Palestine Polytechnic University
College of Engineering

Contribution of Grid Components
In Technical Losses
Case Study: JDECO Grid - Al-Khas Substation (10-MVA)

By

Amjad A. Kamal

Supervisor: Dr. Fouad Zaro

Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor's degree in Electrical Engineering

Hebron, April 2019

Table of Contents

Table of Contents

List of Figures

Acknowledgment

First of all, I would like to acknowledge and thank the Palestine Polytechnic University administration for the efforts and help they made in order to facilitate my work. Besides, I would like to thank my instructor and supervisor Dr. Fouad Zaro for his wise advises.

Special thanks to the teams working in the college of Engineering for everything they had done to help in executing this job.

Finally, greetings to my colleagues in the Jerusalem District Electricity Department for their help in facilitating the use of the resources of both the technical and planning departments in the company. These resources were the core of the study and a valuable bank of data.

Amjad A. Kamal

Abstract

Losses in the electricity distribution grid is considered as one of the main challenges Grid Operators or Distribution Companies are facing. Either technical or non-technical, losses are still one of the main issues that is consuming huge efforts in the related research fields. Technical losses reduction is directly translated into financial profits, whereas non-technical are indirectly affecting the financial side from the point view of grid loading, components lifetime, and maintenance costs.

This project will focus on a sample from a medium and low voltage distribution grid, this part of the grid is examined thoroughly in order to study the technical losses aspect in a real case and see the contribution of each component is this area.

الملخص

تعتبر الخسائر في شبكه توزيع الكهرباء واحده من اهم التحديات التي تواجه مشغلي الشبكة وشركات التوزيع. سواءا كانت الخسائر فنية أو غير فنية فانها تبقى واحده من القضايا الرئيسية التي تستهلك جهدا كبيرا من البحث والتحليل. ينعكس الحد من الخسائر الفنية مباشرة على العوائد المالية للمؤسسة، بينما تؤثر الخسائر الغير فنية بشكل غير مباشر علي الجانب المالي من حيث نقطه تحميل الشبكات، واستهلاك المعدات وتكاليف صيانة.

هذا المشروع ستناول دراسة عينة من شبكة جهد متوسط وجهد منخفض كجزء من شبكة توزيع قائمة، سيتم تحليل هذه الشبكة بدقة من أجل دراسة جانب الخسائر الفنية في تمثيل حقيقي لوضع قائم وذلك لرؤية مساهمة كل عنصر من مكونات الشبكة في هو هذا المجال.

1

OBJECTIVES

&

INTRODUCTION

1.1 Objective

The objective of this project is to analyze one of the main sub-station grids that belongs to Jerusalem district Electricity Company (JDECO), and to study the distribution of technical losses over the different components of the grid related to this sub-station.

The grid will include the medium voltage networks, power transformers, distribution transformers, low voltage networks. Each component will have its own contribution in the technical losses issue and we will study the available scenarios to improve any deficiencies.

1.2 Jerusalem District Electricity Company

Jerusalem District Electricity company (JDECO) is the biggest electricity distribution company in the Jerusalem & the West Bank serving more than "300,000" customers through a huge medium voltage grid. The peak load for the grid reaches about "550 MW" in winter time where almost all the feeding points loading at that period exceeds the "98 %" limit.

The grid is composed of networks on two different voltage levels with about (42) transformation sub-stations (33/11 kV) in between. Part of the grid is supplied through the 33-kV network where distribution transformer from 33/0.4 kV are used, and the other part is supplied using the 11-kV network using 11/0.4 kV transformers.

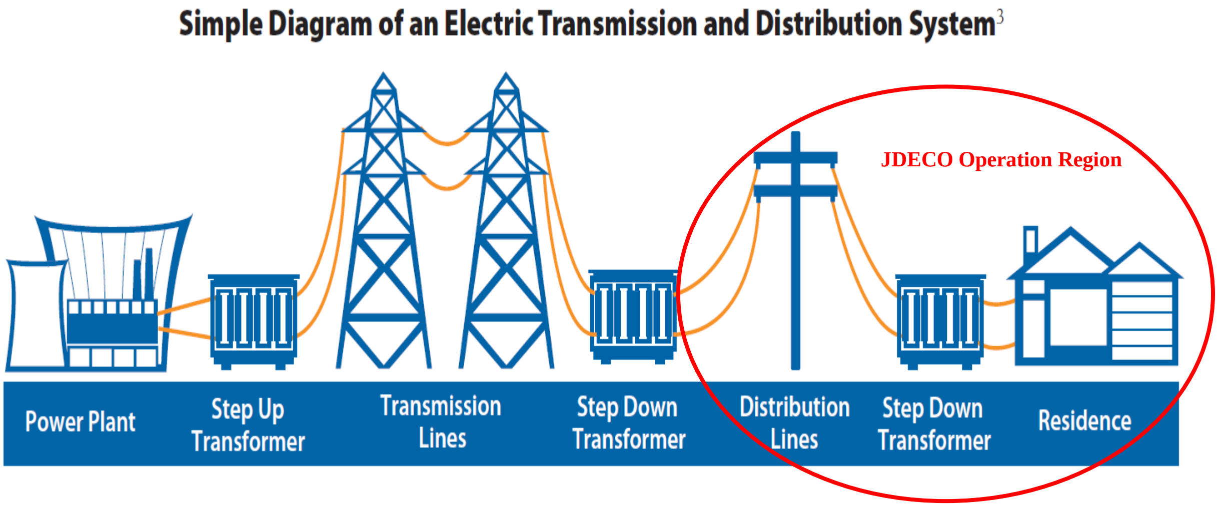


Fig. 1: Electrical Distribution System [1]

JDECO is suffering large losses in the distribution grid which could reach levels of about "40 %" in certain areas. These losses are divided into technical and non-technical losses or black losses resulting mainly from thefts.

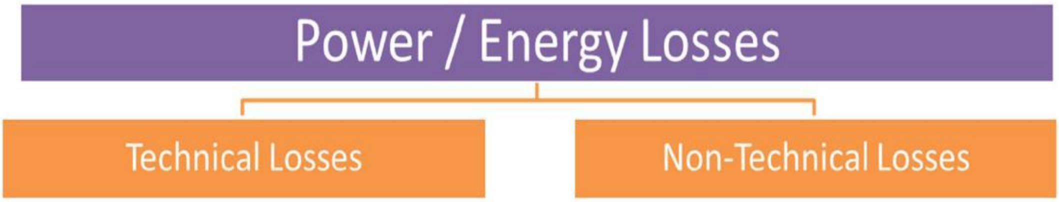


Fig. 2: Types of Energy Losses [2]

1.3 Distribution Losses Sources

In any distribution system, if we study the main components that contribute to technical losses, it will be found that losses in distribution systems are mainly a result of one of the following[1]:

Primary Distribution Lines: Primary lines connect substations to circuits that bring power into customers of all sizes (industrial / residential). These typically run at 4-kV to 34-kV. The higher the voltage, the lower the current, and therefore the lower the resistive losses on these lines. However, higher voltages require more expensive infrastructure, so there is a cost/efficiency tradeoff.

Line Transformers: They convert primary voltage distribution power to the voltages we use in our homes and industries, namely 120-V and 240-V.

Secondary Distribution Lines: These are the lines or networks connecting the transformers to individual homes and industries. They are short lines with low voltages and higher currents (and thus more expensive) conductors. Therefore, they have the biggest contribution in the losses.

2

LITERATURE REVIEW

2.1 Technical Losses in Distribution Networks

Technical losses in power systems are thought of as a natural phenomenon resulting from the energy dissipation in electrical system components such as lines, transformers, connections, measurement systems and other equipment that carry energy to and from customers. They are also referred to as Physical Losses because of their direct relation with the energy transformed to heat and noise while distributing electricity. The losses occur at each stage of a power distribution system, although they are often referred to as Line Losses, the losses related to the conductor lines themselves represent only one type of electricity loss. System average line losses are in the range of (6 – 10 %) on most grids, but they increase exponentially as power lines become heavily loaded [1], [2], [3].

Losses are found in both transmission and distribution stages, part of them are related to the lines or conductors and another part is related to the transformers in the system. Transformer losses are divided into two main components; “core” or “no-load” losses, which results from energizing the transformers in substations and on the distribution system, and “resistive” or “copper” losses which are losses reflecting the resistance of the materials themselves to the flow of electricity.

> **Core losses** are typically (25 – 30 %) of total distribution losses, and do not increase (or decrease) with changes in load. They are largely influenced by the characteristics of the steel laminations used to manufacture the core of transformers.
>
> **Resistive losses** are analogous to friction losses in the lines and transformers. As loads increase, the wires (including those in the transformers) get hotter, the material becomes more resistive, and line losses increase. For this reason, resistive losses increase exponentially with the current on a line.

$$\text{Resistive Losses} = 3.I^2.R$$

Where:

I: Current flowing in the network or component

R: Resistance of the conductors for each phase

2.1.1 Types of Technical Losses

As stated previously, losses are divided into "core" or "resistive"; it is also possible to categories technical losses into the following [2]:

1. Variable Losses
2. Fixed Losses
3. Network Losses

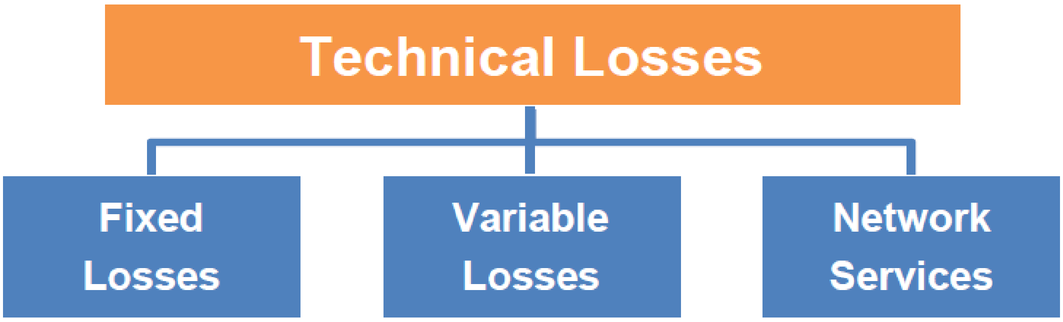


Fig. 3: Types of Technical Losses

Variable Losses: All conductors have an internal electrical resistance which causes them to heat when carrying electric current. Since energy losses resulting from the dissipation of heat to the environment vary with the current flowing through conductors in electrical networks, these losses are called Variable Losses, they are also referred to as "ohmic losses", "copper losses", "Joule losses" or "resistive losses". Because variable losses change as power flows increase and decrease (proportionally to the square of the current), transmission networks experience a lower level of losses because at higher voltages a lower current is required to transmit the same amount of electric power. Additionally, variable losses are also dependent on the length and the cross section of the conductor as they vary in proportion to the resistance.

Fixed Losses: Some electrical energy is dissipated by network components and equipment such as transformers or conductors as a result of being connected to the network and energized. Even if no power flows in the network (or delivered to customers), the system has losses just because it is electrically energized. These losses take the form of heat and noise and are called "fixed losses" or "no-load losses", because they are independent of how much electrical energy the network delivers. Transformers energization are responsible for most of the fixed losses. These losses occur in the transformers core and are called "core losses" or "iron losses".

In addition to transformer inefficiency, another source of fixed losses is the electrical insulation in network equipment. Poor electrical insulation lead to the flow of small continuous currents across them in transformers, lines, cables, and other network equipment. These types of fixed losses are called "dielectric losses" or "leakage current losses". Corona losses, a particular case of these type of losses, occur in high voltage and mainly in extra high-voltage lines. They vary with the voltage level, the physical wire diameter, and with weather conditions such as rain and fog. Corona losses can generate audible and radio-frequency noise and is often seen as a glow in the air adjacent to conductors. They generally contribute to a very small percentage of the overall fixed losses.

These losses are fixed because they depend on the energization of the system equipment and therefore on the voltage level of the network and not on the current following through it; and as long as the voltage level is almost fixed all over the time these losses do not change and remain fixed depending on the network itself mainly on the number of energized components. In this respect, measures to reduce fixed losses mainly aim to reduce the number of energized components or to increase their efficiency. In general, fixed losses contribute to roughly between a quarter and a third of the total technical losses on distribution networks.

Network Losses: Besides the equipment responsible for the dissipation of energy as fixed and variable losses, other equipment connected to the network may consume energy. Network control and measuring elements installed along electrical lines or meters in customer facilities, either mechanic or electronic, are examples of uncontracted consumptions that fails in this category. The separation of this type of network consumption from the technical losses related to energy dissipation allows to exclude them from some international benchmarks relative to the fix and variable losses part. Indeed, losses consumptions due to network equipment have both a fix component (e.g., for permanent use) and a variable component (e.g., depending on communication devices according to data frequency and volumes). Whenever a contract is possible and effective on network equipment (e.g., auxiliary services, future storage capacities), their consumption is excluded from losses and considered as normal consumption. The consideration of whether or not there is a contract behind this consumption is justified with the regulatory context and the source of data frequently used for losses calculation.

2.2 Technical Losses in Transformers

Transformers are thought of the main component in the distribution grid, and therefore it counts for a significant part of the total losses in the network. It was previously mentioned that transformers are involved in both fixed and variable losses, in this section it will be stated in detail what are these losses and how they are calculated. Fig.4 shows the classification of different losses associated with transformers:

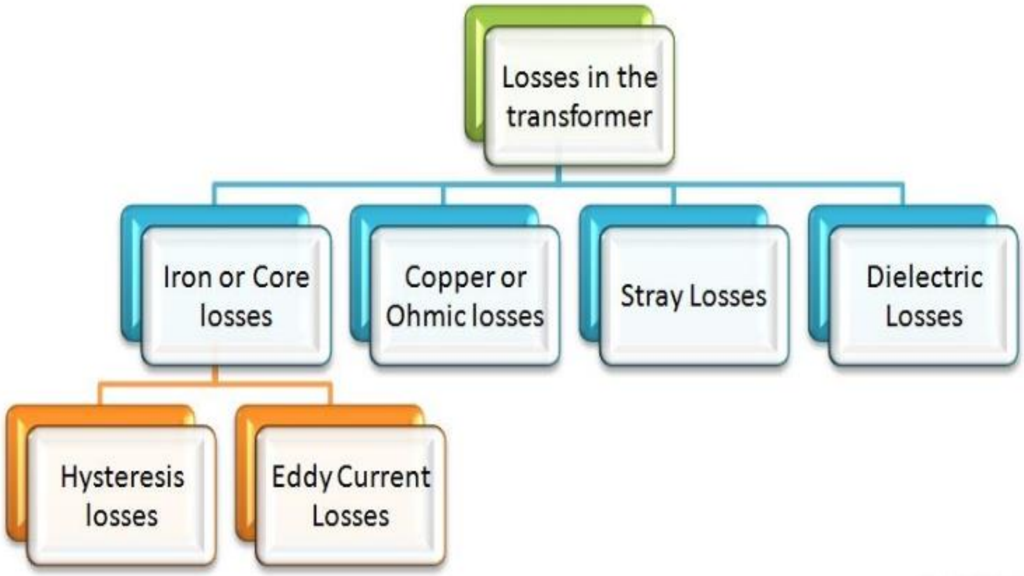


Fig. 4: Types of Technical Losses in Transformers [6]

a. **Iron Losses:** are caused by the alternating flux in the core of the transformer and is divided into hysteresis and eddy current loss.

Hysteresis Loss that stands for the power dissipated in the form of heat as a result of alternating magnetizing force the is implied on the core, and it is given by the equation [6]:

$$P_h = K\eta B_{max}^{1.6} f\, V$$

Where:

P_h: Hysteresis Loss (watts)

$K\eta$: proportionality constant which depends upon the volume and quality of the material of the core used in the transformer.

B_{max}: the maximum or peak value of the flux density in (wb/m^2)

f: supply frequency

Eddy Current Losses results from the flux that links with a closed circuit, where an emf is induced in the circuit and the current flows, the value of the current depends upon the amount of emf around the circuit and the resistance of the circuit. The eddy current losses are given by the equation [6]:

$$P_e = K_e B_m^2 t^2 f^2\, V$$

Where:

P_e: Eddy Current Loss (watts)

K_e: co-efficient of eddy current. Its value depends upon the nature of magnetic material like volume and resistivity of core material, thickness of laminations

B_m: maximum value of flux density in (wb/m^2)

f: supply frequency (Hz)

t: thickness of lamination (m)

V: volume of magnetic material (m^3)

b. **Copper Losses:** These losses occur due to ohmic resistance of the transformer windings and are related directly to the resistance of the primary and secondary winding of the transformer and the current flowing in each of them. It is given by the equation [6]:

$$P_c = I_1^2 R_1 + I_2^2 R_2$$

Where:

P_c: Copper Losses (watts)

I_1: current in the primary winding

R_1: resistance of the primary winding

I_2: current in the secondary winding

R_2: resistance of the secondary winding

c. **Stray Losses:** They occur due to the presence of leakage field. The percentage of these losses are very small as compared to the iron and copper losses, so they can be neglected**.**

d. **Dielectric Loss:** it occurs in the insulating material of the transformer (oil or solid insulations) and are related to the quality of the insulation.

2.3 Reducing Technical Losses

As for Transformer Losses it is divided into two different types, core (no-load) losses and resistive (copper) losses. Core losses are the losses related to the energization of the transformer. These vary with the size of the transformer and the materials used to construct the transformer. It is necessary to choose the right transformers to minimize core losses. The iron or core losses can be minimized by using silicon steel material for the construction of the core of the transformer, whereas, the eddy current loss is minimized by making the core with thin laminations [1], [2].

Resistive losses are primarily a function of the current flowing through a transformer, heating it up. These losses are exponential with the current. For this reason, it is important to not have too small a transformer, or it will “run hot” with high losses. One option is for utilities to install banks of three or more transformers at substations, de-energizing one or more during low-load periods to avoid excessive core losses, but then switching them on during high-demand periods to avoid excessive resistive losses.

Regarding "line losses", it is important to state that conductors are made of very pure aluminum or copper, both of which have inherently low resistance. There are three factors that contribute most significantly to conductor losses.

1. The quality of the connections at each end of the conductors. Corroded connectors, or simple twisted wires, result in significant arcing of the electrical current, which wastes power in the form of heat
2. The size of the conductor relative to the current it carries. Conductor size affects the resistance of the line to current passing through it. High currents

require larger conductors. Utilities sometimes change out the wires or “re-conductor” an existing distribution circuit (without changing its voltage) to increase the capacity and reduce losses on that circuit. This is expensive, but not as expensive as the full reconstruction necessary to increase voltage.

3. The voltage at which the conductors operate. Going up to higher voltages will reduce the current needed to deliver any given amount of power. This is also cost / benefit tradeoff.

The use of distributed generation such as solar photovoltaics and wind can also leads to a reduction in the system losses if planned wisely. Distributed generation assists by providing a source of power closer to the center of the load, thereby avoiding the need for power to be delivered from distant central power stations, suffering huge losses in the way.

3

CASE STUDY

3.1 Case Overview

JDECO has more than (42) transformation sub-stations in its concession area, these sub-stations are (33/11 kV) stations used to step down the voltage of the electrical network from the supply voltage in the provider side (usually 33-kV) into a voltage level compatible with the medium voltage distribution network components installed at the customer side (11-kV).

The choice was "Al-Khas" sub-station, located to the north of Bethlehem city, having one feeding incomer (33-kV), one power transformer (10-MVA), and two outgoing feeders at (11-kV).

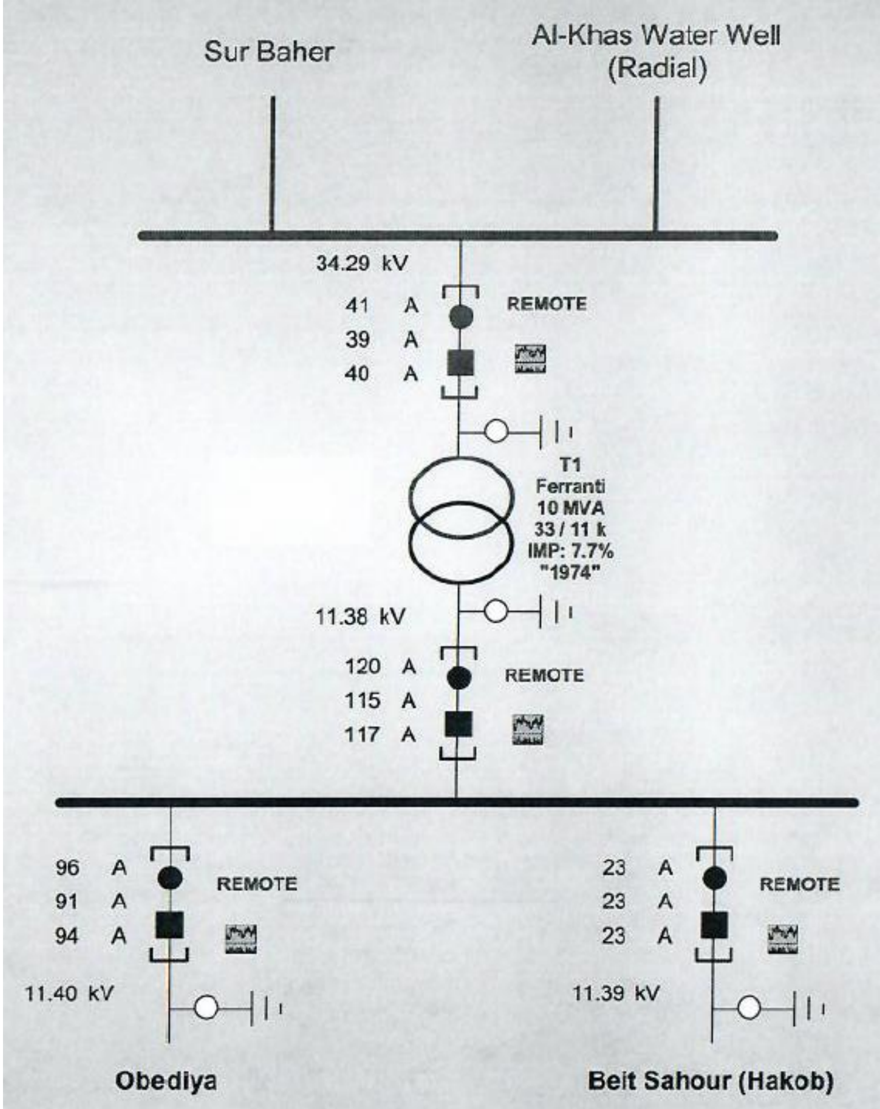


Fig. 5: Al-Khas 33/11 kV Sub-Station Single Line Diagram – "Screenshot from SCADA System"

3.2 Study Methodology

The grid supplied from the sub-station under consideration, was entered to a simulator called "NEPLAN", which is a powerful tool used by JDECO for analysis and planning. The grid components were entered including three levels:

1. Medium Voltage Network
2. Medium Voltage Components (mainly transformers)
3. Low Voltage Networks

The "NEPLAN" can provide statistics related to the grid under consideration including quantitative information for each type of element depending on the quality of the input data. In addition, it can allow the user to run different simulation scenarios under different parameters.

The general procedure followed to input the grid parameters to the simulator was:

1. Determining the borders of the grid under consideration (study area).
2. Exporting the grid information from the GIS – System in form of shape files.
3. Manipulating the shape files to be compatible with the standard templates accepted by the NEPLAN simulator.
4. Importing the grid to the NEPLAN.
5. Checking the grid for missing parameters and connectivity.
6. Determining the study or analysis assumptions.
7. Determining the loading level of the transformers and the customers.
8. Checking the connectivity between medium voltage and low voltage networks.
9. Tuning the simulation parameters.
10. Checking the convergence of the grid to be analyzed.
11. Running the simulation for the required mode "in our case, Load Flow"
12. Getting the results
13. Analyzing.
14. Repeating with other parameters if needed.

3.3 Grid Components

3.3.1 Medium Voltage Grid

As stated previously, the station under consideration is feeding two 11-kV feeders, these feeders are part of an electrically ring network system which is radially operated, feeding about (96 Distribution Transformers) with different capacities.

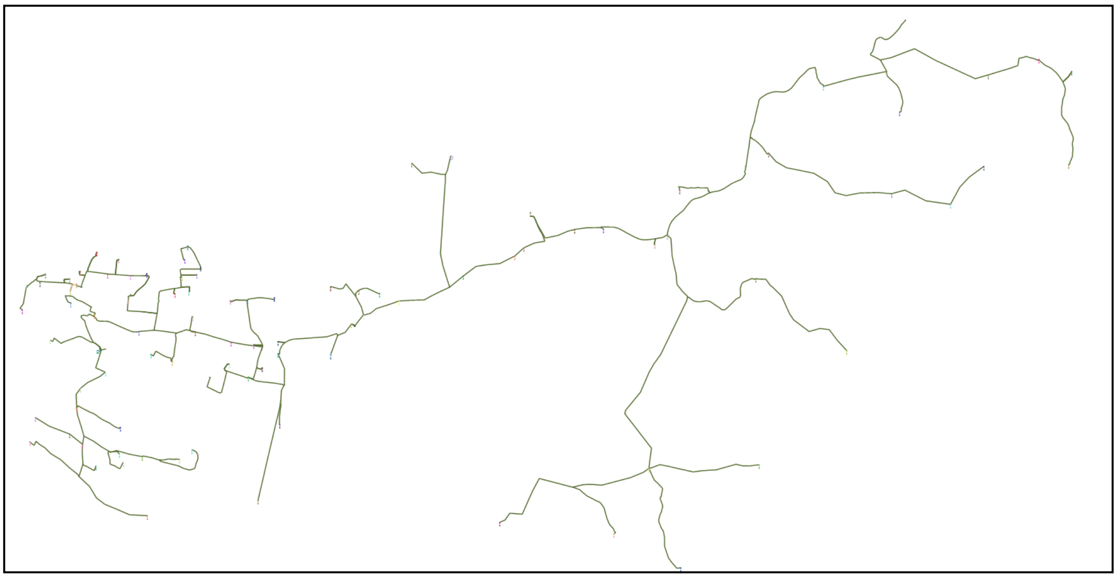


Fig. 6: Al-Khas 11 kV Feeders in NEPLAN Simulator

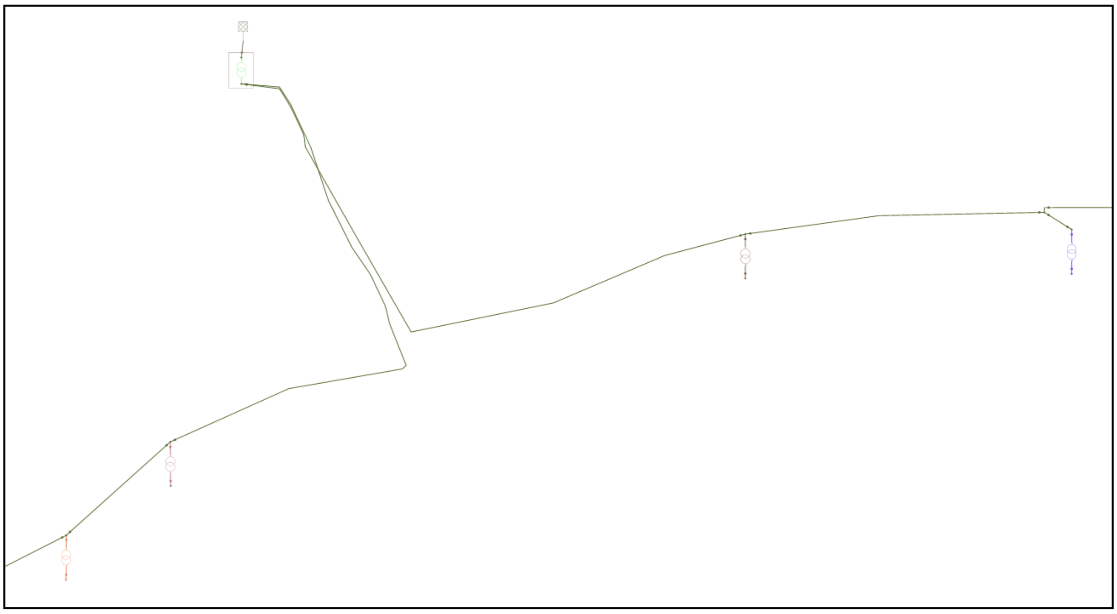


Fig. 7: M.V. Grid showing the route of the two feeders going out from the main sub-station

If we zoom in the view in the simulator main window, there will be clear each transformer and its location on the grid, in addition to, the part of the grid in its original geographical view.

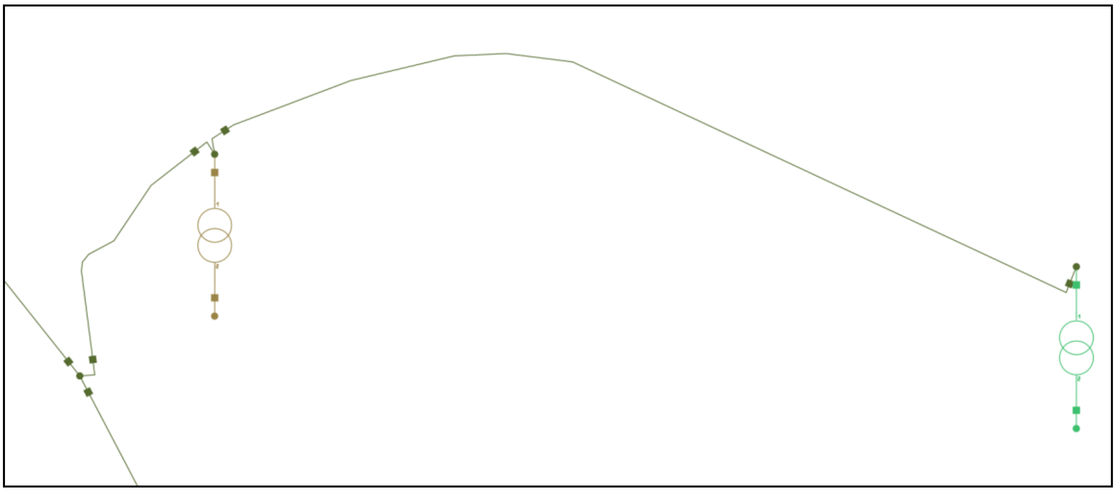
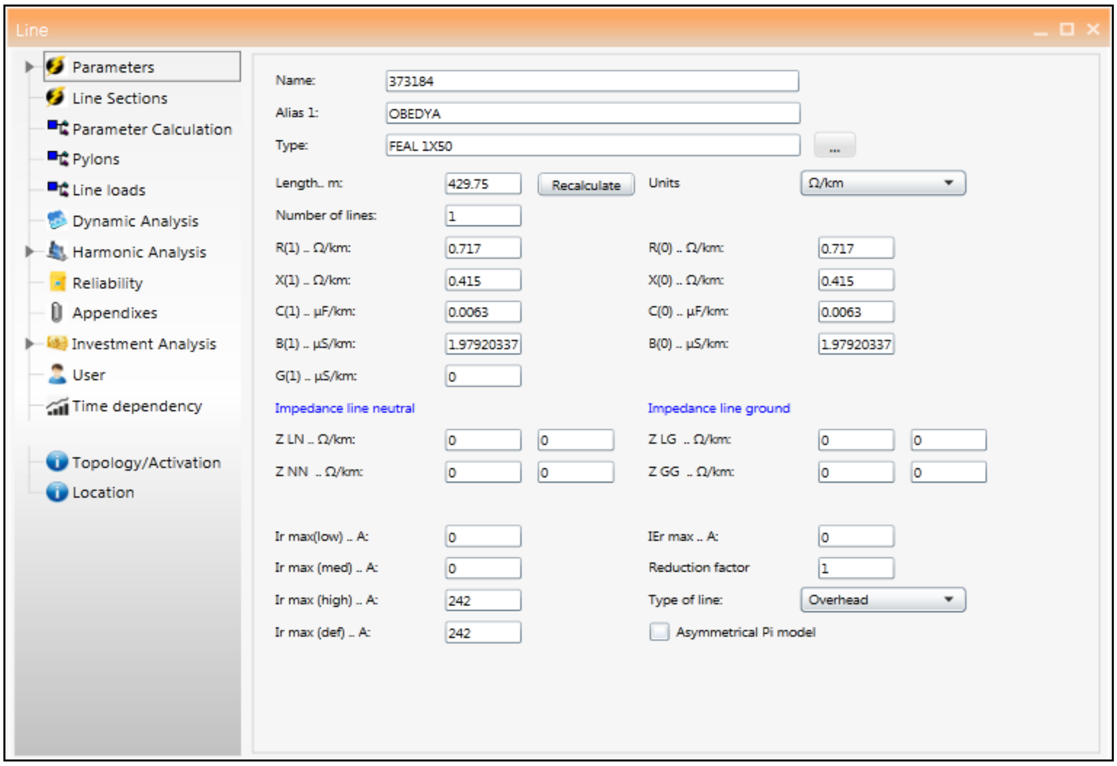


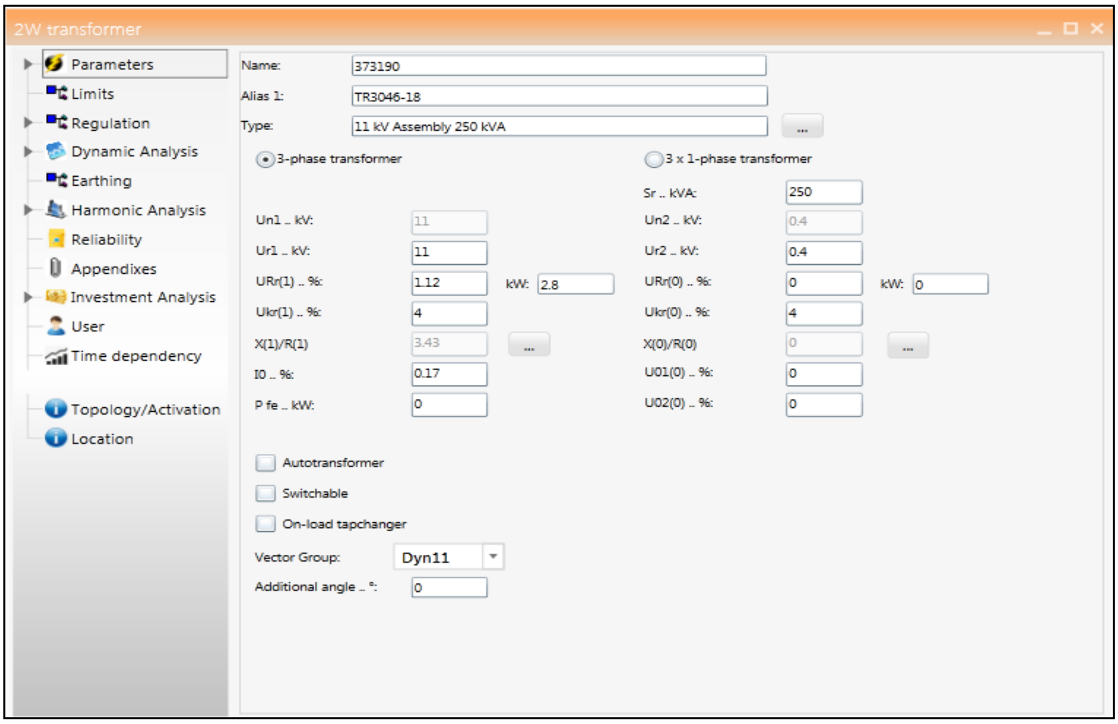
Fig. 8: M.V. Grid and distribution transformers

For each component in the NEPLAN, there exist full properties and specifications, these properties are either inherited from a built-in library or edited and customized by the user.



Name:	373184				
Alias 1:	OBEDYA				
Type:	FEAL 1X50				
Length.. m:	429.75		Units	Ω/km	
Number of lines:	1				
R(1) .. Ω/km:	0.717		R(0) .. Ω/km:	0.717	
X(1) .. Ω/km:	0.415		X(0) .. Ω/km:	0.415	
C(1) .. µF/km:	0.0063		C(0) .. µF/km:	0.0063	
B(1) .. µS/km:	1.97920337		B(0) .. µS/km:	1.97920337	
G(1) .. µS/km:	0				
Impedance line neutral			Impedance line ground		
Z LN .. Ω/km:	0	0	Z LG .. Ω/km:	0	0
Z NN .. Ω/km:	0	0	Z GG .. Ω/km:	0	0
Ir max(low) .. A:	0		IEr max .. A:	0	
Ir max (med) .. A:	0		Reduction factor	1	
Ir max (high) .. A:	242		Type of line:	Overhead	
Ir max (def) .. A:	242		☐ Asymmetrical Pi model		

Fig. 9: Screenshot for a Line-Component in NEPLAN



Name: 373190
Alias 1: TR3046-18
Type: 11 kV Assembly 250 kVA
● 3-phase transformer ○ 3 x 1-phase transformer
Sr .. kVA: 250
Un1 .. kV: 11
Un2 .. kV: 0.4
Ur1 .. kV: 11
Ur2 .. kV: 0.4
URr(1) .. %: 1.12 kW: 2.8
URr(0) .. %: 0 kW: 0
Ukr(1) .. %: 4
Ukr(0) .. %: 4
X(1)/R(1) 3.43
X(0)/R(0) 0
I0 .. %: 0.17
U01(0) .. %: 0
P fe .. kW: 0
U02(0) .. %: 0
☐ Autotransformer
☐ Switchable
☐ On-load tapchanger
Vector Group: Dyn11
Additional angle .. °: 0

Fig. 10: Screenshot for a Transformer-Component in NEPLAN

According to the NEPLAN statistics, the medium voltage grid under consideration consists of the following components:

1. Power Transformer (33/11 kV)

   Capacity: 10 – MVA Transformer
   Voltage: 33 / 11 kV
   Imp: 7.7%

2. Distribution Transformer (11/0.4 kV)

No.	***Transformer Capacity (KVA)***	***Quantity (Unit)***
1	100	1
2	160	5
3	250	32
4	400	36
5	630	21
6	1000	1
	TOTAL	**96**

3. 11-kV lines, including overhead network and under-ground cables:

No.	*Type*	*Length (km)*	*R (ohm)*	*X (ohm)*
1	**Overhead Network – 11-kV**	**18.07**	**12.006**	**7.453**
1.1	FEAL 50-mm	15.86	11.370	6.579
1.2	FEAL 95-mm	2.21	0.6360	0.8740
2	**Cable Network- 11-kV**	**17.09**	**2.668**	**2.041**
2.1	1 X 3 X 120 CU	11.68	1.7980	1.4597
2.2	1 X 3 X 150 CU	2.94	0.4650	0.2155
2.3	3 X 1 X 150 CU	1.36	0.2235	0.1531
2.4	3 X 1 X 240 AL	1.12	0.1818	0.2125
	TOTAL	**35.168**	**14.6743**	**9.4938**

3.3.2 Low Voltage Grid

The low voltage grid mainly supplied from the (96) transformers, consists of customers and the network supplying them. The grid under consideration serves about (5469 customers) at a voltage level of (0.4-kV).

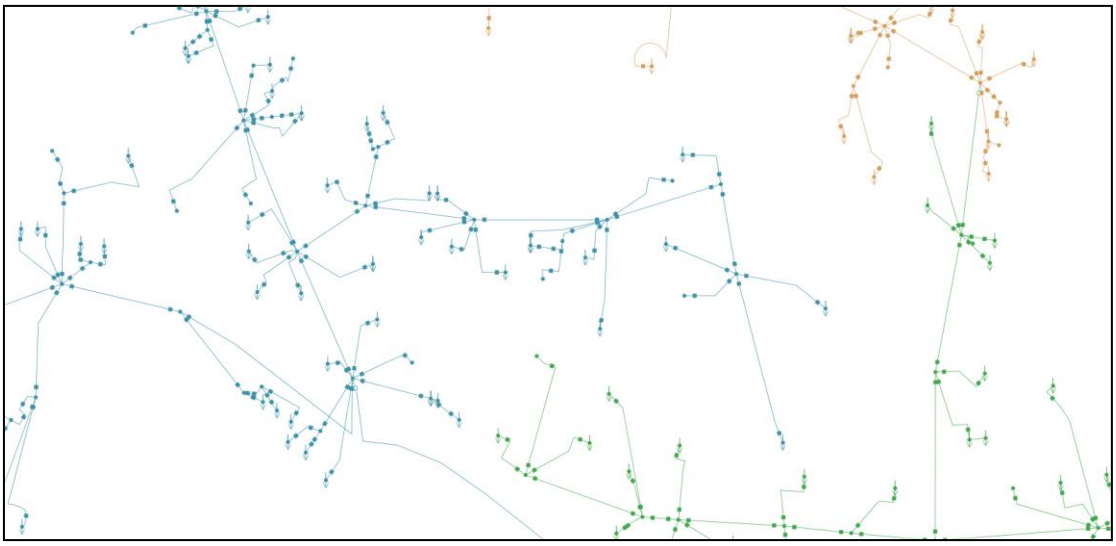


Fig. 11: Part of the L.V. Grid in NEPLAN Simulator

The NEPLAN simulator is very powerful in the graphical interface side, it can present each feeder in the grid in a different color even on the low voltage level so that the user could easily browse the grid and the results.

The 0.4-kV network consists from lines or feeder that distribute energy from the main transformers' pillars to the poles in the neighborhood, in addition to the service cables connecting electricity from the poles into the customer meters (or houses). This network in the case under consideration includes the following:

No.	*Type*	*Length (km)*	*R (ohm)*	*X (ohm)*
1	**Overhead Network – 0.4-kV**	**204.79**	**142.36**	**7.617**
1.1	AL 1 X 25	13.76	20.644	0.00
1.2	AL 1 X 50	22.95	18.360	0.00
1.3	EX 1 X 3 X 25	0.433	0.6672	0.0216
1.4	EX 1 X 4 X 25	8.66	13.350	0.4330
1.5	EX 1 X 4 X 50	55.85	46.130	2.6250
1.6	EX 1 X 4 X 95	103.13	43.210	4.5370
2	**Cable Network- 0.4-kV**	**108.86**	**228.46**	**8.65**
2.1	1 X 3 X 10 CU	81.14	189.06	6.5240
2.2	1 X 3 X 16 CU	26.03	38.270	1.9976
2.3	1 X 3 X 35 CU	1.68	1.1210	0.1250
2.4	1 X 3 X 50 CU	8.00	0.0068	0.0006
	TOTAL	**313.65**	**370.82**	**16.26**

It is important to note that the above values are representing the real case of the grid referring to the data exported from the GIS system. The values of the per unit resistances and reactance are according to the types defined in the libraries of the software itself.

The full data for the grid components, that was used to extract the previous tables is attached in form of excel file with the appendices.

3.4 Grid Simulation Parameters

The grid in the case study is all the network components that are related to transformation sub-station (33/11 kV) which belongs to JDECO. In order to run the simulation in the NEPLAN, a number of assumptions were taken into consideration:

1. **Feeding Points:** Al-Khas sub-station has two outgoing (11-kV) feeders (namely, Obeidya and Beit Sahour). Obeidya is a radial feeder that is not connected to any other medium voltage grid, and it was considered as is. Beit Sahour feeder is part of a medium voltage grid that closes the distribution ring system with another 11-kV feeder from a different sub-station, during the study the case was simulated taking into consideration that all the transformers between the two main sub-stations are fed through Al-Khas sub-station and therefore the feeder from the other sub-station is in "OFF" position.

2. **Network Loading:** the loads in the study case was tuned so that Beit Sahour feeder is fully loaded (100% loaded). In order to reach this loading trend, the individual load for each distribution transformer was set to a certain percentage and the same trend was copied to transformers supplied through Obeidya feeder.

3. **Power Transformer Load:** depending on the loads applied in the previous point for the network the main transformer was almost 57% loaded.

4. **Customers:** all customers supplied from this grid under consideration were assumed to be 3-phase customers with balanced loads.

3.5 Simulation Results

The simulation was made taking into consideration the assumptions mentioned in the previous section, and the results were extracted from the NEPLAN in form of screenshots from the interface itself. (Note: all the figures and the excel files are attached in the appendices of the report in detailed and clear form).

After running the simulation tool, the analysis of the grid converged and gave the grid in two colors as shown in the next figure. These colors are representing the two medium voltage feeders (Obeidya in red, Beit Sahour in green).

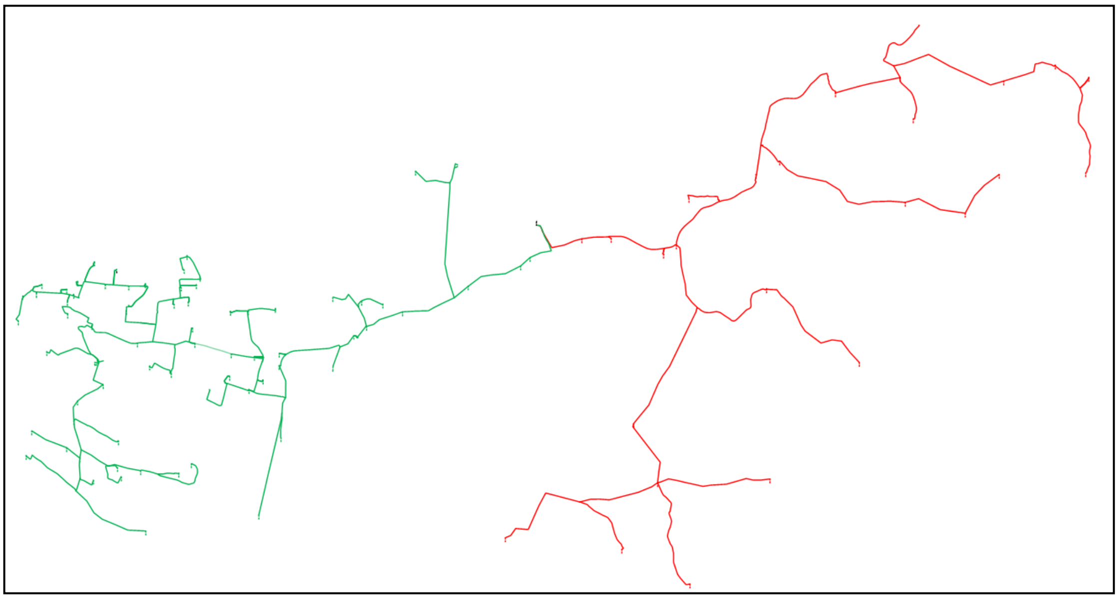


Fig. 12: Medium voltage grid after simulation convergence

3.5.1 Grid Power Consumption and Loading

The output screen shown next in Fig. 13, shows the general results for the simulation for the whole grid. From this figure it could be read that the results were as follows:

- Power imported from the source:
  - P = 5506.5 kW
  - Q = 1709.72 kVAr
- Power delivered to the grid:
  - P = 5493.54 kW
  - Q = 1441.48 kVAr

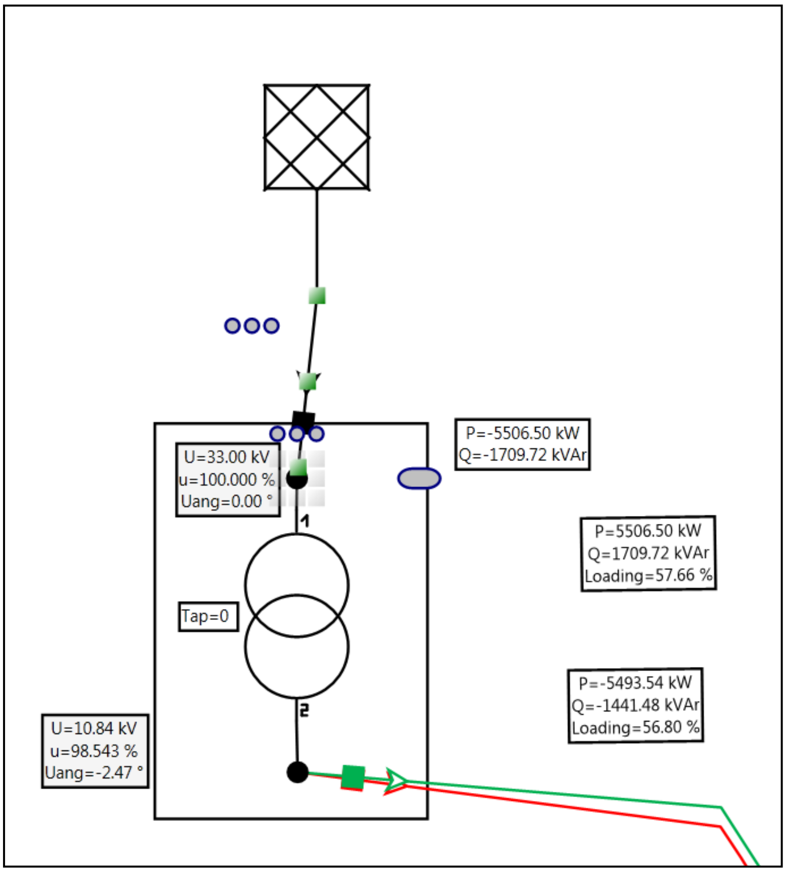
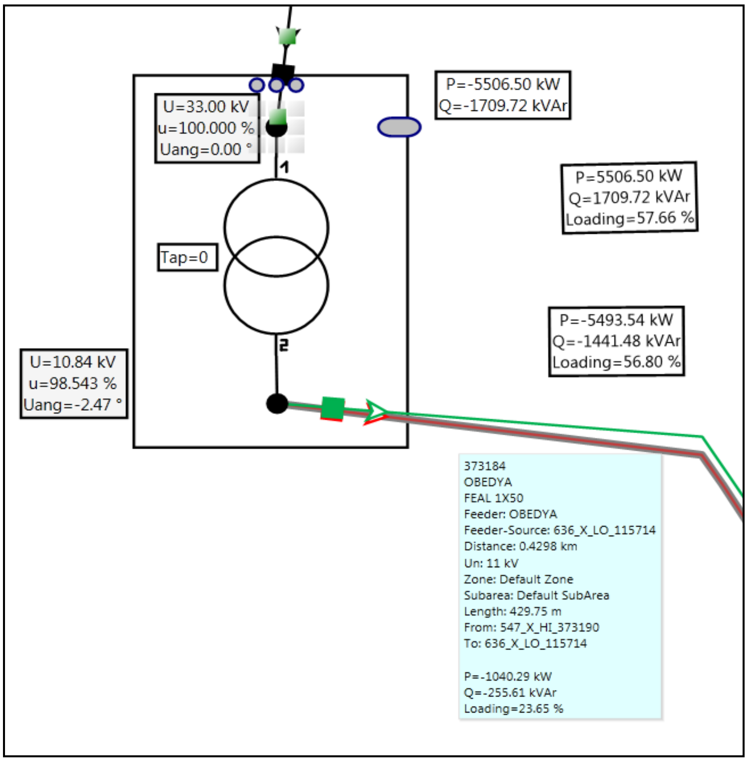


Fig 13: NEPLAN output screen for grid simulation

The difference between the two energies are the technical losses lost in the 10-MVA transformer. In the secondary side of the transformer, it appears that the power transformer was 56.8% loaded.

The output could also be seen on the level of each feeder, where we can see the loading of each one individually. From the figures 14 & 15 it is clear that the medium voltage feeders were loaded in the following manner:

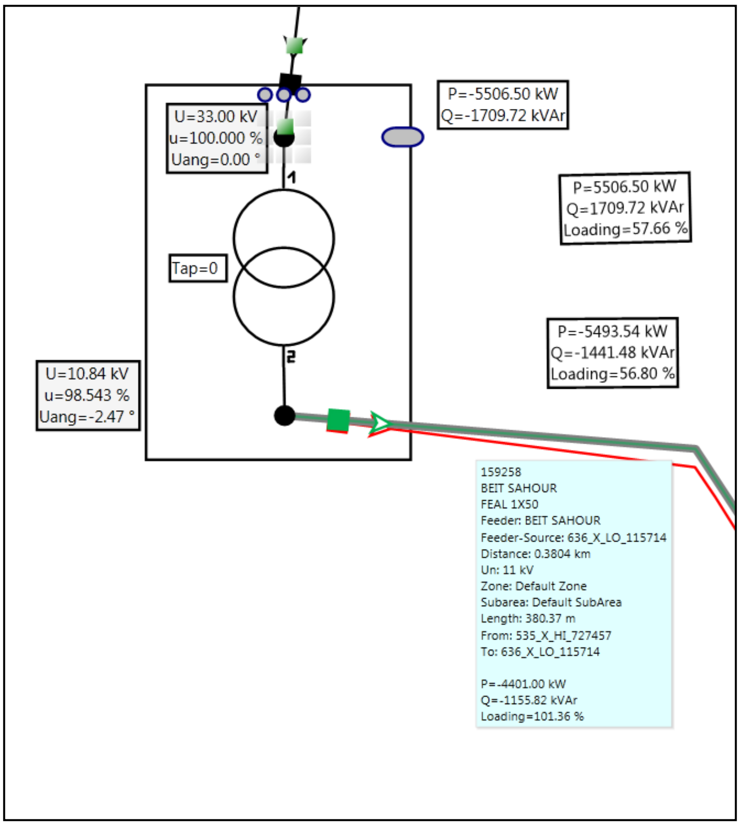
- Obeidya
    - Loading 23.65 %
- Beit Sahour
    - Loading 101.36 %



373184
OBEDYA
FEAL 1X50
Feeder: OBEDYA
Feeder-Source: 636_X_LO_115714
Distance: 0.4298 km
Un: 11 kV
Zone: Default Zone
Subarea: Default SubArea
Length: 429.75 m
From: 547_X_HI_373190
To: 636_X_LO_115714

P=-1040.29 kW
Q=-255.61 kVAr
Loading=23.65 %

Fig 14: NEPLAN output screen for Obeidya results



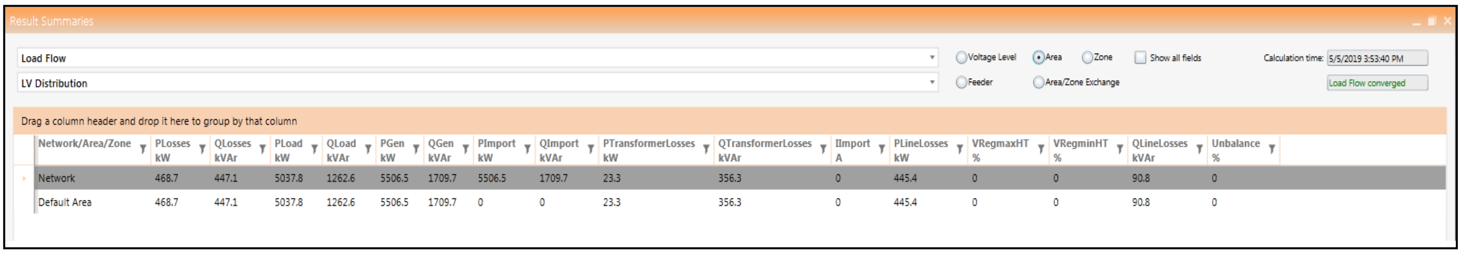
159258
BEIT SAHOUR
FEAL 1X50
Feeder: BEIT SAHOUR
Feeder-Source: 636_X_LO_115714
Distance: 0.3804 km
Un: 11 kV
Zone: Default Zone
Subarea: Default SubArea
Length: 380.37 m
From: 535_X_HI_727457
To: 636_X_LO_115714

P=-4401.00 kW
Q=-1155.82 kVAr
Loading=101.36 %

Fig 15: NEPLAN output screen for Beit Sahour results

3.5.2 Grid Technical Losses

The general output for the simulation of the grid is given by the following figure "16", which indicates the values of the total power injected to the system, and the values of the losses associated with this power level.



Load Flow

LV Distribution

○ Voltage Level ● Area ○ Zone ☐ Show all fields

○ Feeder ○ Area/Zone Exchange

Calculation time: 5/5/2019 3:53:40 PM

Load Flow converged

Drag a column header and drop it here to group by that column

Network/Area/Zone	PLosses kW	QLosses kVAr	PLoad kW	QLoad kVAr	PGen kW	QGen kVAr	PImport kW	QImport kVAr	PTransformerLosses kW	QTransformerLosses kVAr	IImport A	PLineLosses kW	VRegmaxHT %	VRegminHT %	QLineLosses kVAr	Unbalance %
Network	468.7	447.1	5037.8	1262.6	5506.5	1709.7	5506.5	1709.7	23.3	356.3	0	445.4	0	0	90.8	0
Default Area	468.7	447.1	5037.8	1262.6	5506.5	1709.7	0	0	23.3	356.3	0	445.4	0	0	90.8	0

Fig 16: Simulation result of the whole grid

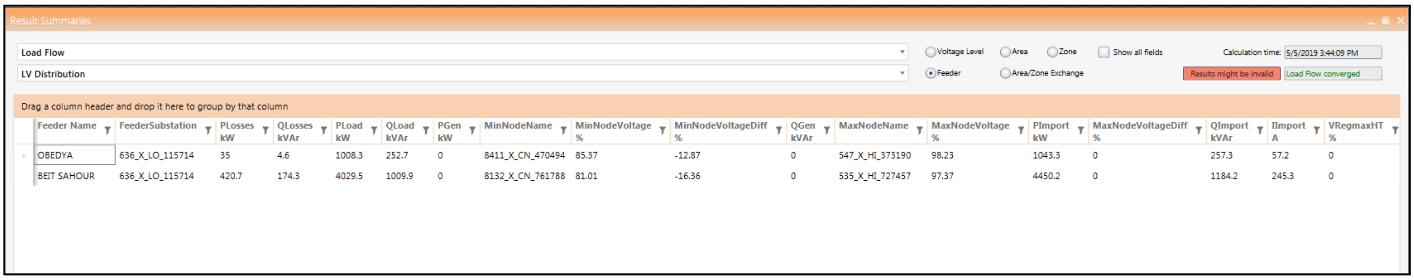
The results in the above figure shows that the total grid has the following power divisions:

Division	***P (kW)***		***Q (kVAr)***	
Total Generated	**5506.5**		**1709.7**	
Load	5037.8		1262.6	
Total Losses	**468.7**	**8.5%**	**447.1**	**26.1%**
Line Losses	445.4	95%	90.8	20.3%
Transformer Losses	23.3	5%	356.3	79.7%

If we calculate the apparent power of the system and the associated technical losses with it according to the results in the above table, the total technical losses for the whole system (medium & low voltage) are calculated as (11.23%), which are divided into (8.5%) P-Losses and (26.1%) Q-Losses, noting that the losses in the main power transformer (10-MVA) feeding the grid are counted as part of these values.

Also, from the table it is obvious the contribution of the lines and the transformers in the loss value, where lines count for (95%) of the total P-Losses and transformers are responsible for almost (80%) of the Q-Losses.

The simulation tool also provided the power imported and the associated losses in the grid on each feeder, so the results were demonstrated on feeders' level as show in the following figure "17".



Load Flow

LV Distribution

○ Voltage Level ○ Area ○ Zone ☐ Show all fields

● Feeder ○ Area/Zone Exchange

Calculation time: 5/5/2019 3:44:09 PM

Feeder Name	FeederSubstation	PLosses kW	QLosses kVAr	PLoad kW	QLoad kVAr	PGen kW	MinNodeName	MinNodeVoltage %	MinNodeVoltageDiff %	QGen kVAr	MaxNodeName	MaxNodeVoltage %	PImport kW	MaxNodeVoltageDiff %	QImport kVAr	IImport A	VRegmaxHT %
OBEDYA	636_X_LO_115714	35	4.6	1008.3	252.7	0	8411_X_CN_470494	85.37	-12.87	0	547_X_HI_373190	98.23	1043.3	0	257.3	57.2	0
BEIT SAHOUR	636_X_LO_115714	420.7	174.3	4029.5	1009.9	0	8132_X_CN_761788	81.01	-16.36	0	535_X_HI_727457	97.37	4450.2	0	1184.2	245.3	0

Fig 17: Simulation result on feeders' level

3.5.2.1 Contribution of Grid Components in Technical Losses

The simulation results for the case under consideration is exported in the form of an excel file in order make it possible to manipulate the data and categorize it upon the need. The excel file is attached to the report as a soft copy in the appendix was as mentioned previously. The excel file include all the detailed information about the grid component (transformers & conductors) in the form of individual links and elements in the same form extracted from the GIS-System and entered to the simulation tool for analysis. In addition, the file includes the output result for the case study simulation analysis, where we can find each element or component under what condition it was operating in this case.

The effect of the transformers on the losses issue is apparent from the previous table, here; the effect of the conductors will be analyzed. From the data table resulting from the simulation, the information related to the (P & Q) losses for each element (conductors) was manipulated and collected in a sum-up table that shows how the losses were distributed among the different grid components.

All Grid Components for All Feeders			
No.	***Type***	***P-Loss (kW)***	***Q-Loss (kVAr)***
1	**Overhead Network – 11-kV**	**295.29**	**168.01**
1.1	FEAL 50-mm	294.01	166.70
1.2	FEAL 95-mm	1.28	1.31
2	**Cable Network- 11-kV**	**29.79**	**- 87.71**
2.1	1 X 3 X 120 CU	27.90	-64.37
2.2	1 X 3 X 150 CU	1.28	-1.28
2.3	3 X 1 X 150 CU	0.52	-15.01
2.4	3 X 1 X 240 AL	0.09	-7.05
3	**Overhead Network – 0.4-kV**	**98.68**	**8.52**
3.1	AL 1 X 25	0.33	0.00
3.2	AL 1 X 50	9.75	0.00
3.3	EX 1 X 3 X 25	0.00	0.00
3.4	EX 1 X 4 X 25	0.67	0.02
3.5	EX 1 X 4 X 50	15.09	0.85
3.6	EX 1 X 4 X 95	72.84	7.65
4	**Cable Network- 0.4-kV**	**19.76**	**1.10**
4.1	1 X 3 X 10 CU	2.96	0.09
4.2	1 X 3 X 16 CU	14.72	0.76
4.3	1 X 3 X 35 CU	1.58	0.18
4.4	1 X 3 X 50 CU	0.50	0.07
	TOTAL	**443.52**	**89.92**

The previous results are also exported from the simulation summary but not as a total grid, they were separated for each feeder alone. The data for the individual feeder is shown in the next tables.

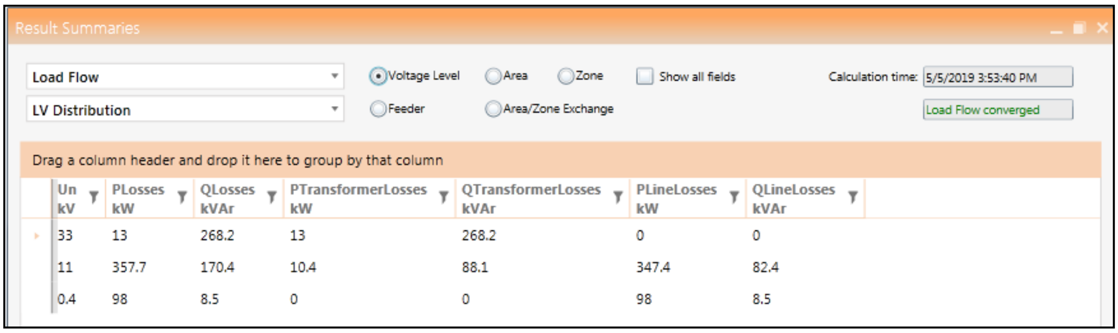
<u>Obeidya 11-kV Feeder --- 23.65 % Loaded</u>			
No.	***Type***	***P-Loss (kW)***	***Q-Loss (kVAr)***
1	**Overhead Network – 11-kV**	**5.74**	**1.30**
1.1	FEAL 50-mm	5.74	1.30
1.2	FEAL 95-mm	0.00	0.00
2	**Cable Network- 11-kV**	**0.81**	**-17.13**
2.1	1 X 3 X 120 CU	0.8032	-17.1298
2.2	1 X 3 X 150 CU	0.0022	0.0010
2.3	3 X 1 X 150 CU	0.0000	0.0000
2.4	3 X 1 X 240 AL	0.0000	0.0000
3	**Overhead Network – 0.4-kV**	**25.73**	**2.09**
3.1	AL 1 X 25	0.0201	0.0000
3.2	AL 1 X 50	2.1158	0.0000
3.3	EX 1 X 3 X 25	0.0006	0.0000
3.4	EX 1 X 4 X 25	0.0109	0.0000
3.5	EX 1 X 4 X 50	7.8607	0.4440
3.6	EX 1 X 4 X 95	15.7260	1.6495
4	**Cable Network- 0.4-kV**	**0.15**	**0.00**
4.1	1 X 3 X 10 CU	0.1369	0.0010
4.2	1 X 3 X 16 CU	0.0074	0.0033
4.3	1 X 3 X 35 CU	0.0013	0.0001
4.4	1 X 3 X 50 CU	0.0000	0.0000
	TOTAL	**32.42**	**-13.73**

Beit Sahour 11-kV Feeder --- 101.36 % Loaded			
No.	***Type***	***P-Loss (kW)***	***Q-Loss (kVAr)***
1	**Overhead Network – 11-kV**	**289.55**	**166.71**
1.1	FEAL 50-mm	288.2735	165.4000
1.2	FEAL 95-mm	1.2753	1.3114
2	**Cable Network- 11-kV**	**28.99**	**-70.58**
2.1	1 X 3 X 120 CU	27.1009	-47.2376
2.2	1 X 3 X 150 CU	1.2728	-1.2818
2.3	3 X 1 X 150 CU	0.5230	-15.0093
2.4	3 X 1 X 240 AL	0.0927	-7.0542
3	**Overhead Network – 0.4-kV**	**72.84**	**6.42**
3.1	AL 1 X 25	0.3113	0.0000
3.2	AL 1 X 50	7.6335	0.0000
3.3	EX 1 X 3 X 25	0.0033	0.0001
3.4	EX 1 X 4 X 25	0.5557	0.0175
3.5	EX 1 X 4 X 50	7.2276	0.4106
3.6	EX 1 X 4 X 95	57.1115	5.9963
4	**Cable Network- 0.4-kV**	**19.04**	**0.95**
4.1	1 X 3 X 10 CU	2.8272	0.0090
4.2	1 X 3 X 16 CU	14.6435	0.7603
4.3	1 X 3 X 35 CU	1.5679	0.1760
4.4	1 X 3 X 50 CU	0.0026	0.0002
	TOTAL	**410.42**	**103.50**

In the following table the losses will be summarized and categorized into two different types, medium voltage network losses and low voltage network losses and on each voltage level there will be two sets; one for cable conductors and the other overhead conductors.

		All Grid		**Obeidya Feeder** 23.65 % Loaded		**Beit Sahour Feeder** 101.36 % Loaded	
		P-Loss (kW)	**Q-Loss (kVAr)**	**P-Loss (kW)**	**Q-Loss (kVAr)**	**P-Loss (kW)**	**Q-Loss (kVAr)**
Medium Voltage Grid	Overhead	295.29	168.01	5.74	1.30	289.55	166.71
	Cable	29.79	-87.71	0.81	-17.13	28.99	-70.58
	Total	**325.08**	**80.30**	**6.54**	**-15.83**	**318.54**	**96.13**
Low Voltage Grid	Overhead	98.68	8.52	25.73	2.09	72.84	6.42
	Cable	19.76	1.10	0.15	0.00	19.04	0.95
	Total	**118.44**	**9.62**	**25.88**	**2.10**	**91.88**	**7.37**
Total		**443.52**	**89.92**	**32.42**	**-13.73**	**410.42**	**103.50**

The results from the simulation tool is also presented in form of voltage levels in the network and this shown in the following figure which complies with all the data listed in the tables above.



Load Flow

LV Distribution

● Voltage Level ○ Area ○ Zone ☐ Show all fields

○ Feeder ○ Area/Zone Exchange

Calculation time: 5/5/2019 3:53:40 PM

Load Flow converged

Drag a column header and drop it here to group by that column

Un kV	PLosses kW	QLosses kVAr	PTransformerLosses kW	QTransformerLosses kVAr	PLineLosses kW	QLineLosses kVAr
33	13	268.2	13	268.2	0	0
11	357.7	170.4	10.4	88.1	347.4	82.4
0.4	98	8.5	0	0	98	8.5

Fig 18: Simulation result according to voltage levels

3.6 Results Analysis

From the simulation results for the grid under consideration, it was obvious that 80% of the Q-losses were related to the transformers in the grid, where lines (or conductors) effect was dominant in the P-losses with about 95%.

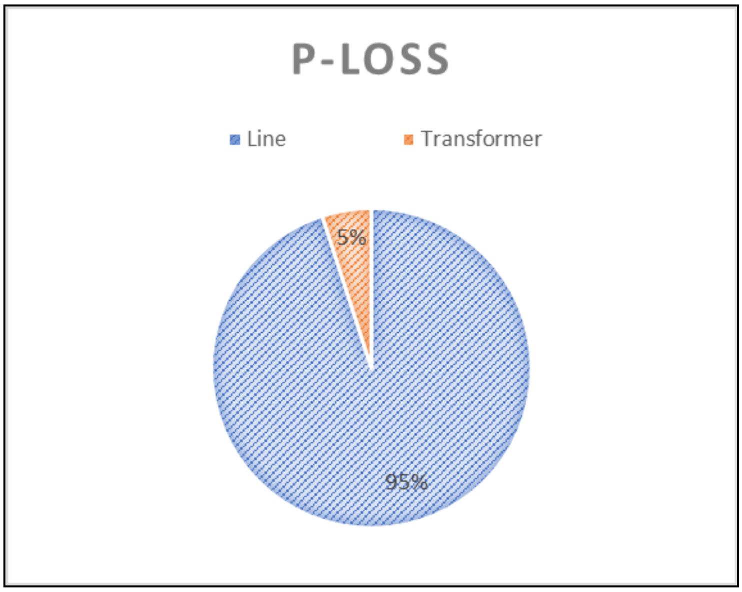


Fig 19: Contribution of Grid Elements in P-Losses

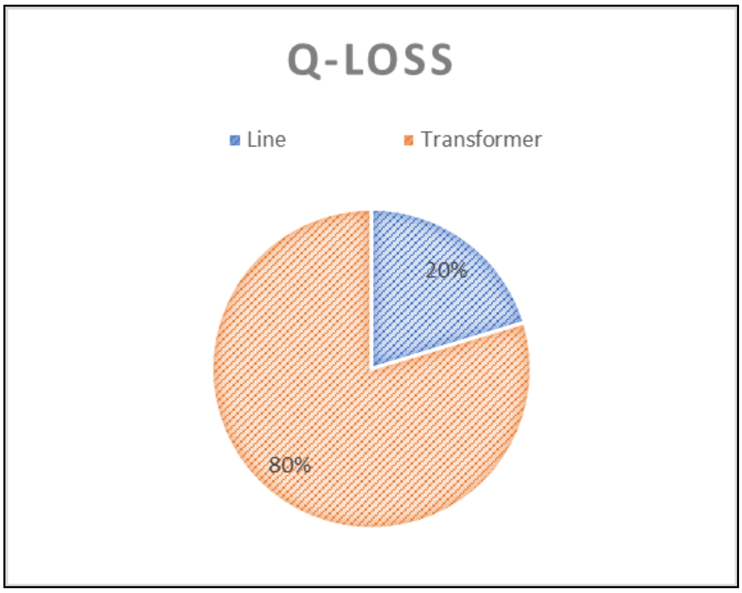


Fig 20: Contribution of Grid Elements in Q-Losses

In normal loading conditions, it is reasonable to have the losses on the medium voltage grid much less than that in the low voltage grid, this is resulting from the idea that in low voltage levels; higher currents are flowing in longer conductors which means more current and more resistance leading to more losses. This was clearly seen in the results for "Obeidya Feeder" that was not loaded so much, and the losses values were dominant in the low voltage grid.

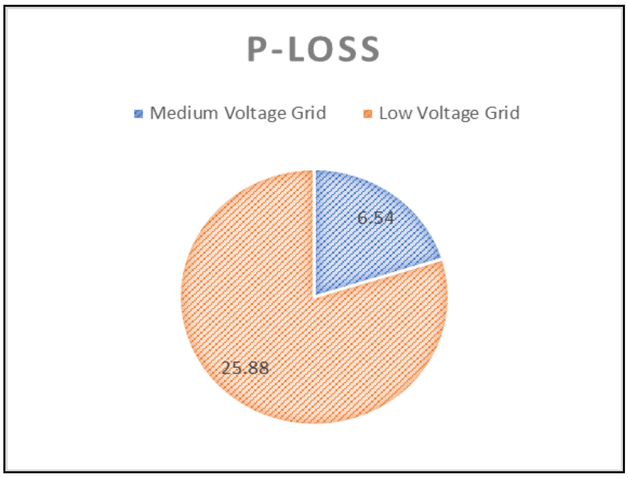


Fig 21: P-Losses in M.V. & L.V. Grids for Obeidya Feeder – 23% loaded

On the other hand, in "Beit Sahour Feeder" that was fully loaded on the medium voltage level, where the low voltage grid was operating in the same manner for the other feeder, it was clear from the results that the losses in the medium voltage grid were high.

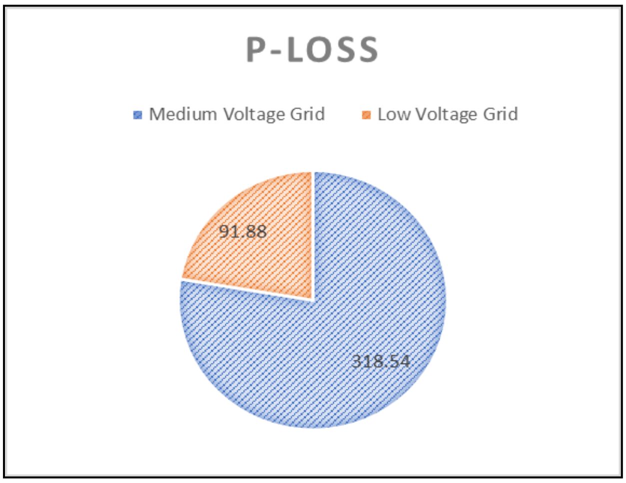


Fig 22: P-Losses in M.V. & L.V. Grids for Beit Sahour Feeder – 100% loaded

The losses in the conductors, were found to be high in the overhead network in the medium voltage level in the sections constructed from (FEAL 1x 50). This was due to the high resistance of this conductor relatively (because of length), in addition to the fact that this conductor is used to construct the beginning of the feeders from the substation to the grid and here it will suffer from high current where all the load of the network will flow through it.

3.7 Cost of Technical Losses

For the case under consideration, we will assume that this grid will run for one hour in the same conditions in order to reflect the financial effect of the technical losses on the distribution company. During 1-hour period, running costs for such a situation will be as follow:

$$\text{Billed Energy} = P_{\text{Generated}} \text{ x } 1_{\text{hr}}$$
$$= 5506.5 \ * \ 1 \ = \ 5506.5 \text{ kWh}$$

- **Given that the power factor of the grid is calculated as 0.95 and the company will not pay for the Q-Power.**

Annual Average Electricity Tariff = 0.38 NIS/kWh

$$\text{Cost}_{\text{1-hour}} = \text{Billed Energy x Tariff}$$
$$= 5506.5 * 0.38 = 2{,}092.5 \text{ NIS}$$

$$\text{Cost}_{\text{Losses}} = P_{\text{loss}} \text{ x Time}_{\text{Period}} \text{ x Tariff}_{\text{Avg}}$$
$$= 468.7 * 1 * 0.38 = 178 \text{ NIS}$$

Operating the grid in the assumed conditions for one hour will cost JDECO a total of (178 NIS) for losses, these are losses that the company has to pay to the supplier and could not register in the meters of the customers.

This financial example is just a small sample of the huge cost distribution companies are withstanding just from issues related to technical losses in their grid components. If we look at JDECO in particular, this amount of money is related to the running of a part of the grid for 1-hour **ONLY**, and we can imagine what will be the cost of losses if we take the whole grid that is consuming more than (2,300 GWh yearly). This could be translated into millions of Shekels that the company is paying just for losses.

3.8 Recommendations

Depending on the study results, it is recommended that JDECO take special actions regarding this part of the grid including:

- Operating the grid in normal loading conditions, avoiding (as much as possible) any over loading to the feeders getting benefits from the ring systems on both voltage levels.

- Study possibilities to go on for a reconductoring projects in certain sections of the grid, taking into consideration the cost / benefit tradeoff.

- Increase the use of underground cable networks, because of there capacitive characteristics role that will compensate in certain places for the Q-Losses.

- Study the possibility to change the distribution system from the customer side, so that all the customers are 3-phase connected.

4

CONCLUSIONS

4.1 Conclusions

- Technical losses are directly related to elements or components in the grid
  - Conductors affect the P-Losses
  - Transformers affect the Q-Losses

- Technical losses are much high in low voltage grids than that in medium voltage grid in normal operating conditions and normal loading profiles.

- Cable networks have a good effect in the compensation for the Q-Losses.

- Conductors with small cross section and high resistance will have bad effect on the grid from the loss aspect side, especially if the loads are relatively high.

- Studies should be made continuously regarding the tradeoff between technical losses issues and reconductoring projects.

References

[1] Implementing EPA’s Clean Power Plan. Chapter 10, Reduce Losses in the Transmission and Distribution System

[2] CIRED WG CC-2015-2. Reduction of Technical and Non-Technical Losses in Distribution Networks

[3] M. C. Anumaka. Analysis of Technical Losses in Electrical Power System.

[4] Yakov Wilms, Sergey Fedorovich, and Nikolai A. Kachalov. Methods of reducing power losses in distribution systems

[5] Jignesh Parmar. Total Losses in Power Distribution and Transmission Lines

[6] https://circuitglobe.com/types-of-losses-in-transformer.html

Appendix A – Grid Data & Simulation Results

The appendix is the attached CD, where it contains soft copies from all the raw and manipulated data used to make the study. The file is "**NEPLAN Data.xlsx**" and contains the following worksheets:

1. "**Transformers**": data table from the *Neplan* that contains all the data for the power transformer and the distribution transformers.

2. "**Lines**": data table from the *Neplan* that contains all the data for the conductors either overhead or underground where they could be sorted according to type.

3. "**Line Sorting**": table that has the totals for each line or conductor type with their electrical specifications. Built by the user using the data from the "Lines" worksheet.

4. "**Customer Loads**": data table from the *Neplan* that contains all the data related to the customers whom are the true loads for the grid. From this table the loading of the grid could be changed.

5. "**PQS Calculation**": table that has the totals for the power consumption and losses of the grid. Built by the user in using the data in the other worksheets.

6. "**Simulation Results**": data table from the *Neplan* that contains the results of the analysis done by the simulator for the case under consideration.

7. "**Losses from Neplan**": table that has the totals for the losses of the grid and for the individual feeder according to the type of conductor. Built by user using data from the previous worksheet.

Appendix B - Grid

The single line diagram of the grid

Softcopy is in the CD

This Diagram is a private document for JDECO