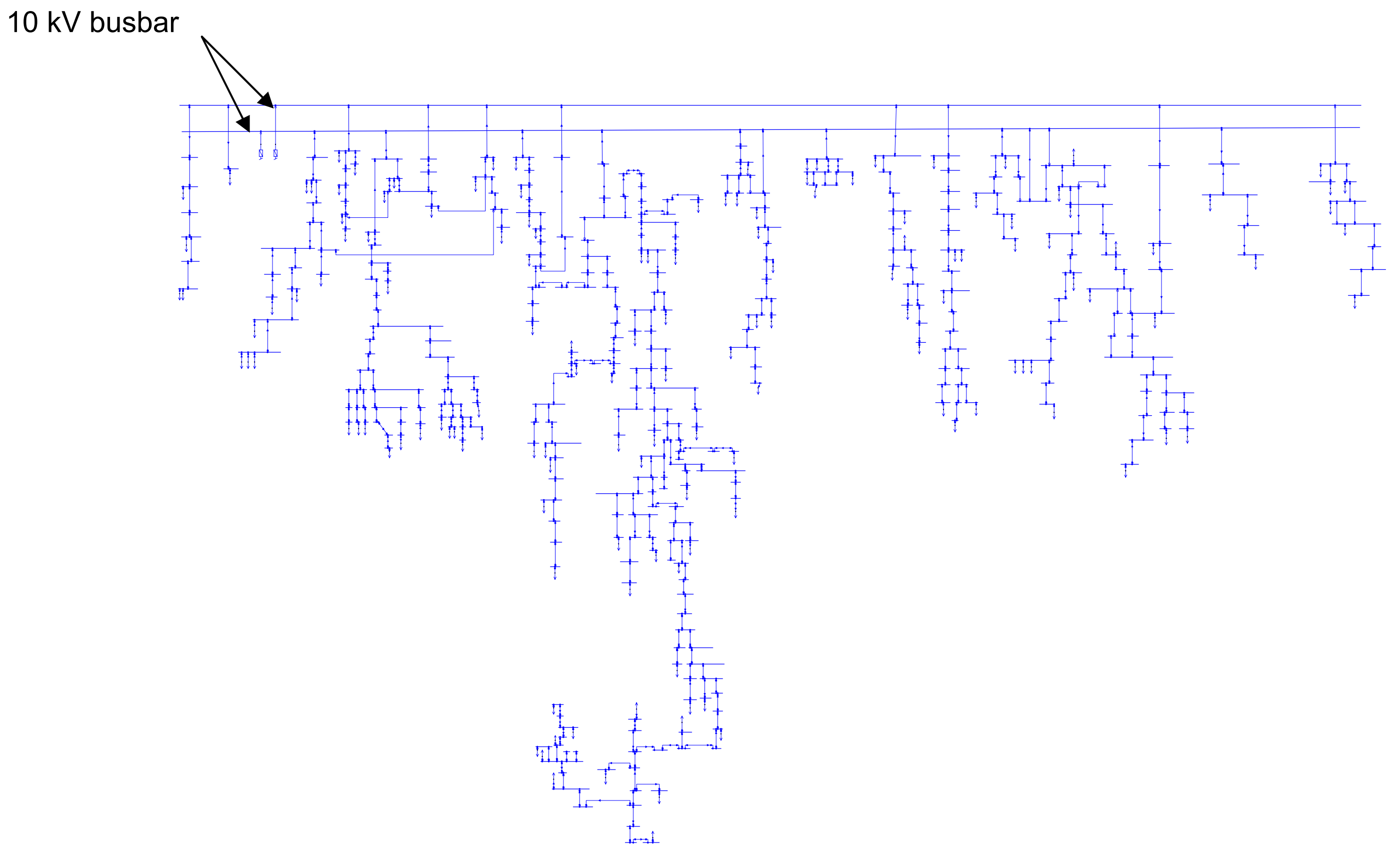


Figure 6-11; Existing 10 kV network

After the calculation of load flow during the existing network, it's noticed that:

- Some voltage problems in bus bars exist
- Some lines become overloaded

See Figure (6-12). The over loaded element parameters are detailed in table (7-3) and the busbar voltage problem are shown in table (7-4).

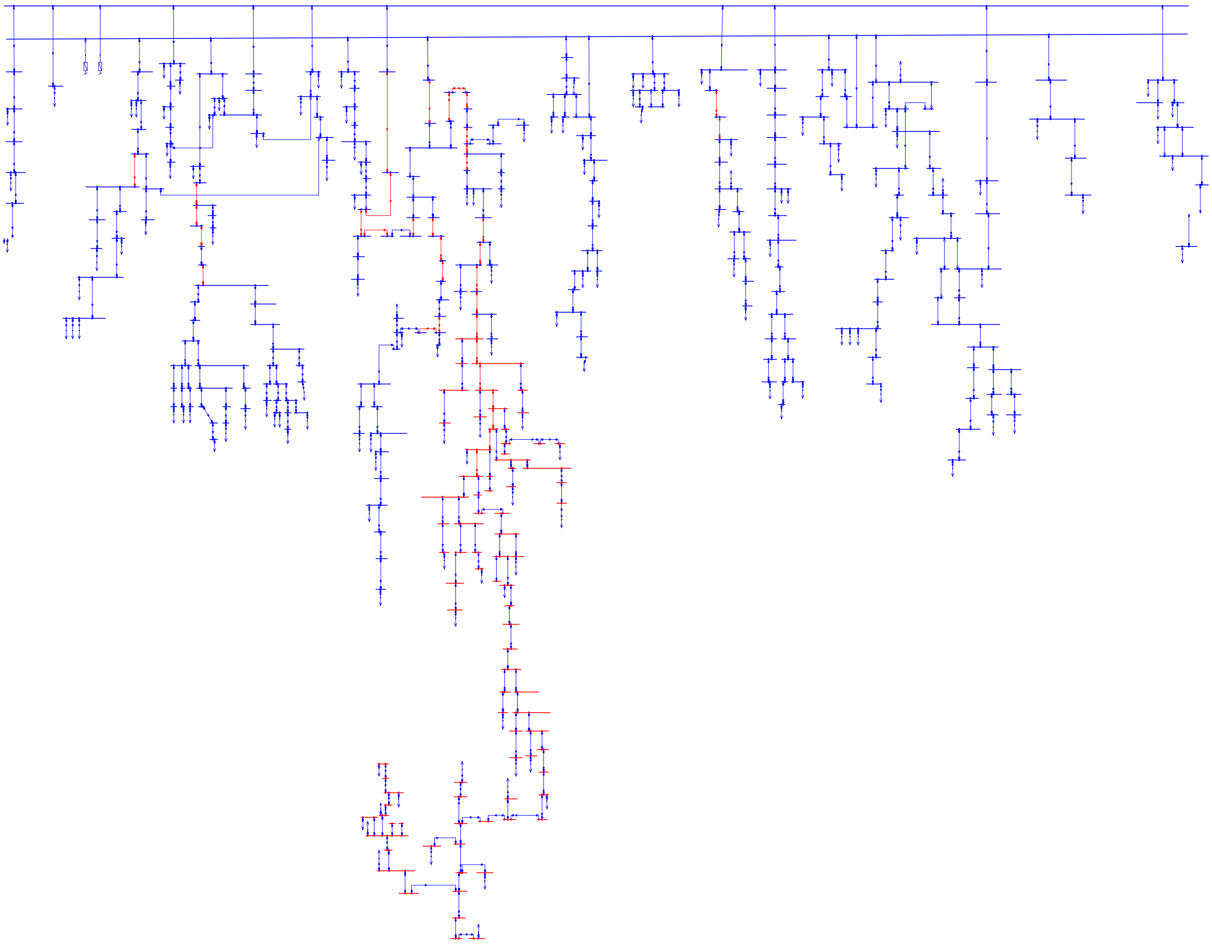


Figure 6-12; Load flow calculation of the existing 10 kV network

Red line = overloaded

6.9.2 Simple Representation of Load Flow Characteristic

One of the most important basics for the network planning and network operation

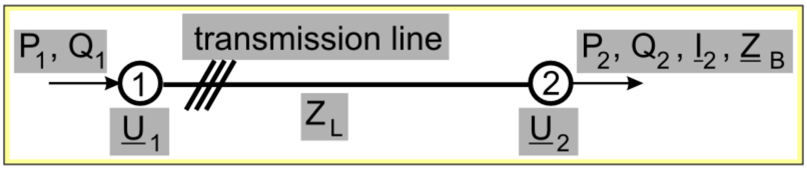


Figure 6-13; Load flow along a line [7]

Under the assumption of a certain load flow along a line the voltages, currents, losses, are determined. Constringency's existing in practical grid operations play an important role. The method and insights can also be extended to transformers, multiple lines and radial grids. Load flow calculation (in medium and high voltage grids) is based on the single line representation, i.e. the representation in the positive sequence system components for sources, lines and loads.

Task	Known values		Comment
	Node 1	Node 2	
1	-	$\underline{U}_2$, P_2, Q_2, (S_2)	Linear tasks
2	$\underline{U}_1$	$\underline{U}_2$	
3	$\underline{U}_1$	$\underline{I}_2$	
4	$\underline{U}_1$	$\underline{Z}_B$	
5	$\underline{U}_1$	P_2, Q_2	Not linear tasks

Table 6-3 Load flow parameter [7]

Voltage level		
Guidelines for deviation of U_n	low voltage (0,4 kV)	+/- 3... 5%
	medium voltage (10 .. 60 kV)	+/- 6... 8%
lt. EN50160	high voltage (.. 110 kV)	+/- 10.. 12%

Table 6-4 Voltage level [7]

Current load: because of economic reason is valid: I ≤ 2kA < thermal current limit.

Transmission losses: high voltage overhead lines: active power loss < 3%

Transmission angle: Guidelines for the transmission angle limit of a high voltage overhead line is: $\vartheta_{gr} = 24°$

Voltage regulator on transformer: setting range must be kept

Evaluation criteria of load flow investigations	
U	At no point of the transmission system the maximum allowed operating voltages must not be exceeded. Neither must the voltage level be below the allowed minimum values.
I	The thermal rating of the conductor (ropes, bus bars, and other operating apparatus) must not be exceeded by the load currents.
P_v	The active power losses and the reactive power losses should be made as small as possible.
ϑ	The limit values of the line transmission angle must not be exceeded. The limits of transmission depend upon the distance of the power transport. (Lines below 500 km are regarded as not critical)

Table 6-5 Evaluation criteria of load flow investigations [7]

6.10 Solutions

Load flow problems could be solved by one of the followings:

- Adding Slack:

There are four quantities of interest associated with each bus:

1. Real power, P
2. Reactive power, Q
3. Voltage magnitude, U
4. Voltage angle, θ

At every bus of the system two of these four quantities will be specified and the remaining two will be unknowns. Each of the system buses may be classified in accordance with which of the two quantities is specified. The following classifications are typical:

Slack bus: The slack bus for the system is a single bus for which the voltage magnitude and angle are specified. The real and reactive powers are unknowns. The bus selected as the slack bus must have a ‘‘slack’’ in the solution. [1]

- Adding transformer & changing the level of the voltage:

The load studies are essential in planning the future development of the system because satisfactory operating of the system depends on knowing the effects of interconnections with other power systems of new loads, new generating stations, and new transmission lines before they are installed. The overload of the busbars and the high drop of voltage at the end of the lines in the sampled network can only be solving by adding a transformer to support the voltage drop and overload in the area. Reactive power tends to flow from higher voltages to lower voltages. In rewiew, if we wish to elevate the voltage level of a particular bus we should inject reactive power ito the bus from appropriate sources. As by load flow calculation the computation of the voltages at all system buses is possible and according to the situation of the network and the ability of supply, solutions of voltages can be found at every busbar by changing the conductor type with another cross section. In the case of sample network as described in the next Section 6.11 this will solve the over load line problems. [21]

6.11 Example and practical Application of Load Flow Calculation

After the load flow calculation of the sample network as described in Section 6.9.1, the voltage at the load end tends to get lower due to the lack of reactive power. In the case of long transmission lines, their active power available at the end of the line during peak load conditions is small and hence according to the system connection and future need of the network, solution should be made by changing conductor type or by inserting a new substation. In the case of overloaded lines as mentioned in the line Nr. 10 (See figure 6-14) it is assumed to change the conductor type with another cross section. The length of the conductor assumed to be changed is 6.859 km. A part of the OHL as shown in table (7-2) was solved by changing it with Aluminum conductor (50 al pex) and it is about 1.46 km. The rest can just be solved by changing with a (95 al pex) and this is about 5.399 km. Because of the small length 1.46 km and the future extension, it will be better to change all OHL with the same type of (95 al pex). See Figure (6-14).

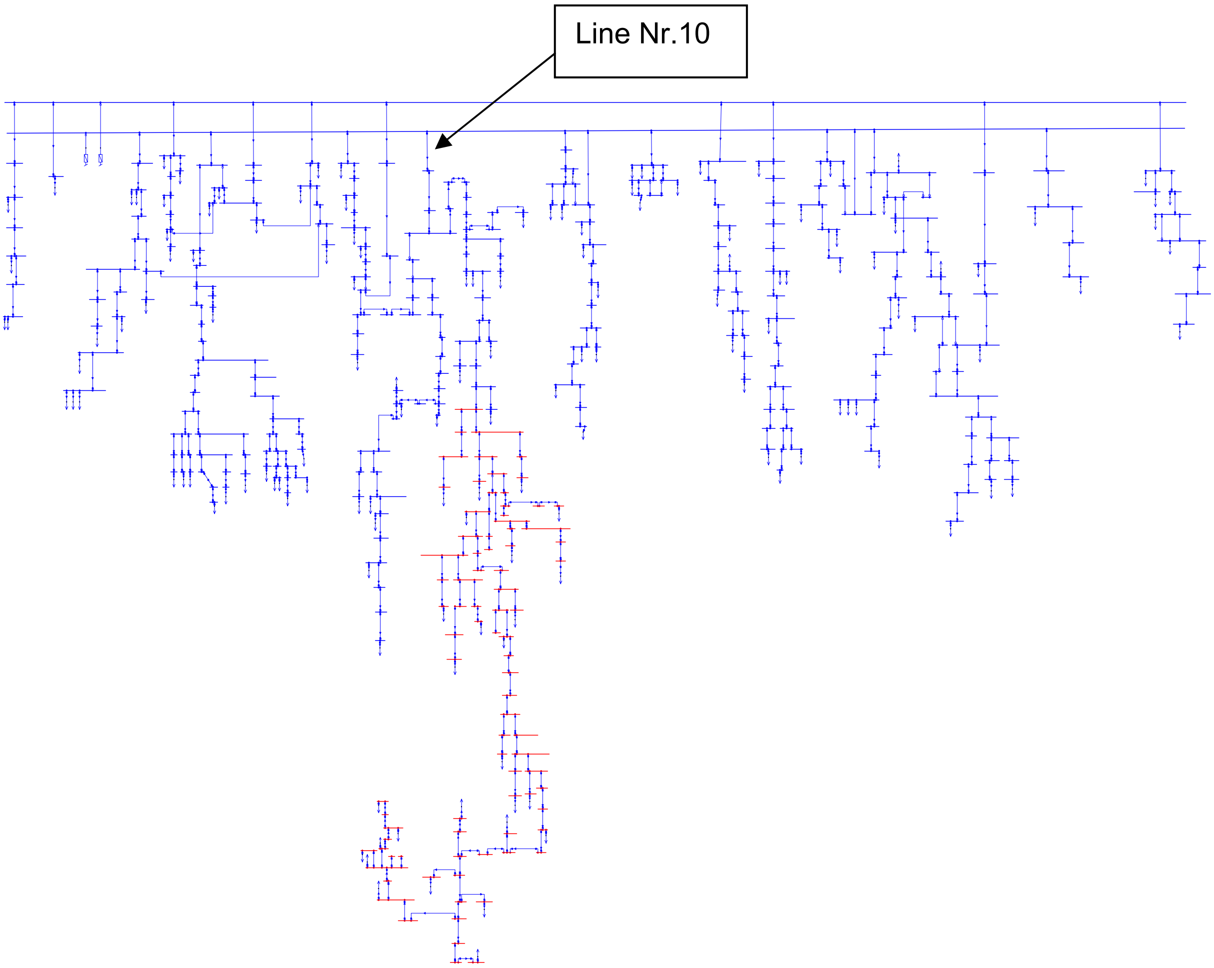


Figure 6-14; The network after changing the conductor type

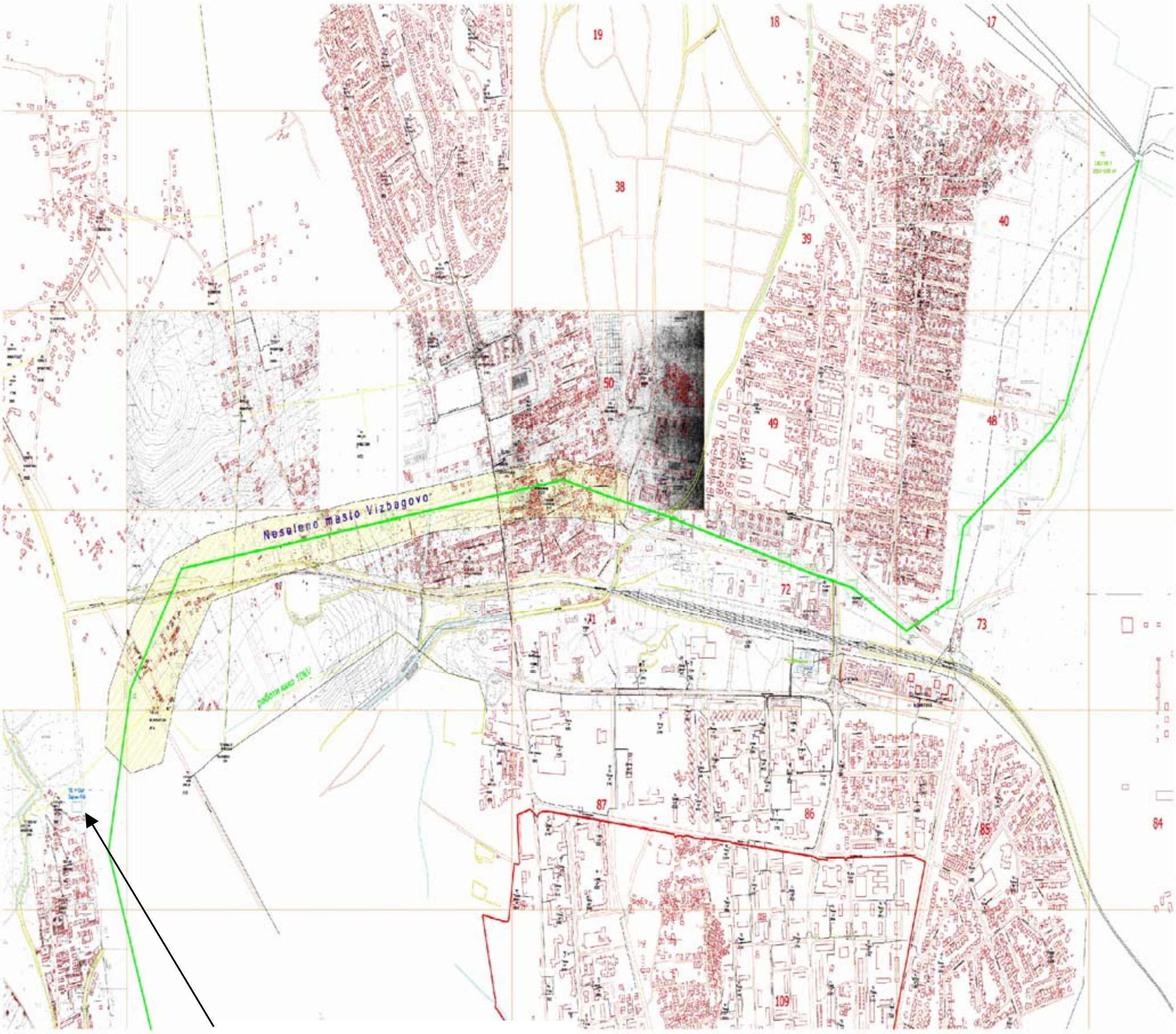
6.11.1 Inserting a new Substation in a Proposed Location

Since the change of conductor cross section has not solved the whole problem as described in Section 6.11, but solved only the overloaded lines problem. The busbar problems are still remaining; the mentioned busbars are with red color as shown in figure (6-14). In the case of long transmission lines, the voltages at the load end are still low. Their active power available at the end of the line during peak load conditions is small and hence according to the system connection and future need of the network, the next solution must be done. To solve the busbars voltage problem it is urgently needed to install a new transformer substation with 1x40 MVA Transformer of (110/10) kV in proposed location. See Figure (6-15) and (6-16). The new proposed transformer substation location is marked with blue color. The busbar voltages of the network after the insertion of the proposed 1x40 MVA transformer are shown in table (7-2).

This location is proposed because of the following reasons:

- One of the important factors in the design of the solution is the determination of the substation location. Special consideration needs to be given to the location to achieve the optimal compromise between the 110 kV line entries to the site and the load centers.
- The city population in this region will increase.
- Substation design considerations present and future location of the load centers.
- Availability of access for the incoming transmission or subtransmission lines and the distribution and communication systems circuits within the main substation.
- Alternative uses of the considered area.
- Location of existing transmission and distribution lines.
- Facilities for the transport of heavy equipment to the site.
- Environmental impacts of the site related to its appearance, noise, or electrical interference or its impact on other facilities.
- Conditions of the ground, its facility of drainage, and its load bearing capability.
- Cost of excavations and earthwork.
- Necessary space for present use and future extensions.
- Governmental or municipal restrictions at the site.
- Security requirements, including any heightened risk of vandalism, theft, or sabotage
- Total cost, including the provision of distribution circuits to the plant and the required control and communication facilities.
- Economical purpose. [4]

The proposed new substation location is shown in Figure (6-15).



Proposed location of the 1x40 MVA Transformer

Figure 6-15; Existing 110-35 kV network

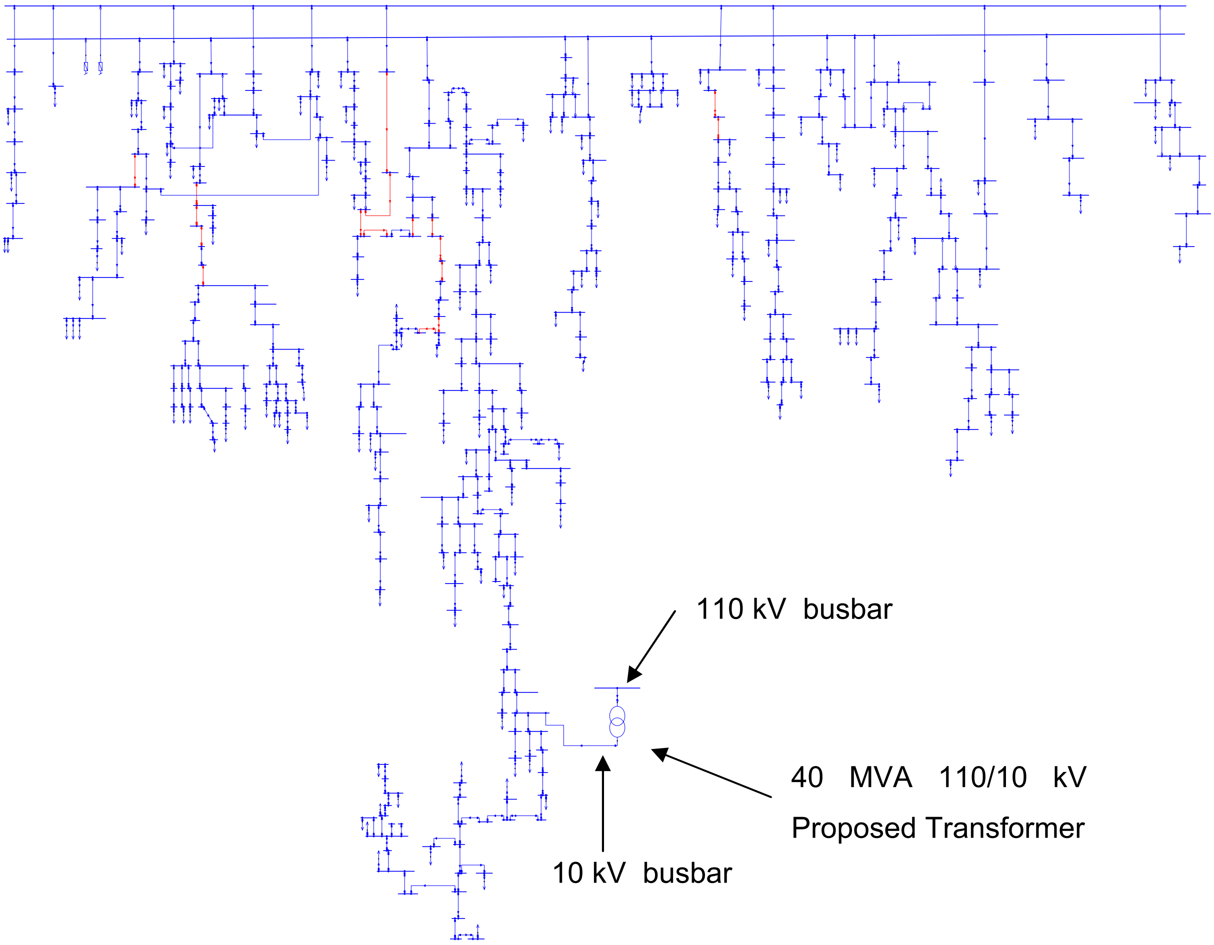


Figure 6-16; Inserting a new transformer

7 Results

7.1 Line Parameter

In the following table are shown the parameters of the 10 kV lines of the sample network. The parameters are for a maximum load in winter, after the calculation of load flow. The lines of the network are numbered from 1-21 from left to Wright as shown in the figure (6-14). The table shows the value of the current and the percentage load in each line. By comparing the data in table of the sample system network with respect to the system network as shown in figure (6-11), it is easy to notice the relation between the length of the line and the measured current. It is also easy to distinguish which lines are heavily loaded.

Line No.	I (A)	Load (%)
1	134,672	42,09
2	79,906	31,34
3	218,794	63,35
4	219,093	68,47
5	248,163	77,55
6	159,082	49,71
7	149,54	46,73
8	69,103	21,59
9	228,495	71,4
10	227,674	71,15
11	69,428	21,7
12	128,844	40,26
13	183,216	57,26
14	243,928	70,23
15	247,341	77,29
16	132,243	41,33
17	243,255	76,02
18	0,759	0,24
19	140,823	44,01
20	89,127	21,22
21	0	0

Table 7-1 Table of parameter for 21 lines

7.2 Changing OHL Cross Section

Table of the OHL conductor changed with the 50 al pex conductor.

Name	Length (km)	Existing type	Change to
L-0889	0,32	AIC 3x25/10	50 al pex
L-1429	0,31	AIC 3x35/10	50 al pex
L-1630	0,25	AIC 3x25/10	50 al pex
L-1634	0,48	AIC 3x25/10	50 al pex
L-1650	0,1	AIC 3x25/10	50 al pex
Total length	1,46 km		

Table 7-2 Table of the OHL solved by changing to 50 al pex conductor

7.3 Overloaded elements

Branches No.	Name	Type	Length (Km)	Ir max. (A)	I (A)	Overload (%)
3	L-0889	AIC3x25/10	0,32	125	129,519	104
5	L-1043	AIC3x35/10	0,02	145	199,495	137,58
5	L-1047	AIC3x35/10	0,05	145	179,496	123,79
5	L-1065	AIC3x35/10	0,02	145	179,497	123,79
5	L-1073	AIC3x35/10	0,05	145	179,585	123,85
9	L-1358	IPO1370/10	0,25	200	228,712	114,36
9	L-1347	IPO1370/10	0,29	200	228,712	114,36
9	L-1351	AIC3x50/10	0,099	170	228,77	134,57
9	L-1362	AIC3x50/10	0,24	170	198,774	116,93
10	L-1378	AIC3x50/10	0,1	170	198,823	116,95
10	L-1398	AIC3x25/10	0,15	125	198,869	159,1
10	L-1406	AIC3x25/10	0,02	125	198,869	159,1
10	L-1413	AIC3x25/10	0,6	125	198,869	159,1
10	L-1425	AIC3x35/10	0,025	145	198,996	137,24
10	L-1429	AIC3x35/10	0,31	145	169,002	116,55
10	L-1469	AIC3x50/10	0,3	170	228,232	132,25
10	L-1465	AIC3x50/10	0,64	170	228,406	134,36
10	L-1480	AIC3x35/10	0,3	145	228,409	157,52
10	L-1496	AIC3x35/10	0,09	145	228,411	157,52
10	L-1504	AIC3x35/10	0,045	145	228,525	157,6
10	L-1508	AIC3x35/10	0,09	145	226,526	156,23
10	L-1516	AIC3x35/10	0,25	145	218,532	150,71
10	L-1536	AIC3x35/10	0,14	145	208,543	143,82
10	L-1540	AIC3x25/10	0,22	125	203,546	162,84
10	L-1548	AIC3x25/10	0,03	125	198,55	158,84
10	L-1558	AIC3x25/10	0,1	125	198,55	158,84
10	L-1562	AIC3x25/10	0,54	125	193,553	154,84
10	L-1574	AIC3x25/10	0,07	125	188,575	150,86
10	L-1596	AIC3x25/10	0,1	125	178,581	142,86
10	L-1630	AIC3x25/10	0,25	125	168,676	134,94
10	L-1634	AIC3x25/10	0,48	125	153,695	122,96
10	L-1650	AIC3x25/10	0,1	125	137,572	110,06
10	L-1642	AIC3x25/10	0,13	125	142,57	114,06
14	L-2312	IPO1370/10	0,22	200	224,491	112,25
14	L-2328	IPO1370/10	0,22	200	224,579	112,29

Table 7-3 Table of overloaded elements

7.4 Voltage Drop at Busbars

Branches No.	Name	Voltage	Voltage drop (%)
10	B-1561	U=9,365 kV	u=93,65%
10	B-1573	U=9,337 kV	u=93,37%
10	B-1569	U=9,365 kV	u=93,65%
10	B-1577	U=9,365 kV	u=93,65%
10	B-1581	U=9,364 kV	u=93,64%
10	B-1595	U=9,298 kV	u=92,98%
10	B-1629	U=9,205 kV	u=92,05%
10	B-1603	U=9,296 kV	u=92,96%
10	B-1633	U=9,044 kV	u=90,44%
10	B-1641	U=9,004 kV	u=90,04%
10	B-1649	U=8,974 kV	u=89,74%
10	B-1659	U=8,973 kV	u=89,73%
10	B-1671	U=8,972 kV	u=89,72%
10	B-1683	U=8,972 kV	u=89,72%
10	B-1675	U=8,970 kV	u=89,70%
10	B-1687	U=8,965 kV	u=89,65%
10	B-1697	U=8,965 kV	u=89,65%
10	B-1705	U=8,965 kV	u=89,65%
10	B-1691	U=8,969 kV	u=89,69%
10	B-1711	U=8,969 kV	u=89,69%
10	B-1663	U=8,892 kV	u=88,92%
10	B-1717	U=8,889 kV	u=88,89%
10	B-1655	U=9,004 kV	u=90,04%
10	B-1743	U=9,004 kV	u=90,04%
10	B-1637	U=9,204 kV	u=92,04%
10	B-1787	U=9,196 kV	u=91,96%
10	B-1791	U=9,196 kV	u=91,96%
10	B-1645	U=9,036 kV	u=90,36%
10	B-1751	U=9,036 kV	u=90,36%
10	B-1755	U=9,036 kV	u=90,36%
10	B-1721	U=8,787 kV	u=87,87%
10	B-1725	U=8,764 kV	u=87,64%
10	B-1733	U=8,760 kV	u=87,60%
10	B-1737	U=8,763 kV	u=87,63%
10	B-1870	U=8,760 kV	u=87,60%
10	B-1874	U=8,729 kV	u=87,29%
10	B-1878	U=8,717 kV	u=87,17%
10	B-1884	U=8,712 kV	u=87,12%
10	B-1892	U=8,709 kV	u=87,09%
10	B-1896	U=8,707 kV	u=87,07%
10	B-1900	U=8,707 kV	u=87,07%
10	B-1908	U=8,707 kV	u=87,07%
10	B-1904	U=8,706 kV	u=87,06%
10	B-1914	U=8,698 kV	u=86,98%
10	B-1922	U=8,698 kV	u=86,98%
10	B-1926	U=8,698 kV	u=86,98%
10	B-1932	U=8,687 kV	u=86,87%
10	B-1946	U=8,661 kV	u=86,61%
10	B-1950	U=8,660 kV	u=86,60%
10	B-1954	U=8,659 kV	u=86,59%
10	B-1960	U=8,655 kV	u=86,55%

10	**B-1970**	**U=8,571 kV**	**u=85,71%**
10	**B-1978**	**U=8,548 kV**	**u=85,48%**
10	**B-1986**	**U=8,523 kV**	**u=85,23%**
10	**B-1982**	**U=8,548 kV**	**u=85,48%**
10	**B-1998**	**U=8,547 kV**	**u=85,47%**
10	**B-2004**	**U=8,522 kV**	**u=85,22%**
10	**B-2008**	**U=8,495 kV**	**u=84,95%**
10	**B-2018**	**U=8,487 kV**	**u=84,87%**
10	**B-2014**	**U=8,494 kV**	**u=84,94%**
10	**B-2026**	**U=8,476 kV**	**u=84,76%**
10	**B-2053**	**U=8,476 kV**	**u=84,76%**
10	**B-2065**	**U=8,476 kV**	**u=84,76%**
10	**B-2022**	**U=8,406 kV**	**u=84,06%**
10	**B-1701**	**U=8,401 kV**	**u=84,01%**
10	**B-2039**	**U=8,339 kV**	**u=83,39%**
10	**B-2071**	**U=8,337 kV**	**u=83,37%**
10	**B-2089**	**U=8,337 kV**	**u=83,37%**
10	**B-2085**	**U=8,337 kV**	**u=83,37%**
10	**B-2077**	**U=8,335 kV**	**u=83,35%**
10	**B-2081**	**U=8,334 kV**	**u=83,34%**
10	**B-2105**	**U=8,332 kV**	**u=83,32%**
10	**B-2109**	**U=8,331 kV**	**u=83,31%**
10	**B-2113**	**U=8,330 kV**	**u=83,30%**
10	**B-2117**	**U=8,328 kV**	**u=83,28%**
10	**B-1609**	**U=9,333 kV**	**u=93,33%**
10	**B-1599**	**U=9,333 kV**	**u=93,33%**
10	**B-1964**	**U=8,655 kV**	**u=86,55%**
10	**B-1942**	**U=8,673 kV**	**u=86,73%**
10	**B-1769**	**U=9,030 kV**	**u=90,30%**
10	**B-1781**	**U=9,030 kV**	**u=90,30%**
10	**B-1792**	**U=9,196 kV**	**u=91,96%**
10	**B-1793**	**U=9,195 kV**	**u=91,95%**
10	**B-1747**	**U=9,036 kV**	**u=90,36%**
10	**B-1936**	**U=8,687 kV**	**u=86,87%**

Table 7-4 Table of voltage drop at busbars

7.5 Busbar Voltage after Inserting the New Substation

Branches No.	Name	Voltage	Voltage drop (%)
10	B-1561	U=9,940 kV	u=99,40%
10	B-1573	U=9,927 kV	u=99,27%
10	B-1569	U=9,940 kV	u=99,40 %
10	B-1577	U=9,940 kV	u=99,40 %
10	B-1581	U=9,939 kV	u=99,39 %
10	B-1595	U=9,910 kV	u=99,10%
10	B-1629	U=9,872 kV	u=98,72%
10	B-1603	U=9,908 kV	u=99,08 %
10	B-1633	U=9,817 kV	u=98,17 %
10	B-1641	U=9,005 kV	u=90,05%
10	B-1649	U=9,796 kV	u=97,96 %
10	B-1659	U=9,795 kV	u=97,95 %
10	B-1671	U=9,795 kV	u=97,95 %
10	B-1683	U=9,795 kV	u=97,95 %
10	B-1675	U=9,793 kV	u=97,93 %
10	B-1687	U=9,788 kV	u=97,88 %
10	B-1697	U=9,788 kV	u=97,88 %
10	B-1705	U=9,788 kV	u=97,88 %
10	B-1691	U=9,792 kV	u=97,92 %
10	B-1711	U=9,791 kV	u=97,91 %
10	B-1663	U=9,784 kV	u=97,84 %
10	B-1717	U=9,784 kV	u=97,84 %
10	B-1655	U=9,8 05 kV	u=98,05%
10	B-1743	U=9,8 05 kV	u=98,05%
10	B-1637	U=9,8 71 kV	u=98,71 %
10	B-1787	U=9,8 63 kV	u=98,63 %
10	B-1791	U=9,8 63 kV	u=98,63 %
10	B-1645	U=9,8 09 kV	u=98,09 %
10	B-1751	U=9,8 08 kV	u=98,08 %
10	B-1755	U=9,8 08 kV	u=98,08 %
10	B-1721	U=9,768 kV	u=97,68 %
10	B-1725	U=9,765 kV	u=97,65 %
10	B-1733	U=9,765 kV	u=97,65 %
10	B-1737	U=9,764 kV	u=97,64 %
10	B-1870	U=9,765 kV	u=97,65 %
10	B-1874	U=9,762 kV	u=97,62 %
10	B-1878	U=9,762 kV	u=97,62 %
10	B-1884	U=9,762 kV	u=97,62 %
10	B-1892	U=9,762 kV	u=97,62 %
10	B-1896	U=9,762 kV	u=97,62 %
10	B-1900	U=9,762 kV	u=97,62 %
10	B-1908	U=9,761 kV	u=97,61 %
10	B-1904	U=9,762 kV	u=97,62 %
10	B-1914	U=10,528 kV	u=105,28 %
10	B-1922	U=10,528 kV	u=105,28 %
10	B-1926	U=10,528 kV	u=105,28 %
10	B-1932	U=10,518 kV	u=105,18 %
10	B-1946	U=10,491 kV	u=104,91 %
10	B-1950	U=10,490 kV	u=104,90 %
10	B-1954	U=10,489 kV	u=104,89 %
10	B-1960	U=10,485 kV	u=104,85 %

10	B-1970	U=10,401 kV	u=104,01 %
10	B-1978	U=10,379 kV	u=103,79 %
10	B-1986	U=10,365 kV	u=103,65 %
10	B-1982	U=10,378 kV	u=103,78 %
10	B-1998	U=10,378 kV	u=103,78 %
10	B-2004	U=10,353 kV	u=103,53 %
10	B-2008	U=10,362 kV	u=103,62 %
10	B-2018	U=10,318 kV	u=103,18 %
10	B-2014	U=10,325 kV	u=103,25 %
10	B-2026	U=10,307 kV	u=103,07 %
10	B-2053	U=10,307 kV	u=103,07 %
10	B-2065	U=10,306 kV	u=103,06 %
10	B-2022	U=10,237 kV	u=102,37 %
10	B-1701	U=10,232 kV	u=102,32 %
10	B-2039	U=10,171 kV	u=101,71 %
10	B-2071	U=10,169 kV	u=101,69 %
10	B-2089	U=10,169 kV	u=101,69 %
10	B-2085	U=10,169 kV	u=101,69 %
10	B-2077	U=10,167 kV	u=101,67 %
10	B-2081	U=10,166 kV	u=101,66 %
10	B-2105	U=10,164 kV	u=101,64 %
10	B-2109	U=10,162 kV	u=101,62 %
10	B-2113	U=10,162 kV	u=101,62 %
10	B-2117	U=10,160 kV	u=101,60 %
10	B-1609	U=9,923 kV	u=99,23%
10	B-1599	U=9,923 kV	u=99,23%
10	B-1964	U=10,485 kV	u=104,85 %
10	B-1942	U=10,503 kV	u=105,03 %
10	B-1769	U=9,803 kV	u=98,03 %
10	B-1781	U=9,803 kV	u=98,03 %
10	B-1792	U=9,863 kV	u=98,63 %
10	B-1793	U=9,862 kV	u=98,62 %
10	B-1747	U=9,804 kV	u=98,04 %
10	B-1936	U=10,517 kV	u=105,17 %

Table 7-5 Table of bus bar voltage after inserting the new substation

8 Discussion

A load flow calculation study is necessary to verify that the electrical system has the adequate capacity to supply the connected load. In addition, this study will provide information regarding the real and reactive power flow, bus voltages (voltage drop), and power factor in each feeder of the electrical system.

The load flow calculation was carried out based on the current data of the network. In the calculation the future development of the network was included, according to previous studies the, load flow forecast for the year 2015 as well as the year 2020 the project reveals a progressive congestion in the medium voltage network, massive overloaded lines and in some areas some voltages problems. It shows that the yearly consumption increase of the sample network in the city is about 4, 1%. It is possible with the same program to evaluate all the calculations used by changing the scaling factors. [14]

The network sample analysis contains a small part of cables and hence it doesn't give a lot of details of cable data's in this thesis.

After the insertion of the new Transformer substation the voltage problem at the bus bars are solved, but higher voltage values to the near end of substation busbars appear which can be solved by changing the tap levels of the transformer.

Conductor size also influences cable impedance and hence the voltage drops along a feeder due to the load current being taken. It is therefore necessary to check that the drop of voltage along the cable route does not exceed the design criteria for the network or the operating voltage range of the equipment being fed. This review needs to take into account both the continuous and noncontinuous loads and any emergency overload that the cable will be required to carry. Voltage drop is a secondary factor and usually only occurs in very large installations with long cable runs. Manufacturers' data sheets also often include voltage drop tables that can be used for a quick parametric check. [4]

9 Bibliography

[1] Leonard Lee Grigsby: „Electric Power Engineering Handbook“, CRC Press Taylor & Francis Group LLC, Boca Rotan, 2007, ISBN-10 0-8493-9288-8

[2] Name2: „Network Planning Criteria Revision“ Revision 2.0, Titel der Zeitschrift, Band/Ausgabe, April 2003, Seite

[3] Ramasamy Natarajan: „Power System Capacitors “, CRC Press Taylor & Francis Group LLC, Boca Rotan, 2005, ISBN-10: 1-57444-710-6

[4] Shoaib Khan: „ Industrial power systems “, CRC Press Taylor & Francis Group LLC, Boca Rotan, 2008, ISBN-13: 978-0-8247-2443-6

[5] D.F, Warne: „ Newnes Electrical Power Engineer's Handbook “, Elsevier, Oxford, 2005 ISBN-13: 978-0-7506-6268-0

[6] http://en.wikipedia.org/wiki/Power_flow_study

[7] Dr.Lothar Fickert: „Electrical Energy System 2“, Networks, Load Flow, TU Graz, Austria Graz Sept.2005

[8] Olle I. Elgerd: „ Basic electric power engineering“, Addison-Wesley, California, 1977, ISBN: 0-201-01717-2

[9] ALSTOM: „ Network Protection & Automation Guide“, 92300 Levallois-Perret, France, 2002, ISBN: 2-9518589-0-6

[10] http://en.wikipedia.org/wiki/Network_topology

[11] http://en.wikipedia.org/wiki/Network_planning_and_design

[12] www.ifea.tugraz.at/ power quality/parameter of power quality

[13] B.L.THERAJA: „ Electrical Technology “, Nirja construction & Development CO. (P) LTD, London, 1985

[14] Lothar Fickert, Beti Trajanoska: „ Das ESM Netz im Jahr 2015, Wissenschaftlich-technische Netzstudie betr.Lastfluss-und Kurzschluss-Analyse für die Netzausbau planung der 110-, 35-und 20-kV-Netze“, Institut für Elektrische Anlagen, Graz, 2007

[15] Europe Standard: Voltage characteristics of electricity supplied by public distribution Systems, EN 50160 for Medium-voltage-supply, September 2005

[16] http://www.geocities.com/SiliconValley/Lab/4223/pflow/bch07.html

[17] www.Iraq.com/electrical power /republic of Iraq/ministry of industry/kurdistan regional governorate.com

[18] William D. Stevenson, JR.: „ ELEMENTS OF POWER SYSTEM ANALYSES“, McGraw-HILL, Oxford, 1975, ISBN: 0-07-061285-4

[19] http://en.wikipedia.org/wiki/Ac_power

[20] Neal J. Balu, Mark G. Lauby: „ Power System Stability and Control“, McGraw-HILL, 1993, ISBN: 0-07-035958-X