An-Najah National University

Faculty of Graduate Studies

ANALYSIS AND IMPROVEMENT OF NEDCO ELECTRICITY DISTRIBUTION NETWORK OF JENIN GOVERNORATE AND CLARIFYING THE IMPACT OF SOLAR PHOTOVOLTAIC PENETRATION

By

Haitham Alawneh

Supervisor

Dr. Maher Khammash

This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Electrical Power Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus - Palestine.

2022

ANALYSIS AND IMPROVEMENT OF NEDCO ELECTRICITY DISTRIBUTION NETWORK OF JENIN GOVERNORATE AND CLARIFYING THE IMPACT OF SOLAR PHOTOVOLTAIC PENETRATION

By

Haitham Alawneh

This Thesis was Defended Successfully on 00/00/2022 and approved by

Dr. Maher Khammash	
Supervisor	Signature
Insert Name	
External Examiner	Signature
Insert Name	
Internal Examiner	Signature

Dedication

إلى أبي وأمي فلولاهما لما وُجِدتُ في هذه الحياة، ومنهما تعلَّمت الصمود وحب الحياة، مهما كانت الصعوبات.

حفظهما الله

إلى زوجتي رفيقة دربي رفيقة الكفاح والظروف الصعبة التي لم تبخل بوقت أو جهد لمساعدتي.

إلى ابنتي جوري وياسمين لكم مني كل الحب شاكر لكما تحملكما انشغالي عنكما وافساح المجال لي بالعمل بكل هدوء.

إلى أخواتي الرائعات اللواتي وقفن الى جانبي بكل الدعم والحب والاسناد والعمل.

إلى أساتذتي الأفاضل فمنكم تعلمت واكتسبت الخبرات خلال مسيرتي الأكاديمية

إلى أستاذي الكريم الدكتور ماهر خماش الذي لم يتوانى في دعمي وتوجيهي لإنهاء هذه الرسالة

أهدي إليكم رسالة الماجستير ثمرة جهدي

Acknowledgements

I would like to thank my family for the constant love and support that has always given me.

My further appreciation goes to my supervisor, Dr. Maher Khammash for his exceptional guidance and insightful comments throughout the duration of this thesis.

Thanks go also to all my friends and fellow graduate students.

My special gratitude and appreciations go to the educational staff of the Electrical Power Engineer Master Program at An-Najah National University.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

ANALYSIS AND IMPROVEMENT OF NEDCO ELECTRICITY DISTRIBUTION NETWORK OF JENIN GOVERNORATE AND CLARIFYING THE IMPACT OF SOLAR PHOTOVOLTAIC PENETRATION

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: ______________________________

Signature: ______________________________

Date: ______________________________

List of Contents

List of Tables

List of Figures

List of Appendices

ANALYSIS AND IMPROVEMENT OF NEDCO ELECTRICITY DISTRIBUTION NETWORK OF JENIN GOVERNORATE AND CLARIFYING THE IMPACT OF SOLAR PHOTOVOLTAIC PENETRATION

By
Haitham Alawneh
Supervisor
Dr. Maher Khammash

Abstract

This thesis starts by getting information from North Electrical Distribution Company (NEDCO) about all parameters and contents of the electrical network of Jenin, such as transmission lines, underground cables, transformers, loads, and PV systems in detail with all lengths, diameters, capacities, average annual consumption and PV systems power.

ETAB simulator program was used to build this network, and the analysis started at a low voltage side at every load. Thesis focus on the power quality and voltage quality through the analysis.

The objective of this thesis is to improve the power and voltage quality of the whole network in different ways, such as improving power factor to be more than 95% with respect to IEEE standards, improving low voltages at some loads and reducing drop voltages to be within 5% as IEEE standards, and reducing power losses using techniques such as: adding new PV systems, adding new capacitor banks, increasing the tap changers. Depending on the readings of the voltage bus and power factor (i.e., real and reactive power) of each load bus.

Also, this thesis discusses another subject: the PV penetration level. It describes in detail the problem led by high penetration in the network and loads. It also discusses the solution to each problem. High PV penetration in the network causes many problems such as power losses, voltage rise, voltage fluctuations, voltage unbalance and reverse power flow that impacts the power quality; also, it causes a negative on power factor, voltage sag, harmonics, and frequency.

The thesis suggests many solutions for these problems, such as: using an on load tap changer, reactive power control, energy storage system, PV generation curtailment, and smart inverter, and passive filters to reduce the harmonics effect. These solutions are described in detail in chapter 4. However, these solutions aim to balance real power and reactive power production to improve the power factor, avoid reverse power flow, store the power and use it at a suitable time and reduce harmonics effect to be within 5% for THD and less than 3% for IHD as IEEE standards.

Keywords: Effect of high PV Penetration; Improve power quality; Improve voltage quality; Improvement of NEDCO; Harmonics Effect.

Chapter One
Introduction

1.1 Introduction

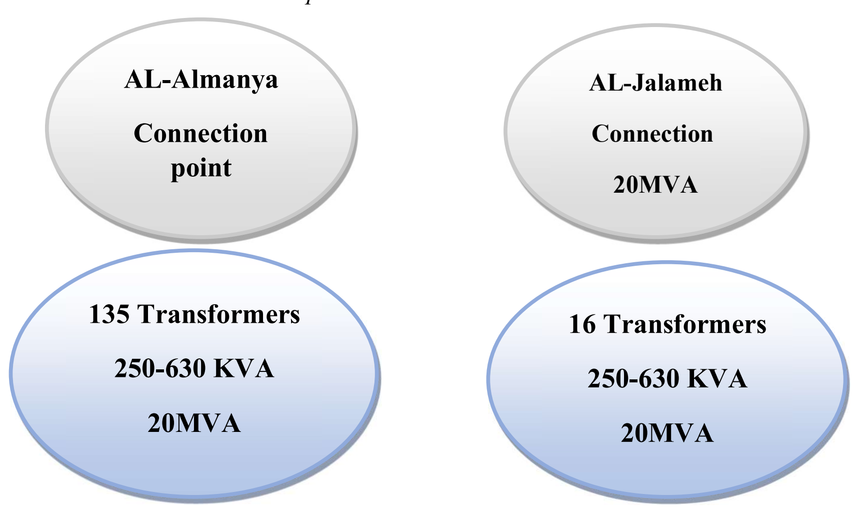
This thesis will analyze NEDCO's- Jenin electrical network using ETAP software and read the result of currents, voltages, real power, reactive power, and power factor on the loads. From the simulation results, the problems such as low power factor, high voltage drop, and losses can be determined. Then the suggested solution can be simulated, such as: adding PV systems or capacitor banks, adding new transformers or transmission lines, and increasing the tap of tap changers of transformers.

Jenin Governorate, located in the north of the west bank of Palestine, is an agricultural area fed the electricity from Qatari Israel Company through NEDCO Company and Tubas Electricity Company. This thesis will work on the region which is under NEDCO Authority.

There are two connection points that feed the region of Jenin Governorate under NEDCO authority. One is located in AL Almanya with 20MVA connected to 135 transformers with different capacities (250-630 KVA), and the second connection point is located in AL-Jalameh with 20MVA connected to 16 transformers with different capacities (250-630 KVA) [67] as shown in figure1.1.1.

Figure1.1.1

Jenin Electrical Network connection points



The electrical network is divided into nine regions to be handle easily, as shown in table 1.1.1 below:

Table1.1.1

Components of Jenin Electrical Network

Connection point	Region Name	Transformer quantity	Transmission line quantity	Underground cable quantity	PV system quantity
AL Almanya	AL Maslakh	10	5	8	4
	AL Almanya	6	5	4	0
	Haddad	30	27	15	15
	Ayash	15	6	14	1
	Nasreh Street	14	7	12	14
	Sinan	22	16	19	4
	Jabriat	13	8	10	0
	Cinema	25	3	22	3
	Total	135	77	104	41
Al Jalameh	Haifa Street	16	11	10	8

The second part of this thesis will be about the effect of PV penetration level on the network. This subject comes from the rapid spread of renewable energy, especially PV systems, leading to some network problems.

Due to the increased demand for energy around the world with different loads, such as domestic, commercial building, and industrial customers, solar energy is the most spread over other renewable energy sources in terms of its simplicity of installation, less dependence on the field, and economy. Solar energy is obtained from photovoltaic (PV), including rooftop, ground-mounted, and building-integrated PV systems. Rooftop PV system applications has increased in recent years due to simple installation, Governmental encouragement, and not occupying an external area. However, the adverse effects of increased PV penetration level on the distribution system lead to problems in the voltage quality and power quality, so the power loss, reverse power flow (RPF), voltage fluctuations, and voltage unbalance are affecting on voltage quality in the power network also variations in system frequency, power factor, and harmonics affect the power quality. Excessive PV penetration is also the root cause of voltage stability and harms the protection system.

This thesis aims to extensively examine the impacts of high PV penetration on NEDCO's – Jenin distribution network and evaluate possible solution methods regarding voltage quality and power quality.

1.2 Over View of ETAP program

ETAP stands for Electrical Transient and Analysis Program. It is the most comprehensive analysis platform for the design, simulation, operation, and automation of generation, distribution, and industrial power systems.

It is used by power systems engineers to create an "electrical digital twin" (i.e., a digital representation of an intended or actual real-world physical product, system, or process (a physical twin) that serves as the effectively indistinguishable digital counterpart of it for practical purposes, such as simulation, integration, testing, monitoring, and maintenance). Also, it analyzes electrical power system dynamics, transients, and protection [1].

1. Farrokh Shokooh is the founder and current CEO of ETAP. While Dr. Shokooh worked at Fluor Corporation [2], he was made in charge of selecting electrical engineering software. Realizing a lack of comprehensive, efficient and intelligent power system analysis software, the vision of the Electrical Transient Analyzer Program (ETAP) was born.
2. Shokooh left Fluor Corporation to develop ETAP and founded Operation Technology, Inc (OTI) in 1986. OTI dba ETAP is an ISO 9001-certified electrical power system design and automation software company headquartered in Irvine, California, with international offices in India, UAE, KSA, Brazil, Mexico, France, UK, Malaysia, and China.

ETAP was developed for utilization on MS-DOS operating system and intended for commercial and nuclear power system analysis [3] and system operations. OTI has been developing ETAP for 30 years by providing comprehensive and widely used enterprise solutions for generation, transmission, distribution, industrial, transportation, and low-voltage power systems.

Power system simulation requires an electrical digital twin consisting of a power system network model that includes system connectivity, topology, electrical device characteristics, historical system response, and real-time operations data in order to make offline or online decisions. ETAP power engineering software utilizes an electrical digital twin in order for electrical engineers and operators to perform the following studies in offline or online mode:

- Load flow or power flow study.[4]
- Short circuit or fault analysis.[5]
- Protective device coordination, discrimination or selectivity.[6]
- Transient or dynamic stability.[7]
- Substation design and analysis.[8]
- Harmonic or power quality analysis.[9]
- Reliability.[10]
- Optimal power flow.
- Power system stabilizer tuning.[11]
- Optimal capacitor placement [12]
- Motor starting and acceleration analysis.[13]
- Voltage stability analysis.[14]
- Arc flash hazard assessment.[15]
- Ground loop impedance calculation.[16]
- Battery modeling and simulation.[17]

The software applications, ETAP software applications include:

- Power system design for ANSI and IEC networks.[18]
- Electric supply substation simulation.[19]
- Monitoring and feeder analysis.[20]
- Simulation of distributed photovoltaic power.[21]
- Study of a DC network.[22]
- Open-phase fault analysis [23] - Multiple events across the nuclear power industry have highlighted the need for a greater understanding of what happens during an

open-phase fault. These open-phase events have occurred on the high side of offsite power supply transformers and have involved the loss of one or two phases.

- Diesel power plant analysis.[24]
- Combined cycle power plant analysis.[25]
- AC/DC hybrid system simulation.[26]
- Wind turbine design and analysis.[27]
- Harmonics in railway power systems.[28]
- Rural distribution system analysis.[29]
- Distributed generation protection.[30]
- Reliability assessment of renewable energy systems.[31]
- Wind and PV penetration studies.[32]

Chapter Two
Analysis of Jenin Electrical Network

2.1 Brief description of Jenin Electrical Network

The network of Jenin is divided into nine regions with two connection points, AL Almaniah connection point with 20MVA and AL Jalameh with 20MVA.

The whole network consists of 151 Transformers with different capacities (100KVA, 250KVA, 400KVA, 630KVA, 1000KVA, 1500KVA, and 2000KVA), 88 Transmission lines with lengths (60m-3910m), and sizes ($50\ mm^2, 70mm^2, 95mm^2$) as these linesare overhead transmission lines, 114 cables with different lengths(40m-1600m) and sizes ($50\ mm^2,\ 95mm^2,\ 120mm^2,\ 150mm^2,\ 240,\ in\ addition,$ the network includes underground lines and 49 solar systems with different sizes (5KW-5000KW)[67].

2.2 Study of Jenin Electrical Network

2.2.1 Study of AL Maslakh Region

2.2.1.1 The parameters of AL Maslakh Region

AL Maslakh is a 33KV bus fed from AL Almaniah connection point, and it feeds parts of the east and northeast regions of Jenin city.

It consists of 10 Transformers (400KVA, 630KVA); three of them are connected to PV systems, T1 is connected to two PV systems, PVA1 and PVA4 with 8KW and 45KW, respectively, T5 is connected to PVA5 with15KW, and T6 is connected to PVA6 with 25KW.

In addition, the region includes 5 Transmission lines; one of them is a ring transmission line (TL5), eight underground cables, and 3 PV systems of (14KW, 22KW, and 52KW) [67].

2.2.1.2 The trouble issues of AL Maslakh Region

The main problem in this region is low voltages at some load busses, which are more than 5 % drop voltage refer to ANSI C84.1 voltage limits are ±5%. The minimum normal utilization voltage limit is −10%. That is the voltage drop can be as high as 10% from the bus nominal voltage for some equipment The nominal voltage at the load side is 0.4KV, so the actual voltages should be not less than 0.38KV to be accepted, and low power factor at some transformers, which is lower than 92 %, The ideal power factor value should be in the range of 0.95 to 1. According to IEEE 1547 and power losses through branches and transformers.

The goal is to improve the electrical network in this region as one unit using different tools such as installation of PV systems, Capacitor banks, and tap changers.
During the improvement process, capacitor banks will be added to improve power factor that leads to improved voltage bus level and reduces power losses in the network. PV systems are not used in this region except those that were used before.
In addition, the tap changer will be adjusted in some transformers to increase the bus voltages.

This region has ten load busses which are shown in the appendix A.1 in the figures from (A.1.1 to A.1.5), and the results of load flow analysis of these figures are concluded in table in the appendix A.1.1.

Table A.1.1 shows the results of the simulation before improvements; this table contains seven columns; the first one is power at the primary side of the transformer, the second one is power demand at the load side, the third one is real power from PV systems, the fourth one is reactive power from capacitor banks, the fifth one is the power losses through the transformer, the sixth one is the voltage at the load bus and finally is power factor at transformer side.

First of all, checking the balance at the load bus to calculate the power at the secondary side of the transformer, it is:
Power at the primary – losses through transformer = power at the secondary
As an example, bus 3 power flow:

The power injected from PV is 52 KW, and (203+113j -2.3-3.5j) KVA is the power flow from the transformer is equal to 252.7+109.5j KVA
The power demand from the load is 255+109j KVA
The solution details for bus 15 and bus 23 will be in chapter 3.2.1 as examples of the rest busses as shown in table 2.2.1.

Bus 15 has very good bus voltage but not good power factor, so a capacitor bank will be added to improve it, and bus 23 needs to improve both voltage level and power factor so a capacitor bank will be added to improve power factor and increase voltage bus level.

2.2.2 Study of AL Almaniah Region

2.2.2.1 The parameters of AL Almaniah Region

AL Almaniah is a 33KV bus fed from AL Almaniah connection point, and it feeds parts of the eastern region of Jenin city and A'aba eastern village. It consists of six Transformers (250KVA, 400KVA, and 630KVA), five Transmission lines, and four underground cables [67].

2.2.2.2 The trouble issues of AL Almaniah Region

In general, this region has a problem with a low power factor that is lower than 92%, so capacitor banks will be added to improve the power factor.

The voltage bus level is very good and in the accepted range. Table A.2.1 shows the load flow results before improvements, and figures A.2.1 and A.2.2 show the simulations of this region.

Table A.2.1 shows the simulation results at this region in details. All the bus voltages are more than the accepted value of 0.38KV, the power factor needs to be improved slightly, and the network balance is good as the injected power at the load bus is almost the same as the demand power at the load side.

The suggested solutions details will focus on bus 30 as an example in chapter 3.2.2, where capacitor banks are used to improve the power factor.

2.2.3 Study of Haddad Region

2.2.3.1 The parameters of Haddad Region

Haddad is a 33KV bus feeding from AL Almaniah connection point, and it feeds parts of the industrial zone at the east of Jenin city and the ring road region.It consists of 30 transformers rated at: (250KVA, 400KVA, 630KVA, and 1000KVA), a 1PV system of (178 KW), 27 transmission lines, and 15 underground cables [67].

2.2.3.2 The trouble issues of Haddad Region

This region has problems with low voltage bus levels and low power factors in the load buses and transformers, respectively. It is not in the accepted range, as mentioned before. The suggested solution details will be shown in chapter 3.2.3. The simulation of this region is shown in figures A.3.1 – A.3.4, and load flow analysis is represented in table 2.2.3.

The A.3.1 shows the load flow analysis of this region, there are low voltage busses level and low power factors, but bus 49 has the worst result for both voltage bus level and power factor due to high penetration of using PV systems at the load bus without using capacitor banks or other techniques to balance the power produced from PV or using other techniques that will be discussed in chapter 4.

In chapter 3.2.3 the suggested solutions details will be for bus 49 and bus 62 as an example.

2.2.4 Study of Ayash Region

2.2.4.1 The parameters of Ayash Region

Ayash is a 33KV bus feeding from AL Almaniah connection point and feeding the north part of downtown Jenin city.

It consists of 15 transformers (400KVA, 630KVA, 1000KVA, and 1500KVA), 1 PV system with 150KW, six transmission lines, one of which is a ring, and 14 cables, one of which is a ring [67].

2.2.4.2 The trouble issues of Ayash Region

This region has problems with low voltage bus levels and low power factors in the load buses and transformers, respectively. They are not in the accepted range, as mentioned before. The suggested solution details will be shown in chapter 3.2.4. The simulation of this region is shown in figures A.4.1 – A.4.2, and load flow analysis is represented in table A.4.1.

Table A.4.1 shows the load flow analysis for Ayash region.
The main problem is low-voltage at the buses; some buses have awful voltage levels due to power losses in the branches before the transformers, the power factor is not very bad, and it will be improved when the voltage bus level increases using capacitor banks and tap changers.

The suggested solution details will be for bus 112 and bus 124 in chapter 3.2.4.

2.2.5 Study of AL Nasreh street Region

2.2.5.1 The parameters of AL Nasreh street Region

AL Nasreh Street is a 33KV bus fed from AL Almaniah connection point through Ayash round region and Haddad region. It feeds residential areas such as Sabah AL Khair and Kharoubeh.
It consists of 14 transformers of (250KVA, 400KVA, and 630KVA), 3 PV systems with (15KW, 114KW, and 178KW), seven transmission lines, and 12 cables [67].

2.2.5.2 The trouble issues of AL Nasreh Street Region

The problems in this region are represented in low voltage at the buses, low power factors, and high PV penetration at two-load busses that negatively affects the power factors and voltage bus levels. The simulation of this region is shown in figures A.5.1 – A.5.6, and the load flow analysis is shown in table A.5.1.

Table A.5.1 shows that there are very low power factors affected by high PV penetration by producing a lot of real power into the network and ignoring reactive power production to balance the network, and there are low voltage bus levels at bus 72 and bus 78; generally, high PV penetration decreases the power factor and increases the voltages at the buses sometimes makes a problem of voltage rise or reverse power flow. This problem will be solved by using capacitor banks, or another technique discussed later in chapter 4.

As an example, the details of the suggested solution will be discussed in chapter 3.2.5 for buses 72 and 92.

2.2.6 Study of Sinan Region

2.2.6.1 The parameters of Sinan Region

Sinan is 33KV bus fed from AL Almaniah connection point; it is feeding the east region of Jenin until the Swetat region. It consists of 22 transformers and 16 transmission lines, one of which is a ring and 19 cables [67].

2.2.6.2 The trouble issues of Sinan Region

This region's problems are primarily low voltage bus levels lower than 0.38KV and low power factors lower than 92%
The simulation of this region is shown in figures A.6.1 – A.6.3, and load flow analysis is represented in table A.6.1

Table A.6.1 shows the load flow analysis of this region before improvements, and it looks like a balanced network by checking injected power and demand power at the load busses; the problems are represented in low voltage at the buses lower than 0.38KV and low power factors that are lower than 92%.
Bus 149 and bus 147 will be discussed later in chapter 3.2.6 as examples of the suggested solutions for the remaining load busses.

2.3 Study of AL Jabriat Region

2.3.1 The parameters of AL Jabriat Region

AL Jabryat is 33KV bus fed from Sinan bus; it feeds the south region of Jenin Nablus Street and Al Jabriat. It consists of 13 transformers, no PV systems, eight transmission lines, and ten cables [67].

2.3.1.1 The trouble issues of Jabriat Region

The problem in this region is represented by low voltage at the buses and low power factor which are lower than the accepted values of 0.38KV and 92% respectively. The network looks balanced by checking the injected power and demand power at the load busses. The simulation of this region is shown in figures A.7.1 – A.7.3 and load flow analysis in table A.7.1.

Table A.7.1 shows the load flow analysis of AL Jabriat region before improvements; the power factors readings are not so bad but they are lower than 92%, and voltages at the buses are lower than 0.38KV, which will be solved by adding capacitor banks.

The suggested solution details will be discussed in chapter 3.2.7 for bus 208 and bus 182 as examples for the remaining load busses, they will be improved by adding capacitor banks almost.

2.3.2 Study of Cinema Region

2.3.2.1 The parameters of Cinema Region

AL Cinema region is a 33 KV bus; it is a part of Sinan bus; it feeds the trade square downtown of Jenin.

It consists of 25 transformers, one PV system, and three transmission lines; one of them is a ring with a Jalameh connection point and 22 cables [67].

2.3.2.2 The trouble issues of Cinema Region

This region has problems of low voltage bus levels and low power factors. Some buses have very bad voltage bus levels due to power losses in the transmission lines and branches before the transformer, which causes the primary voltage at the transformer to be less than the nominal value of 33KV; these problems will be solved by adding capacitor banks and increasing tap changers in some transformers. These problems and their suggested solutions will be discussed in chapter 3.2.8, the simulation of this region is shown in figures A.8.1 – A.8.3, and the load flow analysis is represented in table A.8.1.

Table A.8.1 shows the load flow analysis of this region before improvements; there are low voltages at the buses and low power factors which need some improvements by adding capacitor banks, PV systems, and increasing the tap changer for the transformers to increase the bus voltages.

The network looks balanced in this region by checking the injected power and demand power at the load buses.

The suggested solutions in chapter 3.2.8 will be for bus 226, bus 242, and bus 241, which are different cases as examples for the remaining load buses.

2.3.3 Study of Haifa street Region

2.3.3.1 The parameters of Haifa street Region

Haifa Street region is a 33 KV bus fed from AL Jalameh connection point; it feeds parts of Haifa Street, Jenin Camp, and the surrounding region.
It consists of 16 transformers, 5 PV systems, 11 transmission lines, and ten cables [67].

2.3.3.2 The trouble issues of Haifa Street Region

This region has a very good voltage bus level and a little bit low power factor in some busses which will be improved by adding capacitor banks.

The simulation of this region is shown in figures A.9.1 – A.9.4, and the load flow analysis is represented in table A.9.1.
Table A.9.1 shows the load flow analysis for the Haifa Street region connected to the AL Jalameh connection point. The network looks balanced by checking the injected power and demand power at the load bus. The main problems in this region is the low power factor.
The suggested solution details will be for bus 283 and bus 286; as examples for the remaining load buses, which will be by adding capacitor banks to improve the power factor. This suggested solution is represented in chapter 3.2.9.

Chapter Three

Suggested solutions of Jenin network

3.1 Description of some equations and concept used in solutions

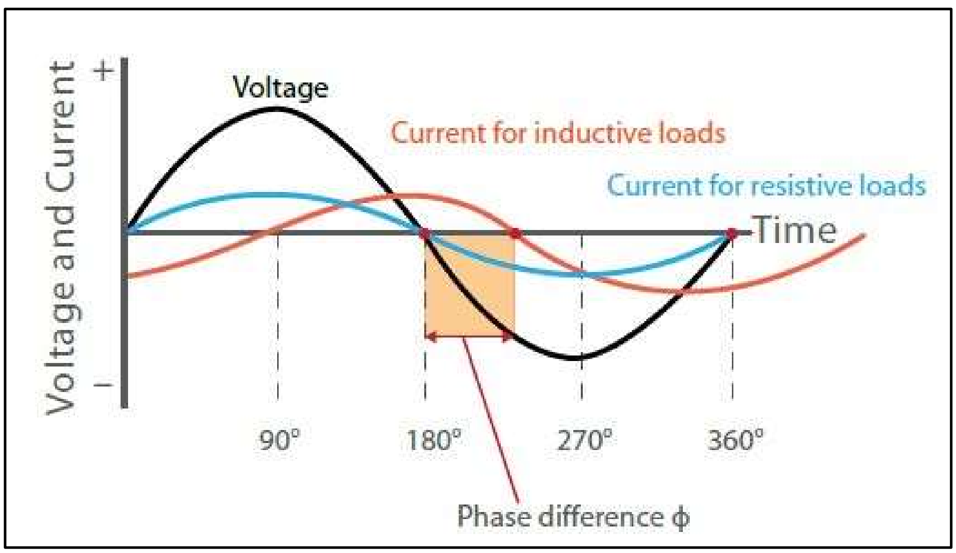
a. Power factor

This chapter will explain brief information about power factors due to their importance in the electrical networks and this thesis.

Power factor measures the phase difference between the voltage and current in an AC power system. In purely resistive loads, the current is in phase with the voltage, and there is a ‘unity’ power factor. Capacitive and inductive loads will cause the current to ‘lead’ or ‘lag’ the voltage, resulting in a ‘non-unity’ power factor. An example of a lagging and unity power factor is shown infigure3.1.1 [69].

Figure 3.1.1

lagging power factor representation



The relationship between active and reactive power is shown in Figure 3.1.2. The vectors for active power (measured in Watts) and reactive power (measured in Volt-Amps reactive – VAR) are added at right angles to give apparent power (measured in VA). Apparent power is what a generator must produce. The angle between the active and apparent power vectors gives the phase angle.

The power factor is the cosine of the phase angle in a power triangle. It is defined as the ratio between the active power (W) and the apparent power (VA) [69].

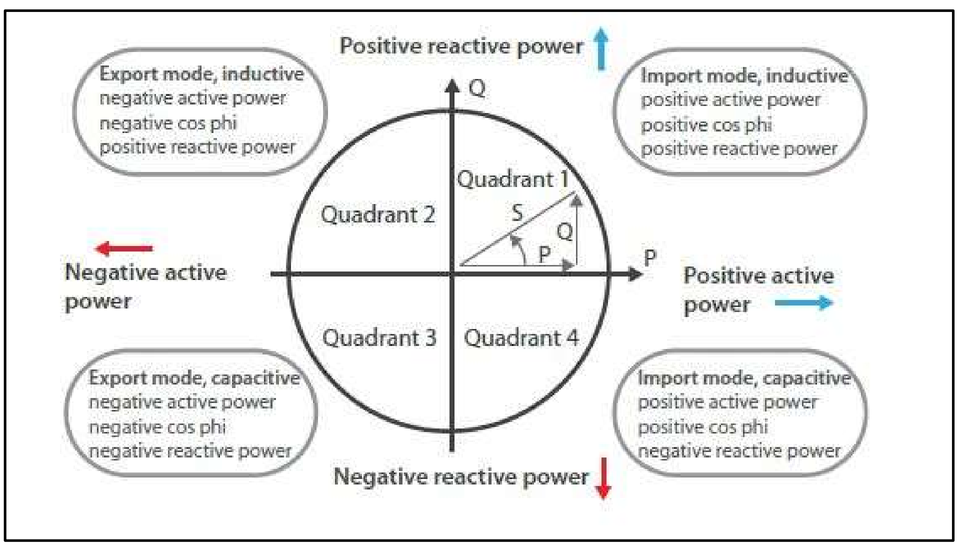
The power factor will vary between 0 and 1 and be either leading or lagging as shown in equation (3.1)

$$Power\ Factor = \frac{Active\ Power(W)}{Apperant\ Power(VA)} = cos\theta \quad (3.1)$$

Figure 3.1.3 below shows the four-quadrant representation of power flow and power factor. The sign of active power P and power factor (cos ø) provides details about the direction of energy flow. A positive sign indicates the import mode, and a negative sign indicates the export mode. In quadrants 1 and 4, a positive reactive power indicates an inductive load, and a negative reactive power indicates a capacitive load in the import mode. On the other hand, in export mode quadrants 2 and 3, an inductive generator is indicated by a positive reactive power, and a negative reactive power indicates a capacitive generator [69].

Figure 3.1.3

Four quadrant of power factor and power flow

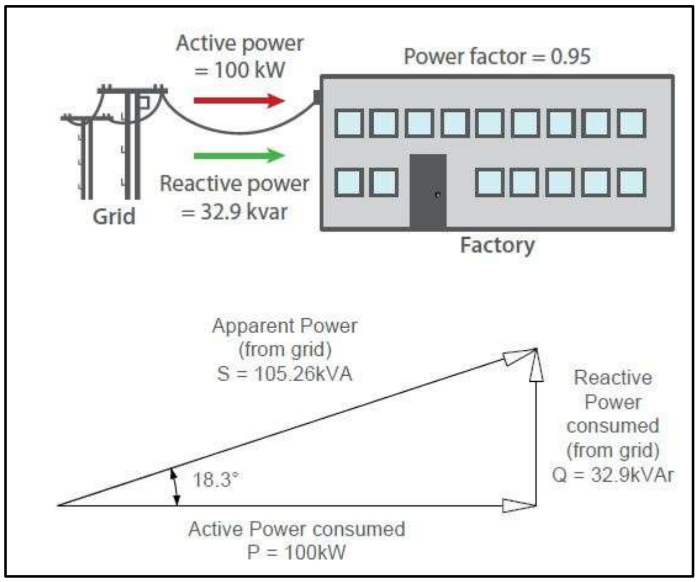


Power Factor and Grid-Connected PV Systems

Most grid-connected PV inverters inject power at the unity power factor, meaning they only produce active power, which reduces the power factor, as the grid supplies less active power but the same amount of reactive power. Consider the situation in Figure 3.1.4. The factory consumes 100kW of active power and 32.9kVAr of reactive power, resulting in a power factor of 0.95 lagging [69].

Figure 3.1.4

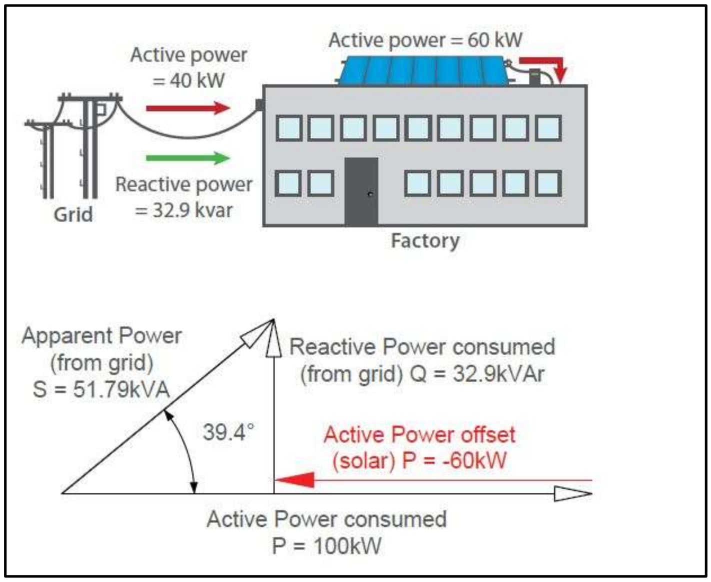
Factory consuming active and reactive power



If this factory were to install a 60kW PV system 3.1.4 that is exported at a unity power factor, only the active power imported from the grid would be affected. The imported active power from the grid has been reduced to 40kW, while the reactive power imported from the grid remains constant at 32.9kVAr. As can be seen from the phase diagram, this has the effect of reducing the power factor to 0.77 – lagging [69].

Figure 3.1.5

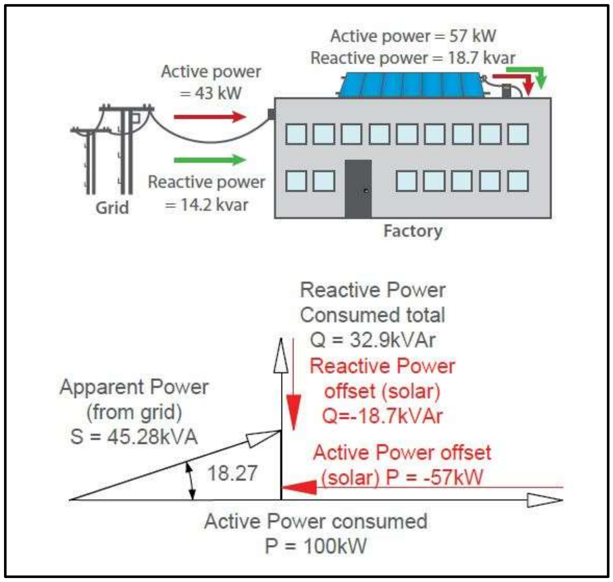
Factory with 60kW PV system producing power at a unity power factor



However, this problem of poor power factor can be addressed by selecting appropriate inverter products. Inverters with reactive power control can be configured to produce both active and reactive power. This means that the load's power factor can be kept within reasonable limits. Figure 3.1.5 shows the factory with the inverter set to a power factor of 0.95 - leading. The PV system is now producing 57kW of active power and 18.7kVAr of reactive power, reducing the amount of both active and reactive power from the grid. The resultant power factor is therefore maintained at what it was originally at 0.95 – lagging [69].

Figure 3.1.6

System installed with reactive power control to produce both active and reactive power



3.2 The solutions proposed to the problems of Jenin Network

3.2.1 The solutions proposed to the problems of Al Maslakh

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.1 are explained in details. The improvement results are clearly shown in table B.1.1 and in the figures from B.1.1 to B.1.5

In general, the thesis solves the problems in the electrical network as one unit, that means it deals with the problems in each bus which has a problem and monitors the effect in the whole region of the electrical network, so the improvement has done step by step, starting with improving the worst and the farthest load bus from the source gradually until the nearest load bus to the source.

Suggested solutions are focused on improving the voltage bus levels and reducing the power losses, subsequently improving the power factor. Capacitor banks were used to improve the power factor by decreasing the reactive power consumed from the source, that is, making the real power more than reactive power at the source side and refer to the power factor equation (1):

$$PF = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} = \frac{P}{\sqrt{P_l+(Q_l^2-Q_c^2)}} \quad (3.2)$$

It is shown from equation (3.2) [70] that the relation between the power factor and the reactive power is inverse; the power factor increases by decreasing reactive power.
To choose the best value of the capacitor bank needed to improve the power factor on the transformer side will use equation (3.3).

$$Q_c = P(\tan(cos^{-1}(PF_{old})) - \tan(cos^{-1}(PF_{new}))) \quad (3.3)$$

PV systems are used to decrease power losses at the branches and to improve the voltage bus level, also using tap changers at the transformers are used to improve the voltage bus level.

As mentioned in chapter 2.2.1, the buses that will be explained in details here are buses 15 and 23 as examples of the other buses in this region.

Taking bus 15 as an example, it has 232.6+111.9j KVA injected from the transformer at the secondary side and 22Kw injected from the PV system installed (i.e., total power injected 254.6+111.9j) KVA. In contrast, the demand at the load side is 260+111j KVA which means the balance is verified, but the problems in this bus are low power factor, which equals 88.7%, the voltage at the bus is accepted, it is equal to 0.398 kV. The suggested solution was to install a capacitor bank equals to 50KVAR.

Applying equation (3.3) [70] to choose the suitable capacitor bank,

$$Q_c = 236\big(\tan\big(cos^{-1}(0.887)\big) - \tan\big(cos^{-1}(0.975)\big)\big) = 69KVAR$$

So by applying equation 2, the best value of the capacitor bank to get 97.5% power factor on the transformer side is by adding 69 KVAR. However, using simulation, 51KVAR has been used as the best choice because other capacitor banks are installed on different busses, which will affect each other.

Taking bus 23 as an example. It has 156.7+68.6j KVA transmitted from the transformer at the secondary side, and 160+68 KVA is the demand at the load side, which means that it is almost balanced, but the problems in this bus are low power factor, which equals 90.6%, and low voltage at the bus which equals 0.361 KV.

The suggested solution was to install a capacitor bank equals to 37KVAR, as seen below:

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 159\left(\tan\left(cos^{-1}(0.906)\right) - \tan\left(cos^{-1}(0.974)\right)\right) = 37KVAR$$

So by applying equation 2, the best value of the capacitor bank to get 97.4% power factor on the transformer side is by adding 37 KVAR which is improve power factor to 97.4% and voltage bus to 0.383Kv.

The problems at the other busses have been solved the same way as these two busses discussed above; almost the suitable solution was adding capacitor banks. Increasing the tap changer at the transformer in some load busses was needed to improve the voltage bus level.

3.2.2 The solutions proposed to the problems of Al Almanya

The proposed solutions to the previous problems mentioned in chapter 2.2.2 will be discussed in detail in this part. The improvement results are clearly shown in table B.2.1 and in the figures from B.2.1 to B.2.2.

As mentioned in chapter 2.2.2, the bus that will be explained in details is bus 30 as an example for the other busses.

Taking bus 30 as an example, it has 100.7+48.1j KVA injected power from the transformer at the secondary side and 102+44j KVA demand power at the load side, which means that it is almost balanced, but the problems in this bus are low power factor, which equals to 89.6%. The Voltage bus level is accepted and equals 0.392 KV. The suggested solution was to install a capacitor bank equal to 20KVAR, as seen by the equation below:

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 102\left(\tan\left(cos^{-1}(0.896)\right) - \tan\left(cos^{-1}(0.971)\right)\right) = 25.4KVAR$$

So by applying equation2, the best value of the capacitor bank to get 97.1% power factor on the transformer side is by adding 25.4 KVAR. However, using simulation, 20 KVAR has been used because other capacitor banks installed on different busses, which will affect each other.

The problems at the remaining busses were solved the same way as bus 30; almost the suitable solution was adding capacitor banks.

3.2.3 The solutions proposed to the problems of Haddad Region

The proposed solutions to the previous problems mentioned in chapter 2.2.3 will be discussed in details in this part.

The improvement results are clearly shown in table B.3.1, and simulation results after improvements are shown in the figures from B.3.1 to B.3.4.

As mentioned in chapter 2.2.3, buses 49 and 62 will be explained in details as an example for the other buses.

Taking bus 49 as an example to explain it, it has 71.2+103.8j KVA injected power from the transformer at the secondary side and 178Kw injected power from the PV system installed (i.e., total power injected 249.2+103.8j KVA) and 248+106j KVA demand power at the load side that means it is almost balanced, but the problems in this bus are bad power factor equals to 56.4%, low voltage bus level equals to 0.351 KV, the suggested solution was to install a capacitor bank equals to 101KVAR. Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 72\left(\tan\left(cos^{-1}(0.564)\right) - \tan\left(cos^{-1}(0.993)\right)\right) = 96.85KVAR$$

So by applying equation (2), the best value of the capacitor bank to get a 99.3% power factor on the transformer side is by adding 96.85 KVAR. However, using simulation, 101KVAR has been used as the best choice because other capacitor banks are installed on different busses which will affect each other.

Taking bus 62 as another example, it has 244.3+107.5j KVA injected power from the transformer at the secondary side, and 151+107j KVA demand power at the load side, that is mean it is almost balanced. However, the problems in this bus are not very bad power factor equals to 91%, low voltage bus level equals to 0.364 KV. The suggested solution was to install a capacitor bank equals to 18KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 248(\tan(cos^{-1}(0.91)) - \tan(cos^{-1}(0.936))) = 19.7KVAR$$

So by applying equation (2), the best value of the capacitor bank to get a 93.6% power factor on the transformer side is by adding 18 KVAR, which is near the theoretical value. The bus voltage is increased from 0.364 to 0.379 by the capacitor bank effect, then the tap of the transformer has been increased by one step (i.e., each step equals 3.33%), which increases the bus voltage to 0.382.

The problems at the remaining busses were solved by the same way as done to the two busses above, almost the most suitable solution was by adding capacitor banks. In some load busses, they also needed to increase the taps at the transformer to improve the voltage bus level.

3.2.4 The solutions proposed to the problems of Ayash Region

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.4 are explained in details. The improvement results are clearly shown in table 3.2.1, and the simulation results are shown in the figures from B.4.1 to B.4.2.

Table 3.2

Load flow of Ayash region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Origin network							
Bus107	161+70j	158+67j	0	0	2.1+3.2j	0.351	91.7
Bus122	259+112j	252+107j	0	0	4.6+6.9j	0.365	91.7
Bus124	154+74j	153+65j	0	0	2.8+4.1j	0.316	90.1
Bus110	401+184j	394+168j	0	0	4.8+16.8j	0.349	90.8
Bus112	245+105j	236+101j	0	0	4.9+7.3j	0.292	91.9
Bus114	243+105j	235+100j	0	0	5.1+7.6j	0.285	91.7
Edited network							
Bus107	167+44j	165+70j	0	30	2+3j	0.397	96.7
Bus122	264+86j	258+110j	0	28	4+5.9j	0.39	95
Bus124	166+49j	163+70j	0	28	2.5+3.7j	0.387	95.9
Bus110	410+97j	404+172j	0	88	3.9+13.5j	0.376	97.3
Bus112	264+68j	258+110j	0	48	4.4+6.6j	0.393	96.8
Bus114	262+69j	257+109j	0	47	4.5+6.7j	0.38	96.7

As mentioned in chapter 2.2.4, the buses that will be explained in details are buses 112 and 124 as examples of the remaining buses.

Taking bus 112 as an example, it has 240.1+97.7j KVA injected power from the transformer at the secondary side and 236+101j KVA demand power at the load side, meaning that it is almost balanced. However, the problems in this bus are a low power factor equals to 91.9% and a bad voltage bus level equals to 0.292 kV; the suggested solution was to install a capacitor bank equal to 48KVAR and increase the tap changer of the transformer.

Applying equation 2 to choose the suitable capacitor bank,

$$Q_c = 245\left(\tan\left(cos^{-1}(0.919)\right) - \tan\left(cos^{-1}(0.968)\right)\right) = 41.59KVAR$$

So, by applying equation (3.3), the best value of the capacitor bank to get 96.8% power factor on the transformer side was by adding 41.59 KVAR. However, by simulation, 48KVAR has been used as the best choice because other capacitor banks installed on different buses will affect each other.

The bus voltage increased from 0.292 to 0.37 by the capacitor bank effect; then, after increasing the tap changer, the bus voltage increased to 0.393.

Taking bus 124 as another example, it has 151.2+69.9j KVA injected power from the transformer at the secondary side and 153+65j KVA demand power at the load side, meaning it is almost balanced. However, the problems in this bus are not very bad power factor equals to 90.1%, and the low voltage bus level equals to 0.316 kV; the suggested solution was to install a capacitor bank equals to 28KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 154\left(\tan\left(cos^{-1}(0.901)\right) - \tan\left(cos^{-1}(0.959)\right)\right) = 28.6KVAR$$

So by applying equation (2), the best value of the capacitor bank to get a 95.9% power factor on the transformer side is by adding 28 KVAR, and the voltage bus increased to 0.387KV.

The problems at the remaining busses were solved in the same way as done to the two busses above; almost the suitable solution was by adding capacitor banks. In some load busses, they also need to increase the taps at the transformer to increase or improve the voltage bus level.

3.2.5 The suggested solutions to the problems of Nasreh Street:

In this part, the suggested solutions to the previous problems mentioned in chapter 2.2.5 are explained in details. The improvement results are clearly shown in table 3.2.2, and the simulation results are in the figures from B.5.1 to B.5.6.

Table 3.2.2

Load flow of Nasreh street region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Origin network							
Bus92	162+73j	163+69j	0	0	2.2+3.3j	0.383	91.2
Bus94	161+73j	162+69j	0	0	2.3+3.4j	0.375	91.2
Bus96	85+45j	100+43j	15	0	1.1+1.7j	0.371	88.3
Bus98	99+45j	100+43j	0	0	0.9+1.3j	0.371	91
Bus88	98+45j	100+42j	0	0	1.4+2.1j	0.365	90.8
Bus68	98+45j	100+42j	0	0	1.4+2.1j	0.336	90.8
Bus72	75+106j	j	178	0	0.8+1.2j	0.368	57.7
Bus86	96+44j	98+42j	0	0	1.4+2.1j	0.349	90.9
Bus78	47+68j	160+68j	114	0	0.5+0.8j	0.367	56.8
Bus80	97+45j	99+42j	0	0	1.4+2.1j	0.364	90.7
Bus82	237+113j	251+107j	9	0	3.4+5.1j	0.364	90.2
Bus84	97+45j	99+42j	0	0	1.4+2.1j	0.363	90.7
Edited network							
Bus92	166+44j	165+70j	0	30	1.9+2.9j	0.399	96.6
Bus94	165+44j	165+70j	0	29	2+2.9j	0.394	96.6
Bus96	88+16j	102+44j	15	29	0.9+1.3j	0.393	98.3
Bus98	102+16j	102+44j	0	29	0.7+1.1j	0.393	98.7
Bus88	101+36j	101+43j	0	9	1.3+1.9j	0.384	95.1
Bus68	101+17j	102+43j	0	28	1.2+1.8j	0.386	98.6
Bus72	80+24j	257+110j	178	85	0.3+0.5j	0.389	95.7
Bus86	99+28j	100+43j	0	17	1.2+1.8j	0.367	96.2
Bus78	50+13j	164+70j	114	56	0.2+0.3j	0.387	96.7
Bus80	101+45j	101+43j	0	0	1.4+2.1j	0.382	92
Bus82	245+96j	256+109j	9	18	3.1+4.7j	0.382	93.1
Bus84	101+27j	101+43j	0	18	1.2+1.8j	0.383	96.6

As mentioned in chapter 2.2.5, buses 72 and 92 will be explained in details as examples of the rest buses.

Taking bus 72 as an example to explain it, it has 74.2+104.8j KVA injected power from the transformer at the secondary side, and 178Kw injected power from the PV system installed (i.e., total power injected 252.2+104.8j KVA) and 252+108j KVA demand power at the load side. It is almost balanced, but the problems in this bus are a low power factor equals to 57.7% and a low voltage bus level equals to 0.368 kV; the suggested solution was to install a capacitor bank equals to 85KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 75\left(\tan\left(cos^{-1}(0.577)\right) - \tan\left(cos^{-1}(0.957)\right)\right) = 83.4KVAR$$

So by applying equation (3.3), the best value of the capacitor bank to get a 95.7% power factor on the transformer side is by adding 83.4 KVAR, which is similar to the value used in the simulation.

Taking bus 92 as an example, it has 159.8+69.7j KVA injected power from the transformer at the secondary side and 163+69 KVA demand power at the load side, meaning it is almost balanced. However, the problem at this bus is low power factor equals 91%, and the bus voltage is an accepted value equals to 0.383 kV; the suggested solution was to install a capacitor bank equals to 30KVAR to improve the power factor to 96.6%.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 162\left(\tan\left(cos^{-1}(0.912)\right) - \tan\left(cos^{-1}(0.966)\right)\right) = 29.5KVAR$$

So by applying equation (3.3), the best value of the capacitor bank to get 96.6% power factor on the transformer side is by adding 29.5 KVAR, which is similar to the value used in the simulation.

The problems at the remaining buses were solved in the same way as done to the two buses above; almost the suitable solution was by adding capacitor banks. In some load buses, they also needed to increase the tap changer at the transformer to improve the voltage bus level.

3.2.6 The solutions proposed to the problems of Sinan Region

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.6 are explained in details. The improvement results are clearly shown in table 3.2.3, and the simulation results are shown in the figures from B.6.1 to B.6.3.

Table 3.2.3

Load flow of Sinan region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF %
Origin network							
Bus142	99+43j	97+41j	0	0	1.4+2.1j	0.337	91.7
Bus145	252+109j	246+105j	0	0	3.5+5.3j	0.339	91.7
Bus143	252+110j	246+105j	0	0	3.5+5.3j	0.339	91.6
Bus147	252+109j	246+105j	0	0	3.5+5.3j	0.341	91.7
Bus149	99+43j	97+41j	0	0	1.4+2.1j	0.338	91.7
Bus151	250+108j	244+104j	0	0	3.7+5.6j	0.33	91.8
Bus152	249+108j	242+103j	0	0	3.8+5.7j	0.324	91.7
Edited network							
Bus142	103+17j	101+43j	0	28	1.2+1.9j	0.383	98.6
Bus145	261+86j	256+109j	0	28	3.4+5.1j	0.383	94.9
Bus143	261+86j	256+109j	0	28	3.4+5j	0.385	94.9
Bus147	261+86j	256+109j	0	28	3.4+5.1j	0.384	94.9
Bus149	103+17j	101+43j	0	28	1.2+1.9j	0.383	98.6
Bus151	261+86j	257+110j	0	28	3.6+5.4j	0.388	94.9
Bus152	260+87j	256+109j	0	28	3.7+5.5j	0.383	94.8

As mentioned in chapter 2.2.6, buses 147 and 149 will be explained in details as examples for the rest buses.

Taking bus 147 as an example, it has 248.5+103.7j KVA injected power from the transformer at the secondary side, and 246+105j KVA demand power at the load side, which means it is almost balanced; however, the problems in this bus are low power factor equals to 91.7%, and a low voltage bus level equals to 0.341 kV, the suggested solution was to install a capacitor bank equals to 28KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 252\left(\tan\left(cos^{-1}(0.917)\right) - \tan\left(cos^{-1}(0.949)\right)\right) = 25.9KVAR$$

So by applying equation (3.3), the best value of the capacitor bank to get a 94.9% power factor on the transformer side is by adding 25.9 KVAR, which is similar to the value used in the simulation of 28 KVAR.

Taking bus 149 as an example, it has 97.6+40.9j KVA injected power from the transformer at the secondary side and 97+41j KVA demand power at the load side; that means it is almost balanced, but the problems in this bus are low power factor of 91.7%, and low voltage bus level of 0.338 kV, the suggested solution was to install a capacitor bank equals to 28KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 99\left(\tan\left(cos^{-1}(0.917)\right) - \tan\left(cos^{-1}(0.986)\right)\right) = 26.3KVAR$$

So by applying equation (3.3), the best value of the capacitor bank to get 98.6% power factor on the transformer side is by adding 26.3 KVAR, which is similar to the value used in the simulation of 28KVAR.

The problems at the remaining busses were solved in the same way as done to the two buses above; almost the suitable solution was by adding capacitor banks. In some load buses, they also need to increase the taps at the transformer to increase or improve the voltage bus level.

3.2.7 The solutions proposed to the problems of Jabryat

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.7 are explained in detail. The improvement results are concluded in table 3.2.4, and the simulation results are in the figures from B.7.1 to B.7.3.

Table 3.2.4

Load flow of Jabryat region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Origin network							
Bus179	157+71j	158+67j	0	0	2.1+3.1j	0.348	91.1
Bus182	61+28j	62+26j	0	0	0.9+1.3j	0.328	90.8
Bus184	151+70j	154+66j	0	0	2.2+3.3j	0.326	90.7
Bus192	60+28j	62+26j	0	0	0.9+1.3j	0.33	90.6
Bus194	151+70j	155+66j	0	0	2.2+3.3j	0.33	90.7
Bus206	240+110j	244+104j	0	0	3.4+5.1j	0.333	90.9
Bus208	95+44j	97+41j	0	0	1.4+2j	0.331	90.7
Bus198	95+44j	97+41j	0	0	1.3+2j	0.334	90.7
Edited network							
Bus179	164+45j	163+69j	0	28	1.8+2.7j	0.384	96.4
Bus182	66+0.91j	65+28j	0	28	0.7+1j	0.387	99.9
Bus184	164+45j	163+69j	0	28	1.9+2.8j	0.383	96.4
Bus192	65+1j	65+28j	0	28	0.7+1j	0.383	99.9
Bus194	163+8j	163+69j	0	64	1.7+2.6j	0.383	99.8
Bus206	257+22j	256+109j	0	92	2.8+4.1j	0.383	99.6
Bus208	102+8j	101+43j	0	37	1.1+1.6j	0.382	99.7
Bus198	102+17j	101+43j	0	28	1.1+1.7j	0.383	98.6

As mentioned in chapter 2.2.7, buses 208 and 182 will be explained in details as examples for the rest buses.

Taking bus 282 as an example, it has 93.6+42j KVA injected power from the transformer at the secondary side and 97+41j KVA demand power at the load side that means it is almost balanced; however, the problems at this bus are low power factor equals to 90.7%, and low voltage bus level equals to 0.331 KV. The suggested solution was to install a capacitor bank equals to 37KVAR.

Applying equation (2) to choose the suitable capacitor bank,

$$Q_c = 95\left(\tan\left(cos^{-1}(0.907)\right) - \tan\left(cos^{-1}(0.997)\right)\right) = 36.7KVAR$$

By applying equation (3.3), the best value of the capacitor bank to get a 97.5% power factor on the transformer side was by adding 36.7 KVAR, which is similar to the value used in the simulation of 37KVAR that improves the power factor from 91.7% to 99.7% and the bus voltage from 0.331KV to 0.382KV.

Taking bus 182 as another example, it has 60.1+26.7j KVA injected power from the transformer at the secondary side, and 62+26j KVA demand power at the load side, that means it is almost balanced; however, the problems at this bus are low power factor equals to 90.8% and low voltage bus level equals to 0.328 kV, the suggested solution was to install a capacitor bank of 28KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 61\left(\tan\left(cos^{-1}(0.908)\right) - \tan\left(cos^{-1}(0.999)\right)\right) = 25.4KVAR$$

By applying equation (3.3), the best value of the capacitor bank to get a 99.9% power factor on the transformer side was by adding 25.4 KVAR, which is similar to the value used in the simulation of 28KVAR. That increased the power factor from 90.8% to 99.9% and the bus voltage from 0.328KV to 0.387KV.

The problems at the remaining buses were solved in the same way as done to the two busses above, almost the suitable solution was by adding capacitor banks, and in some load buses they also needed to increase the tap changer at the transformer to increase or improve the voltage bus level.

3.2.8 The solutions proposed to the problems of Cinema Region

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.8 are explained in details. The improvement results are clearly concluded in table 3.2.5, and the simulation results are in the figures from B.8.1 to B.8.3.

Table 3.2.5

Load flow of cinema region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF %
Origin network							
Bus226	245+108j	239+102j	0	0	4.1+6.1j	0.308	91.5
Bus225	245+108j	239+102j	0	0	4.1+6.1j	0.308	91.5
Bus228	96+42j	93+40j	0	0	1.8+2.7j	0.286	94.8
Bus230	238+105j	231+99j	0	0	5.1+7.6j	0.266	91.5
Bus232	236+104j	229+98j	0	0	5.5+8.2j	0.253	91.5
Bus233	236+104j	229+98j	0	0	5.5+8.2j	0.253	91.5
Bus238	237+105j	230+98j	0	0	5.4+8.1j	0.257	91.4
Bus239	237+105j	230+98j	0	0	5.4+8.1j	0.257	91.4
Bus241	234+104j	228+97j	0	0	5.8+8.7	0.244	91.3
Bus242	194+100j	228+97j	44	0	4.2+6.3	0.245	88.8
Edited network							
Bus226	265+86j	259+110j	0	29	3.9+5.8j	0.395	98.1
Bus225	265+86j	259+110j	0	29	3.9+5.8j	0.395	98.1
Bus228	105+16j	103+44j	0	29	1.7+2.5j	0.395	98.8
Bus230	265+87j	260+111j	0	30	5.1+7.7j	0.399	94.6
Bus232	216+85j	257+109j	44	28	3.8+5.8j	0.385	93
Bus233	216+85j	257+109j	44	28	3.8+5.8	0.385	93
Bus238	258+92j	259+110j	0	29	5.1+7.6j	0.394	94.2
Bus239	258+92j	259+110j	0	29	5.1+7.6j	0.394	94.2
Bus241	209+91j	256+109j	44	27	3.7+5.6j	0.383	91.6
Bus242	210+54j	256+109j	44	65	3.4+5j	0.384	96.8

As mentioned in chapter 2.2.1, buses 226,242, and 241 will be explained in detail as examples for the rest buses.

Taking bus 226 as an example, it has 240.9+101.9j KVA injected power from the transformer at the secondary side and 239+102j KVA demand power at the load side that means it is almost balanced; however, the problems at this bus are low power factor of 91.5%, and low voltage bus level of to 0.308 kV, the suggested solution was to install a capacitor bank of 29KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 245\left(\tan\left(cos^{-1}(0.915)\right) - \tan\left(cos^{-1}(0.981)\right)\right) = 59.5KVAR$$

By applying equation (3.3), the best value of the capacitor bank to get 98.1% power factor on the transformer side is by adding 59.5 KVAR; however, practically, by simulation, 29KVAR has been used as the best choice because other capacitor banks installed on different busses will affect each other.

By adding 29KVAR and slightly increasing the tap changer at the transformer. The power factor improved from 91.5% to 98.1%, and the bus voltage increased from 0.308KV to 0.395KV.

Taking bus 242 as another example, it has 189.8+93.7j KVA injected power from the transformer at the secondary side and 44Kw injected power from the PV system installed (i.e., total power injected 233.8+93.7j KVA) and 228+97j KVA demand power at the load side that means it is almost balanced but the problems in this bus are low power factor of 88.8%, low voltage bus level of 0.245 kV. The suggested solution was to install a capacitor bank of 65KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 194\left(\tan\left(cos^{-1}(0.888)\right) - \tan\left(cos^{-1}(0.968)\right)\right) = 50.16KVAR$$

By applying equation (3.3), the best value of the capacitor bank to get 96.8% power factor on the transformer side is by adding 50.16 KVAR; practically by simulation 65KVAR has been used as the best choice because other capacitor banks installed on different busses will affect each other. It increases the power factor from 88.8% to 96.8% and the bus voltage from 0.245KV to 0.384KV with a slightly increased tap changer at the transformer.

Taking bus 241 as another example, it has 228.2+95.3j KVA injected power from the transformer at the secondary side and 228+97j KVA demand power at the load side, meaning it is almost balanced. However, the problems at this bus are a low power factor equals to 91.3% and a low voltage bus level equals to 0.244 kV; the suggested solution was to install a capacitor bank of 27KVAR and a PV system of 44KW.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 234\left(\tan\left(cos^{-1}(0.913)\right) - \tan\left(cos^{-1}(0.938)\right)\right) = 18KVAR$$

So by applying equation (3.3), the best value of the capacitor bank to get 93.8% power factor is by adding 18 KVAR; practically using the simulation, 25KVAR has been used as the best choice because other capacitor banks installed on different busses will affect each other.

The value of the added capacitor increases the power factor from 91.3 % to 93.8% and the bus voltage from 0.244KV to 0.369KV.

PV system of 44KW is added to increase the bus voltage from 0.369 to 0.383. This value was chosen by on multi trials in the simulation, it is started with a small value of 5Kw as a common value usually used then by simulation this value has been increased until giving the best bus voltage without effecting negatively on the network, notice that the power factor decreases from 93.8% to 91.6% but it stills accepted to avoid troubles in the other parameters of the network. This example also shows the difference of the effects of using capacitor banks and PV systems.

The problems at the remaining buses were solved in the same way as these three busses above; almost the suitable solution was by adding capacitor banks and PV systems. Some load buses also need to increase the tap changer at the transformer to increase or improve the voltage bus level.

3.2.9 The solutions proposed to the problems of Haifa street

In this part, the proposed solutions to the previous problems mentioned in chapter 2.2.9 are explained in details. The improvement results are clearly shown in table 3.2.6 and in the figures from B.9.1 to B.9.4.

Table 3.2.6

Load flow of Haifa Street region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF %
Origin network							
Bus281	253+117j	256+109j	0	0	2.9+4.3j	0.383	90.7
Bus280	147+43j	162+69j	14	0	1.6+2.4j	0.38	95.9
Bus283	126+73j	163+69j	36	0	1.2+1.9j	0.384	86.5
Bus286	231+116j	256+109j	24	0	2.5+3.7j	0.385	89.3
Bus297	256+117j	258+110j	0	0	2.9+4.3j	0.389	90.9
Bus300	163+74j	164+70j	0	0	1.8+2.8j	0.387	91
Bus302	252+117j	258+110j	5	0	2.8+4.1j	0.391	90.7
Bus304	164+74j	164+70j	0	0	1.8+2.7j	0.393	91.1
Bus308	97+46j	102+44j	5	0	1+1.5j	0.393	90.3
Edited network							
Bus281	264+64j	262+112j	0	52	2.5+3.7j	0.406	97.1
Bus280	154+42j	166+71j	14	31	1.3+2j	0.404	96.4
Bus283	132+20j	167+71j	36	52	0.9+1.4j	0.408	98.8
Bus286	240+42j	263+112j	24	73	2+3j	0.408	98.5
Bus297	273+101j	264+112j	0	11	2.7+4.1j	0.412	93.7
Bus300	174+60j	167+71j	0	11	1.7+2.6j	0.41	94.5
Bus302	269+101j	264+112j	5	11	2.6+4j	0.413	93.6
Bus304	171+67j	167+71j	0	5	1.7+2.6j	0.409	93.1
Bus308	101+40j	104+44j	5	5	1+1.5j	0.409	92.9

As mentioned in chapter 2.2.1, buses 283 and 286 will be explained in detail as an example for the rest buses.

Taking bus 283 as an example, it has 124.8+71.1j KVA injected power from the transformer at the secondary side, and 36Kw injected power from the PV system installed (i.e., total power injected 160.8+71.1j) and 163+69j demand power at the load side that is mean it is almost balanced. However, the problems in this bus are low power factor equal to 86.5%; the voltage bus level is accepted equal to 0.384 kV, and the suggested solution was to install a capacitor bank equal to 52KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 126\big(\tan\big(cos^{-1}(0.865)\big) - \tan\big(cos^{-1}(0.988)\big)\big) = 53.4KVAR$$

By applying equation 2, the best value of the transformer to get 98.8% power factor is by adding 53.4 KVAR, which is similar to the simulation 52KVAR has been used, which improved the power factor from 86.5% to 98.8% and bus voltage from 0.384KV to 0.408KV.

Taking bus 286 as an example, it has 228.5+112.3j KVA injected power from the transformer at the secondary side and 24Kw injected power from the PV system installed (i.e., total power injected 252.5+112.3j) and 256+109j demand power at the load side that is mean it is almost balance but the problems in this bus are low power factor equal 89.3%, and low voltage bus level is equal 0.385 KV, the suggested solution was to install capacitor bank equal 73KVAR.

Applying equation (3.3) to choose the suitable capacitor bank,

$$Q_c = 231\left(\tan\left(cos^{-1}(0.893)\right) - \tan\left(cos^{-1}(0.985)\right)\right) = 75.9KVAR$$

By applying equation 2, the best value of the capacitor bank to get a 98.5 % power factor is by adding 75.9 KVAR, which is similar to the value used in the simulation of 73KVAR has been used, which improved the power factor from 89.3% to 98.5% and bus voltage increased from 0.385KV to 0.408KV.

The remaining buses were solved in the same way as these two busses above, almost the suitable solution was by adding capacitor banks. In some load buses, they also need to increase the tap at the transformer to increase or improve the voltage bus level.

Chapter Four

Effect of PV Penetration Level on the Network

4.1 Identification of PV penetration level

4.1.1 Brief introduction of PV penetration level

The energy demand has increased worldwide with different loads such as domestic, commercial building, and industrial customers; PV is the third most important renewable energy source after hydro and wind power [33].In Palestine, PV source is the most renewable energy used (RES) due to determinants of wind energy from Israel, and it does not have a waterfall to make hydropower instead; it is costly to build these two systems, so PV systems are most spread than other renewable energy sources in terms of its simplicity of installation, less dependence on the field and its economy. Solar energy obtained from photovoltaic (PV), including rooftop, ground-mounted, and building-integrated PV systems. Rooftop PV system applications has increased in recent years due to simple installation, Governmental encouragement, and not occupying an external area; the most consumed power in Palestine is the domestic part, with 68% of total power consumed, as shown in figure C.1.1.

However, the adverse effects of increased PV penetration level on the distribution system are cause problems in the voltage quality and power quality, so the power loss, reverse power flow (RPF), voltage fluctuations, and voltage unbalance are affecting on voltage quality in the power network also variations in system frequency, power factor, and harmonics affect the power quality. Increased of PV penetration is also cause of voltage stability and harms the protection system.

Various definitions for the PV Penetration level have been presented in different studies. According to [34], PV penetration is defined as the ratio of maximum PV power to the maximum apparent power of the load. In [35], PV penetration is defined as the total PV energy generation ratio to total energy generation. Cheng et al. [36] defined it as the ratio of the total PV nameplate to the annual circuit peak load. Paper [37] defined PV penetration on the low voltage network as:

$$PV_{pen} = \frac{S_{PVFeeder}}{n_{loads} S_{peak}} \quad (4.1)$$

Where $S_{PVfeeder}$the PV power is installed under a given feeder, n_{loads} the number of consumers tied to the feeder, and S_{Peak}an estimated value of peak PV power at the feeder.

Various works gave different percentage values as high PV penetration. Authors of [38] suggested values greater than 20% of total generation, while reports by [39, 40] consider high penetrations to levels up to 15% and 50%, respectively. Although there is no literary standard as to what percentage of PV penetration constitutes a high PV penetration, as a rule of thumb, many works suggest that at penetration above 15%, the challenges of high PV penetrations become noticeable [41,42].

4.1.2 Impact of PV Penetration on Distribution Network

There are many problems happened due to high PV penetration, as said before. Reverse power flow (RPF) caused when the voltage produced from PV system more than the demand power at the load. Increased voltage in low voltage feeder cause malfunction to the devices, especially electronic devices for houses also can do damages heavy machines in factories due to unbalance current resulting from unbalance voltage. These problems affect power quality, voltage quality, system protection problems, and system stability.

4.1.2.1 Impact on voltage quality

a) Power losses

Power losses occurs, from the components that integrate the PV panel into the system, the use of panels with different I-V characteristics in the same system, shading and contamination of the panel surfaces, and increased PV penetration level [43, 44]. If the energy produced from PV panels is more than the power demand of the consumer, it will reverse toward the network, and the feeder current changes that is called high PV penetration.

b) Reverse power flow

Reverse power flow means the power flow has an opposite direction; it will flow from the customer to the network due to not using energy or the energy being greater than the customer's energy demand. They suggest using a storage device that reduces RPF by 44% to solve this problem. [45]

c) Voltage Rise

Voltage rise caused by reverse power flow which is mean power flows from the customer to the network. The voltage at the Point of Common Coupling (PCC) of the inverter and the grid increases when the PV system produce power more than the consumer power demand [46].

d) Voltage Unbalance

Voltage Unbalance happened due to unbalance between net demand and net generation which happened due to uncertain current and impedance. Also, voltage unbalance increases due to the random placement of PV panels [48].when the voltage increases in the LV distribution feeder, it causes harmful effects on household devices, in 3 phase network Voltage Unbalance happens when the voltage magnitude of every phase is not same or if there is a difference in phase angle between two phase voltage.

It states that 1% of the voltage unbalance can produce 6–10 times the current unbalance [49], increasing the temperature of motor winding that causes a short lifetime.

e) Voltage Fluctuation

Voltage fluctuation is the voltage difference between the generation and consumption point along the distribution line [50]. Voltage fluctuations are often caused by bad weather or connection problems, leading to power quality problems. Since voltage fluctuations happened when the voltage at the PCC exceed a certain limit, the voltage variations must be within certain permissible ranges. Long-period and short-period flicker severity indices determine these limits. These indices should not be more than 1 in the shortest period and 0.65 in the long period [51]

4.1.2.2 Impact on power quality

a) Power Factor

The power factor is the phase angle between real power and apparent power.

In PV-integrated networks, power factor affecting PV penetration since the PV system produce real power only which is mean increasing of PV systems without control systems led to decreasing of power factor. The ideal power factor value should be in the range of 0.95 to 1, according to IEEE 1547 and UL 17 [78.79].

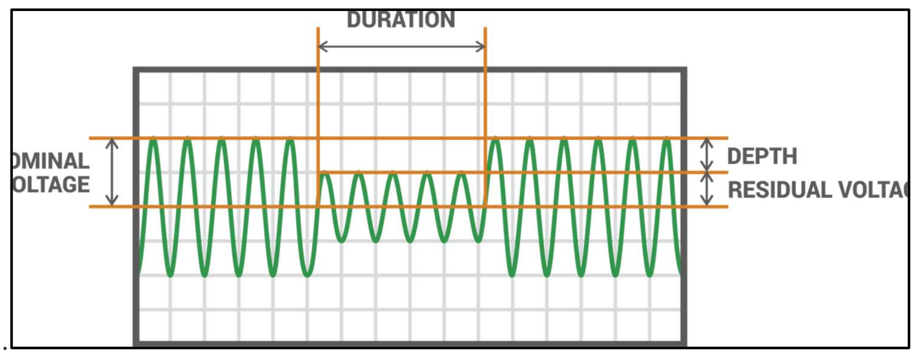
b) Voltage Sag

Voltage sag is a short drop of 10% below the nominal voltage mains supply level. As shown in figure 4.1.1

Voltage sags are happened by many reasons such as starting the motors, lightning, short-circuits between phases or between phases and ground, overloading, network failures, and voltage sags continue until the disturbance is rectified with a fuse or breaker [52]. Also, Voltage sags in the PV systems make a harmonics in the network and power losses.

Figure 4.1.1

Voltage sag representation

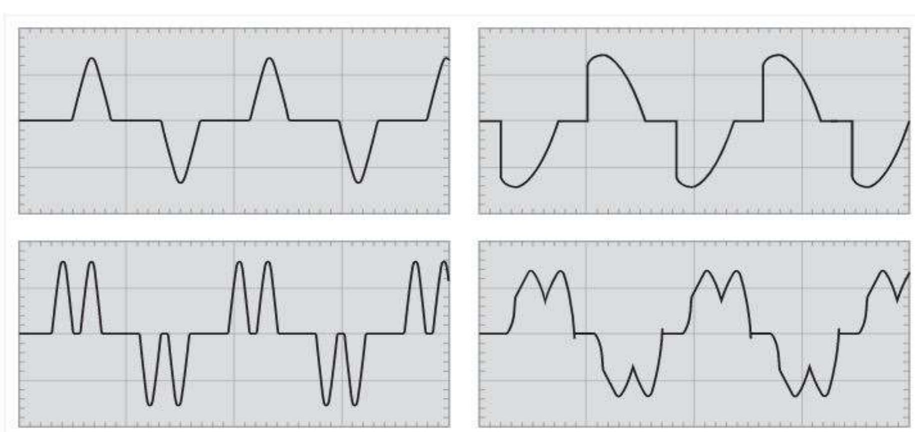


c) Harmonics

Harmonics is a sinusoidal waveform distorted and frequency-modified waveforms.it is happened when current and voltage are distorted and deviate from sinusoidal waveforms. As shown in figure 4.1.2

Figure 4.1.2

Distorted current wave form



Nonlinear loads such as vacuum cleaners, air conditioners, transformers, etc. are reason of harmonics in the network. Harmonics increase because of the integration of high-level PV into the network, and the harmonic resonances, that occur at the PCC. There are many disadvantages of harmonics such as in correct opening of circuit breakers and deterioration of the isolation of the devices connected to the system. [53, 54].

4.2 Solutions to the problems caused by PV penetration

4.2.1 On Load Tap Changer (OLTC)

OLTC working principle is a voltage regulation in the transformer loaded by changing the tap without interrupting the voltage stability and safely. However, it is used to solve a problem such as irregular increases, over-voltage, and fluctuations occur in the voltage of the system due to the intermittent nature of PVs [71].

4.2.2 Reactive Power control

The rapidly increased of using PV systems cause some problems due to high active power produced to the grid such as RPF, voltage fluctuation, and voltage unbalance in the network.

However, to avoid this problem, it should be to control the reactive power to achieve balance of producing and consuming real and reactive power. RPC technique is more effective in high voltage systems since the R/X ratio is lower than in LV systems [72].

Inverters can be used to adjust voltage by limiting active power and consuming reactive power. [73].

4.2.3 Energy storage system (ESS)

There are different storage devices such as lead-acid batteries, supercapacitors, and li-on batteries used to solve the problems caused by high PV penetration level. These devices efficiently manage energy, improve grid stability, mitigate the effects of voltage fluctuations, regulate frequency, and solve power quality.

Storage systems should be placed correctly so that voltage instability can be effectively improved with ESSs. Also the problems of voltage increase and energy losses can be reduced by the optimal size of ESSs [74].

Also, using ESS can help the customer in some countries that use more than one price of energy during the day to manage the energy produced in a day by the store the power in the meantime and using it later in the critical time that will be more expensive than is called Demand Side Management (DSM).

4.2.4 Static Synchronous Compensator

A STATic synchronous COMpensator (STATCOM) is a fast-acting device capable of providing or absorbing reactive current and thereby regulating the voltage at the point of connection to a power grid; that means it injects reactive power when the mains voltage is higher than the nominal voltage by acting as an inductor at the PCC point and feeding the reactive power when the primary voltage is smaller than the nominal voltage by dealing as a capacitor [76].

The advantages of using STATCOM are supplying a balance current to the system, rapid response to the system and its ability to handle system imbalance, minimize harmonics and control the DC voltage on the DC link capacitor, using a hysteresis current controller to decrease the voltage drop due to the sudden load increase [77].

4.2.5 Smart Inverter

There are many problems caused by high PV penetration level effect on voltage and power quality. Intelligent inverter can produce or consume reactive power on the grid. It has a fast response to the control signal; it can maintain distribution system integrity if the exciting distribution system is optimally configured with the controller.

Since the reactive power capacity of the PV inverter is restricted by the degree of the inverter and the total level of harmonic distortion measured, the inverter is compelled to generate/absorb reactive power up to a limit set by a specific power factor, thereby eliminating operational disturbances [58]. The advantages of using an intelligent inverter are shown in figure C.1.2

4.3 Case study of PV penetration of Jenin Electrical Network

This section will analyze some PV penetration problems in Jenin electrical network, such as poor power factor, reverse power flow, and voltage rise. Solving these problems will be using the same ideas and techniques mentioned in section 4.2.

Refer to chapter 3.2.5 AL Nasreh Street; there are two busses:72 and 78 that use a vast amount of PV systems of 178KW and114KW without using reactive power compensation to balance the power produced to the network, and that affects negatively the bus voltage and power factor.

In this example, the problems were solved by adding capacitor banks of 85KVAR and 56KVAR, respectively, which improved the power factor and voltage bus level as shown in table 4.3.1

Table 4.3.1

Load flow results for some busses that have high PV penetration

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF
Origin network							
Bus72	75+106j	252+108j	178	0	0.8+1.2j	0.368	57.7
Bus78	47+68j	160+68j	114	0	0.5+0.8j	0.367	56.8
Edited network							
Bus72	80+24j	257+110j	178	85	0.3+0.5j	0.389	95.7
Bus78	50+13j	164+70j	114	56	0.2+0.3j	0.387	96.7

The capacitor reactive power values were obtained using the equation (3.2):

$$Q_c = P\left(\tan\left(cos^{-1}(PF\ old)\right) - \tan\left(cos^{-1}(PF\ new)\right)\right)$$

$$Q_{c\ bus72} = 75\left(\tan\left(cos^{-1}(0.577)\right) - \tan\left(cos^{-1}(0.957)\right)\right) = 83KVAR$$

$$Q_{c\ bus78} = 47\left(\tan\left(cos^{-1}(0.568)\right) - \tan\left(cos^{-1}(0.967)\right)\right) = 55KVAR$$

This method (i.e., control of reactive power supplied to the network to reduce reactive power consumed from the source) can also be done using controllable devices such as smart inverters and static synchronous compensators in a more intelligent way; smart inverters can supply/absorb reactive power to the network, a static compensator injects reactive power at the PCC point when the mains voltage is higher than the nominal voltage and feeding the reactive power when the voltage is smaller than the nominal voltage.

Reverse power flow is one of the problems caused by high PV penetration, as mentioned later in this chapter; for example, the PV system at bus 72 will be increased step by step until it reaches the reverse power flow, then this problem will be solved by installing capacitor banks and increasing tap changer.

Table 4.3.2

Load flow result for bus72 with RPF

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF
Origin network							
Bus72	75+106j	252+108j	178	0	0.8+1.2j	0.368	57.7
Increasing of PV to make RPF							
Bus72	59+108j	256+109j	198	0	0.7+1j	0.382	48
Bus72	11+107j	256+109j	248	0	0.5+0.8j	0.383	10
Bus72	-8+106j	256+109j	268	0	0.5+0.8j	0.384	-7.9
Bus72	-37+106j	256+109j	297	0	0.6+0.9j	0.385	-32.6
The maximum limit of using PV							
Bus72	68+22j	259+110j	192	87	0.2+0.3j	0.394	95.3

Table 4.3.2 shows the reverse power flow (RPF) status due to high PV penetration; in the first row, when the load bus has a PV system of 178Kw, the power factor was 57.7%, and the bus voltage was 0.368%.

The procedure is to increase the capacity of the PV system and to monitor what is happening to the power supplied from the network, so when using 198 kW, the real power supplied by the network to load bus reduces from 75 kW to 59 kW with no change in the reactive power, that effects the power factor to decrease to 48% and increase the bus voltage to 0.382Kv. However, the usage of 268KW of the PV system is the critical point that makes the power to reverse its direction toward the source. It was 59Kw from the network and now it is 8KW to the network (minuse sign) and so on, which causes the power factor to become -7.9% and the bus voltage to increasefrom 0.368Kv to 0385kV.

The same results to use 297Kw of PVsystems are shown in figure C.2.1. This simulation shows the negative effect on the power factor and bus voltage during increasing real power produced from the PV systems without applying the control techniques.

Inorder to solve this problem, in this simulation, capacitor banks, and tap changers are used to improve the power factor and bus voltage, but the solution is done to the case of using 192kW of PV because the trials on the solutions by 268Kw and 297KW failed; this means the maximum limit to use PV system is 192KW.

A capacitor bank of 87KVAR and tap changer with seven steps (i.e., each step 5%) improve the power factor to 95.3% lagging and the bus voltage to 0.394kV

In the actual solution, the On-Line Tap Changer (OLTC) used to regulate the voltage in the loaded transformer by changing the taps without interrupting the voltage stability and safety.

4.4 Case study of harmonics effect on power quality due to Photovoltaic System:

Harmonics are the reason behind a low power factor and increased losses. Due to harmonics, the machines cannot work normally and cause overheating in the motors coils and it is the reason of equipment's failure. The electronic equipment used in the power systems generate harmonics more than once. Tripled harmonics are the most dangerous kind (3rd, 9th, 15th, etc.) [80].

In this thesis there are high PV penetration in AL Nasreh Street region connected to the busses 72 and 78 with 178 KWP and 114KWP respectively which effect on the power factor to be 57.7% and 56.8% respectively, so the harmonics study will be occur in this region and try to improve power quality in the network by using passive filter to decrease THD and IHD as IEEE 1547 standards, THD should be within 5% and under 3% for IHD. Table 4.3.3 shows the harmonics order in the busses before and after adding single tuned passive filter for 5^{th} order harmonic.

After adding single tuned passive filter for each bus which be sized according to information got it from load flow analysis such as: apparent power KVA, Ampere and existing PF to the load bus and desired PF needed, all THD in this region reduced within 5% and IHD below 3%, for example the passive filter sizing for bus 78 is as shown in figure C.3.1 and C.3.2.

From the window shown in figure C.3.1, choose size filter then from window in figure C.3.2 appear fill harmonic order, harmonic current, apparent power MVA ,existing and desired power factor which have been got it from load flow analysis.

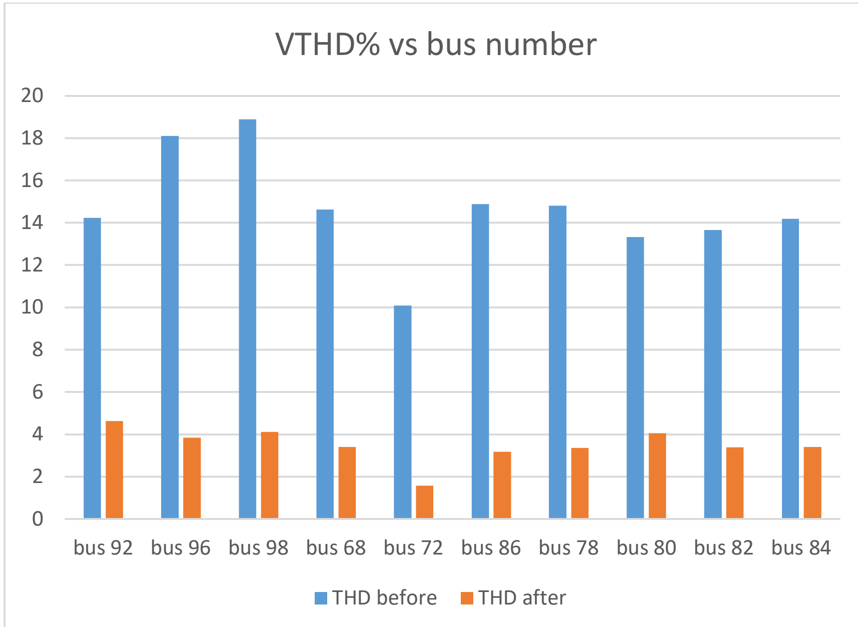
Table 4.3.3

THD for busses of AL Nasreh Street region.

Before adding filter				
Bus	IHD% 5th	IHD% 7th	IHD% 11th	THD%
92	13.58	3.74	1.81	14.24
96	17.16	5.47	1.58	18.1
98	17.78	5.93	2.09	18.88
68	13.98	3.99	0	14.62
72	9.66	2.58	0	10.09
86	14.2	3.99	1.68	14.87
78	14.16	4.07	0	14.8
80	12.74	3.41	0	13.32
82	13.04	3.56	1.53	13.65
84	13.56	3.8	1.58	14.19
After adding filter 5th order harmonic				
Bus	IHD% 5th	IHD% 7th	IHD% 11th	THD%
92	0	3.15	2.56	4.63
96	0	2.52	2.17	3.84
98	0	2.59	2.32	4.11
68	0	2.22	1.96	3.4
72	0	1.57	0	1.57
86	0	1.98	1.87	3.18
78	0	2.19	1.93	3.36
80	1.52	2.55	2.11	4.05
82	0	2.21	1.95	3.39
84	0	2.21	1.96	3.4

Figure 4.4.1

THD % before and after filter



From figure 4.4.1 clearly can see the improving on the electrical network in AL Nasreh Street Region by decreasing the total harmonic distortion (THD %) from 18.88% to 4.11% as an example for bus 98, also this improving lies on the other busses as shown in the figure.

Chapter Five

Conclusions & Recommendations

After completing the analysis of Jenin NEDCO electricity network, the main conclusions and recommendations obtained as follows:

1. Using the ETAB simulator solves many problems in the network, such as low power factor, low voltage bus level, and high PV penetration by using different techniques, such as adding capacitor banks, PV systems, and regulating tap changers.
2. Electrical network of Jenin has been built using ETAP program.
3. Using ETAP simulator there are problems of low power factors at transformers side due to power losses in the branches or high PV penetration was solved using a capacitor banks.
4. Using ETAP simulator a problems of low voltage level was solved using capacitor banks, regulation tap changer or PV systems in some cases.
5. Almost the PV system running in the NEDCO network is an on-grid system, which means that when the electricity is off due to any reason, the loads also will be interrupted from electricity.
6. There are many advantages of using the off-grid PV system that are using a storage device. As mentioned in chapter 4.2.3
7. A storage device used to solve the problems that appears by high PV penetration, these devices used to manage energy, improve grid stability, mitigate the effects of voltage fluctuations, regulate frequency, and solve power quality.
8. There are two connection points AL ALmaniah connection point and Al-Jalameh connection point with 20MW for each of them which are feeding Jenin.
9. The transmission lines in Jenin NEDCO Electricity Network consist of 24.660 Km and underground cables of 27.983 Km.
10. Clarify the negative effect of PV penetration level on power quality and voltage quality, such as voltage sag, voltage unbalance, harmonics, low power factor, reverse power flow, and voltage rise.
11. Clarify the solution of PV penetration by using the On Load Tap Changer (OLTC), smart inverter, synchronous compensator, Energy Storage System (ESS), and PV Generation Curtailment (PVGC).

12. Power factor should be more than 92%, and the voltage bus level should be more than 0.38 kV.
13. A PV system should be used carefully and with specific values to avoid a high PV penetration effect; they should be controlled by a smart inverter or something else.
14. The best value of capacitor banks have been chosen using equation (3.2)

$$Q_c = P(\tan(cos^{-1}(PF_{old})) - \tan(cos^{-1}(PF_{new})))$$

15. PV systems used to increase voltage bus levels slightly in some cases but after using capacitor banks which are improved power factor and voltage bus level.
16. The electrical network of Jenin has been divided into nine regions to analyze it easily.
17. Power losses in the whole network decreased after improvements from 11% to 6% which is obtained from $\frac{apparent\ power\ losses}{total\ demand\ power}$
18. PV penetration simulated by ETAP and notice the effect on the network such as RPF, low power factor and voltage rise, and solved by capacitor banks and regulated tap changer instead of intelligent techniques used in actual life.
19. Study the effect of harmonics that is led from high PV penetration and eliminate it.
20. Eliminate the 5^{th} harmonic order from AL Nasreh Street by using passive filter.

List of Abbreviations

Abbreviation	Meaning
NEDCO	North Electrical Distributed Company
ETAB	Electrical Transient and Analysis Program
PV	Photovoltaic
AC	Alternating Current
DC	Direct Current
P	Real Power
Q	Reactive Power
KW	Kilo Watt
A	Ampere
V	Voltage
KWP	Kilo Watt Peak
KVA	Apparent Power unit
KVAR	Reactive Power Unit
PF	Power Factor
IEEE	Institute of Electrical and Electronics Engineers
OLTC	On Load Tap Changer
RPF	Reverse Power Flow
ESS	Energy Storage System
PVGC	Photovoltaic Generation Curtailment
PCC	Point of Common Coupling
DSM	Demand Side Management
STATCOM	STATic synchronous COMpensator
FACT	Flexible AC Transmission System
LV	Low Voltage
IEC	Israel Electrical Company
ANSI	American National Standards Institute
OTI	Office Of Transient Initiative
ISO	International Organization of Standardization
CEO	Chief Executive Officer
Dba	doctor of business administration

References

1. Electrical Network's Modeling & Simulation Tools: The State of the Art .

2. The Leading Electrical Power System Analysis & Operation Software ETAP - Operation Technology, Inc . The Silicon Review. Retrieved 2019-09-28.

3. Shertukde, Hemchandra (January 29, 2019). Power systems analysis illustrated with matlab and etap. PRODUCTIVITY Press. ISBN 9781498797214.

4. Soni, C. J.; Gandhi, P. R.; Takalkar, S. M. (April 2015). "Design and analysis of 11 KV distribution system using ETAP software". 2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC):0451–0456.

5. Zeggai, A.; Benhamida, F. (February 2019). "Power flow and Short circuit of 220kV Substation using ETAP". 2019 Algerian Large Electrical Network Conference (CAGRE): 1–6.

6. Pathan, M.; Shah, A. (August 2017). "Co-ordination of protective relays for 16MW load system using ETAP". 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS): 2222–2231.

7. Bashir, Adnan; Jabbar Khan, Rana A.; Junaid, Muhammad; MansoorAsghar, M. (2010-06-15). "Etap software based transient, ground grid and short circuit analyses of 132 kv grid". AIP Conference Proceedings. 1239 (1): 25–30.

8. Zeggai, A.; Benhamida, F. (February 2019). "Power flow and Short circuit of 220 kV Substation using ETAP". 2019 Algerian Large Electrical Network Conference (CAGRE): 1–6.

9. Alsaaq, Mohammed (2014-08-06). Power System Harmonic Analysis Using Etap.Lap Lambert Academic Publishing GmbH KG.

10. Gómez, Cristhian A. Giraldo; M, Rafael Franco (April 2012). Análisis de ConfiabilidadUsando El Software Etap (in Spanish). EAE.

11. Saber, A. Y. (December 2014). "Power system stabilizer tuning using swarm based optimization in ETAP". 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES): 1–5.

12. Chopade, P.; Bikdash, M. (March 2011). "Minimizing cost and power loss by optimal placement of capacitor using ETAP". 2011 IEEE 43rd Southeastern Symposium on System Theory: 24–29.

13. Zhu, H.; Liu, X.; Mastorakis, N. E. (September 2014). "The Simulation Analysis of Motor Startup Based on the ETAP Platform". 2014 International Conference on Mathematics and Computers in Sciences and in Industry: 245–248.

14. Ullah, M. A.; Qaiser, A.; Saeed, Q.; Abbasi, A. R.; Ahmed, I.; Soomro, A. Q. (March 2017). "Power flow voltage stability analyses and remedies for a 340MW nuclear power plant using ETAP". 2017 International Conference on Electrical Engineering (ICEE): 1–6.

15. *Khan*, A.; Aman, M. M. (April 2018). "Investigation of the effects of critical incident energy parameters using ETAP® to reduce arc flash hazards Liu, H.; Mitolo, M.; Qiu, J. (March 2014). "Ground-Fault Loop Impedance Calculations in Low-Voltage Single-Phase Systems". IEEE Transactions on Industry Applications. 50 (2): 1331–1337.

16. Sheng Chen; Saber, A.; Khandelwal, T. (July 2016). "General battery modeling and simulation using non-linear open circuit voltage in power system analysis". 2016 IEEE Power and Energy Society General Meeting (PESGM): 1–5.

17. *Prabhu*, J. A. X.; Sharma, S.; Nataraj, M.; Tripathi, D. P. (March 2016). "Design of electrical system based on load flow analysis using ETAP for IEC projects". 2016 IEEE 6th International Conference on Power Systems (ICPS): 1–6.

18. Khan, Faisal; Usjict, Editor. "Electric Supply Substation Simulation using ETAP Software".

19. Analyses and monitoring of 132 kV grid using ETAP software".

20. Wang, Wen Bin; Xiong, Jun Jie (2015). "Simulation of Distributed Photovoltaic Power Connecting to Grid Based on ETAP". Advanced Materials Research. Retrieved 2019-09-29.

21. "Study of a DC network with ETAPCAPSIM" **www.capsimulation.com.n**Retrieved 2019-09-29.

22. "ETAP addresses open-phase faults - World Nuclear News " www.world-nuclear-news.org Retrieved 2019-09-29.

23. Klungtong, S.; Chompoo-inwai, C. (October 2016). "Power flow monitoring and analysis for 24.6 MW at 6.9 kV bus Diesel Power Plant (DPP) using ETAP". 2016 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE): 307–312.

24. *Reddy*, D. S.; Kumari, C. S. (January 2017). "Transient Stability Analysis of a Combined Cycle Power Plant Using Etap Software". 2017 IEEE 7th International Advance Computing Conference (IACC): 510–515.

25. Xiaran Chen; Guorong Zhang (May 2016). "Harmonic analysis of AC-DC hybrid microgrid based on ETAP". 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia): 685–689.

26. Afifi, S. N.; Wang, H.; Taylor, G. A.; Irving, M. R. (September 2013). "Impact of DFIG wind turbines on short circuit levels in distribution networks using ETAP". 2013 48th International Universities' Power Engineering Conference (UPEC): 1–4.

27. Yan Pang; Yonghai Xu (October 2016). "Analysis and treatment of harmonic in power network with railway based on ETAP software". 2016 IEEE PES Asia- Pacific Power and Energy Engineering Conference (APPEEC): 1424–1429.

28. Zala, Y. (August 2017). "Comparative study and simulative analysis of high voltage and low voltage distribution systems for rural agricultural loads: Simulation using etap software". 2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE): 46–50.

29. Yadav, S. K.; Sharma, N. K.; Choube, S. C.; Varma, A. (October 2017). "Optimal coordination of overcurrent relays in power systems for reliability assessment under the presence of distributed generation using ETAP". 2017 6th International Conference on Computer Applications in Electrical Engineering-Recent Advances (CERA): 51–56.

30. Kamaruzaman, M. Z.; Wahab, N. I. A.; Nasir, M. N. M. (November 2018)."Reliability Assessment of Power System with Renewable Source using ETAP". 2018 International Conference on System Modeling Advancement in Research Trends (SMART): 236–242.

31. *Waqfi*, R. R.; Nour, M. (April 2017). "Impact of PV and wind penetration into a distribution network using Etap". 2017 7th International Conference on Modeling, Simulation, and Applied Optimization (ICMSAO): 1–5.

32. Masson G, Latour M, Biancardi D. Global market outlook for photovoltaics until 2016. European Photovoltaic Industry Association; 2012.

33. Hoke, A.; Butler, R.; Hambrick, J.; Kroposki, B. Steady-State Analysis of Maximum Photovoltaic Penetration Levels on Typical Distribution Feeders. IEEE Trans. Sustain. Energy 2012.

34. Mukwekwe, L.; Venugopal, C.; Davidson, I.E. A Review of the Impacts and Mitigation Strategies of High PV Penetration in Low Voltage Networks. In Proceedings of the 2017 IEEE PES Power Africa, Accra, Ghana.

35. Cheng, D.; Mather, B.A.; Member, S.; Seguin, R.; Hambrick, J.; Broadwater, R.P.; Member, L. Photovoltaic (PV) Impact Assessment for Very High Penetration Levels. IEEE J. Photovolt. 2015.

36. Yang, G.; Marra, F.; Juamperez, M.; Kjaer, S.B.; Hashemi, S.; Østergarrd, J.; Ipsen, H.H.; Fredriksen, K.H. Voltage rise mitigation for solar PV integration at LV grids: Studies from PVNET. dk. J. Mod. Power Syst. Clean Energy 2015.

37. Enslin, J.H.R. Network Impacts of High Penetration of Photovoltaic Solar Power Systems. In Proceedings of the IEEE PES General Meeting, Providence, RI, USA, 25–29 July 2010.

38. Bank, J.; Mather, B.; Keller, J.; Coddington, M. High Penetration Photovoltaic Case Study Report High Penetration Photovoltaic Case Study Report. Contract 2013.

39. Bebic, J. Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics; Technical Report; National Renewable Energy Laboratory (NREL): Golden, CO, USA, 2008.

40. McPhail, D.; Croker, B.; Harvey, B. A study of solar PV saturation limits for representative low voltage networks. In Proceedings of the 2016 Australasian Universities Power Engineering Conference (AUPEC), Brisbane, QLD, Australia, 25–28 September 2016.

41. Anzalchi, A.; Sundararajan, A.; Moghadasi, A.; Sarwat, A. Power quality and voltage profile analyses of high penetration grid-tied photovoltaics: A case study. In Proceedings of the 2017 IEEE Industry Applications Society Annual Meeting, Cincinnati, OH, USA, 1–5 October 2017.

42. Maghami, M.R.; Hizam, H.; Gomes, C.; Radzi, M.A.; Rezadad, M.I.; Hajighorbani, S. Power loss due to soiling on solar panel: A review. Renew. Sustain. Energy Rev. 2016.

43. Hsieh,W.; Lin, C.; Chen, C.; Hsu, C.; Ku, T.; Tsai, C.; Ho, C. Impact of PV generation to voltage variation and power losses of distribution systems. In Proceedings of the 2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT),Weihai, China, 6–9 July 2011.

44. Alam, M.J.E.; Muttaqi, K.M.; Sutanto, D. Mitigation of Rooftop Solar PV Impacts and Evening Peak Support by Managing Available Capacity of Distributed Energy Storage Systems. IEEE Trans. Power Syst. **2013**, 28, 3874–3884.

45. Patil, A.; Girgaonkar, R.; Musunuri, S.K. Impacts of increasing photovoltaic penetration on distribution grid—Voltage rise case study. In Proceedings of the ICAGE 2014—International Conference on Advances in Green Energy, Melbourne, Australia, 25 February 2014.

46. Alshaikh, A.T.; Alquthami, T. Characterization of Voltage Rise Issue due to Distributed Solar PV Penetration. Int. J. Appl. Eng. Res. 2018.

47. Haque, M.M.;Wolfs, P. A review of high PV penetrations in LV distribution networks: Present status, impacts and mitigation measures. Renew. Sustain. Energy Rev. 2016.

48. Kordkheili, R.A.; Pourmousavi, S.A.; Savaghebi, M.; Guerrero, J.M.; Nehrir, M.H. Assessing the potential of plug-in electric vehicles in active distribution networks. Energies **2016**, 9, 34.

49. Peng, W.; Haddad, S.; Baghzouz, Y. Improving power quality in distribution feeders with high PV penetration through inverter controls. In Proceedings of the CIRED 2012Workshop: Integration of Renewables into the Distribution Grid, Lisbon, Portugal, 29–30 May 2012.

50. Sikorski, T. Power quality in low-voltage distribution network with distributed generation. In Proceedings of the 2015 International School on Nonsinusoidal Currents and Compensation (ISNCC), Lagow, Polan, 15–18 June 2015.

51. Taghizadeh, M.; Sadeh, J.; Kamyab, E. Protection of grid connected photovoltaic system during voltage sag. In Proceedings of the 2011 International Conference on Advanced Power System Automation and Protection, Beijing, China, 16–20 October 2011.

52. Pinyol, R. Harmonics: Causes, Effects and Minimization; Salicru: Barcelona, Spain, 2015; pp. 1–32.

53. Fekete, K.; Klaic, Z.; Majdandzic, L. Expansion of the residential photovoltaic systems and its harmonic impact on the distribution grid. Renew. Energy **2012**, 43, 140–148.

54. Katiraei, B.F. Studies for Utility-Scale Photovoltaic Distributed Generation. IEEE Power Energy Mag. 2011.

55. Obi, M.; Bass, R. Trends and challenges of grid-connected photovoltaic systems–A review. Renew. Sustain. Energy Rev. **2016**, 58, 1082–1094.

56. Manzoni, R.C. Microgeneration Impact on LV Distribution Grids: A Review of Recent Research on Overvoltage Mitigation Techniques. Int. J. Renew. Energy Res. **2016**, 6, 117–131.

57. Malekpour, A.H.; Pahwa, A.; Das, S. Inverter-based var control in low voltage distribution systems with rooftop solar PV. In Proceedings of the 2013 North American Power Symposium (NAPS), Manhattan, KS, USA, 22–24 September 2013; pp. 1–5.

58. Jayasekara, N.;Wolfs, P. Analysis of power quality impact of high penetration PV in residential feeders. In Proceedings of the**n**2010 20th Australasian Universities Power Engineering Conference, Christchurch, New Zealand, 5–8 December 2010.

59. Ram, G.; Prasanth, V.; Bauer, P.; Barthlein, E.M. Comparative analysis of on-load tap changing (OLTC) transformer topologies. In Proceedings of the 2014 16th International Power Electronics and Motion Control Conference and Exposition, Antalya, Turkey, 21–24 September 2014; Volume 2014, pp. 918–923.

60. Jin, L.; Cai, Y. A Review of Fault Diagnosis Research on On-Load Tap-Changers. E3S Web Conf. **2020**, 155, 1–7.

61. Mazman, M.; Yilmaz, C.H. EnerjiDepolamaÇözümleriveGenel E˘ gilimler. ElektrikMühendisli˘gi**2019**, 466, 32–40. 200. Kocer, M.C.; Cengiz, C.; Gezer, M.; Gunes, D.; Cinar, M.A.; Alboyaci, B.; Onen, A. Assessment of Battery Storage Technologies for a Turkish Power Network. Sustainability **2019**, 11, 3669.

62. Barrios-Martínez, E.; Ángeles-Camacho, C. Technical comparison of FACTS controllers in parallel connection. J. Appl. Res. Technol. **2017**, 15, 36–44.

63. Yolda¸s, Y.; Önen, A.; Muyeen, S.M.; Vasilakos, A.V.; Alan, ˙I. Enhancing smart grid with microgrids: Challenges and opportunities. Renew. Sustain. Energy Rev. **2017**, 72, 205–214.

64. Tonkoski, R.; Lopes, L.A.C. Impact of active power curtailment on overvoltage prevention and energy production of PV inverters connected to low voltage residential feeders. Renew. Energy **2011**, 36, 3566–3574.

65. Lulbadda, K.T.; Hemapala, K.T.M.U. The additional functions of smart inverters. AIMS Energy **2019**, 7, 971–988.

66. The North Electricity Company. (http://www.nedco.ps/)

67. Chopade, P.; Bikdash, M. (March 2011). "Minimizing cost and power loss by optimal placement of capacitor using ETAP". 2011 IEEE 43rd

68. Power factor and grid connected photophilic (www.gses.com.au)

69. Saadat, Hadi. Power Systems Analysis. 2nd Ed. McGraw Hill. International Edition.2004.

70. Ku, T.T.; Lin, C.H.; Chen, C.S.; Hsu, C.T. Coordination of transformer on-load tap changer and pv smart inverters for voltage control of distribution feeders. IEEE Trans. Ind. Appl. **2019**, 55, 256–264.

71. Pukhrem, S.; Basu, M.; Conlon, M.F.; Sunderland, K. Enhanced Network Voltage Management Techniques under the Proliferation of Rooftop Solar PV Installation in Low-Voltage Distribution Network. IEEE J. Emerg. Sel. Topics Power Electron. **2017**, 5, 681–694

72. Chaudhary, P.; Rizwan, M. Voltage regulation mitigation techniques in distribution system with high PV penetration: A review.Renew. Sustain. Energy Rev. **2018**, 82, 3279–3287.

73. Ariyaratna, P.; Muttaqi, K.M.; Sutanto, D. A novel control strategy to mitigate slow and fast fluctuations of the voltage profile at common coupling Point of rooftop solar

PV unit with an integrated hybrid energy storage system. J. Energy Storage **2018**, 20, 409–417z.

74. Buchroithner, A. Decentralized low-cost flywheel energy storage for photovoltaic systems. In Proceedings of the 2016 International conference on Sustainable Energy Engineering and Application (ICSEEA), Jakarta, Indonesia, 3–5 October 2016; pp. 41–49.

75. Nour, A.M.M.; Hatata, A.Y.; Helal, A.A.; El-Saadawi, M.M. Review on voltage-violation mitigation techniques of distribution networks with distributed rooftop PV systems. IET Gener. Transm. Distrib. **2020**, 14, 349–361.

76. Oyegoke, S.; Habtay, Y.; Skarvelis-Kazakos, S. Contribution of inverter based photovoltaic generators to power quality at low voltage. In Proceedings of the 2015 50th International Universities Power Engineering Conference (UPEC), Stoke on Trent, UK,1–4 September 2015; pp. 1–6.

77. Alquthami, T.; Sreerama, K.R.; Shaikh, A. Mitigation of voltage rise due to high solar PV penetration in Saudi distribution network. Electr. Eng. **2020**, 102, 881–890.

78. Reveles-Miranda, M.; Sánchez-Flórez, D.F.; Cruz-Chan, J.R.; Ordoñez-López, E.E.; Flota-Bañuelos, M.; Pacheco-Catalán, D. The Control Scheme of the Multifunction Inverter for Power Factor Improvement. Energies **2018**, 11, 1662.

79. E.C. Dugan, M.F. McGranagham, **S.** Santoso and H.W. Beaty, "*Elecirical power systems quality"***,** McGraw-Hill, 2002

Appendices

Appendix A

Study of Jenin electrical network

A.1. Study of AL Maslakh Region

Figure A.1.1

Part1 of AL Maslakh Region before improvements

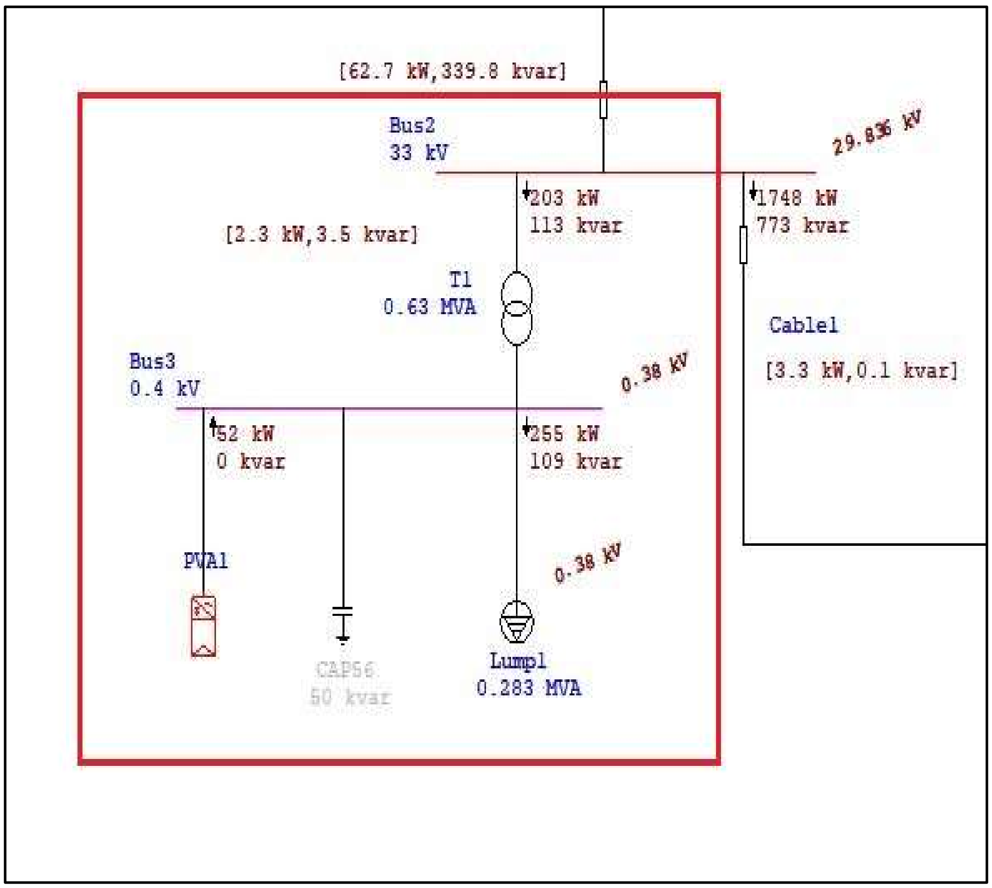


Figure A.1.2

Part2 of AL Maslakh Region before improvements

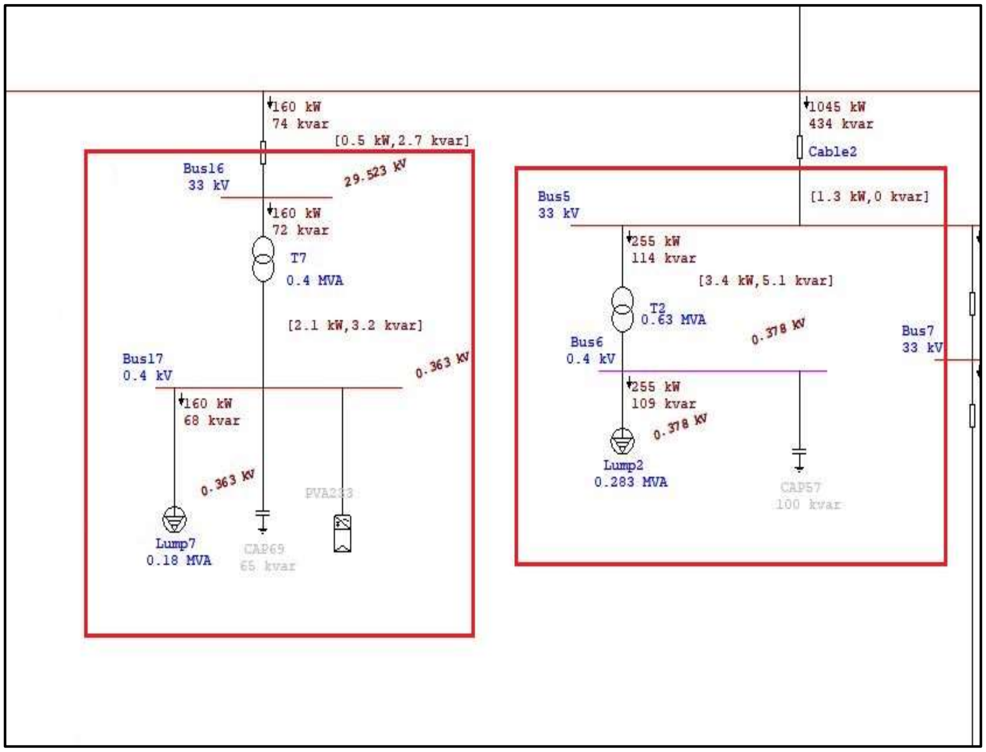


Figure A.1.3

Part3 of AL Maslakh Region before improvements

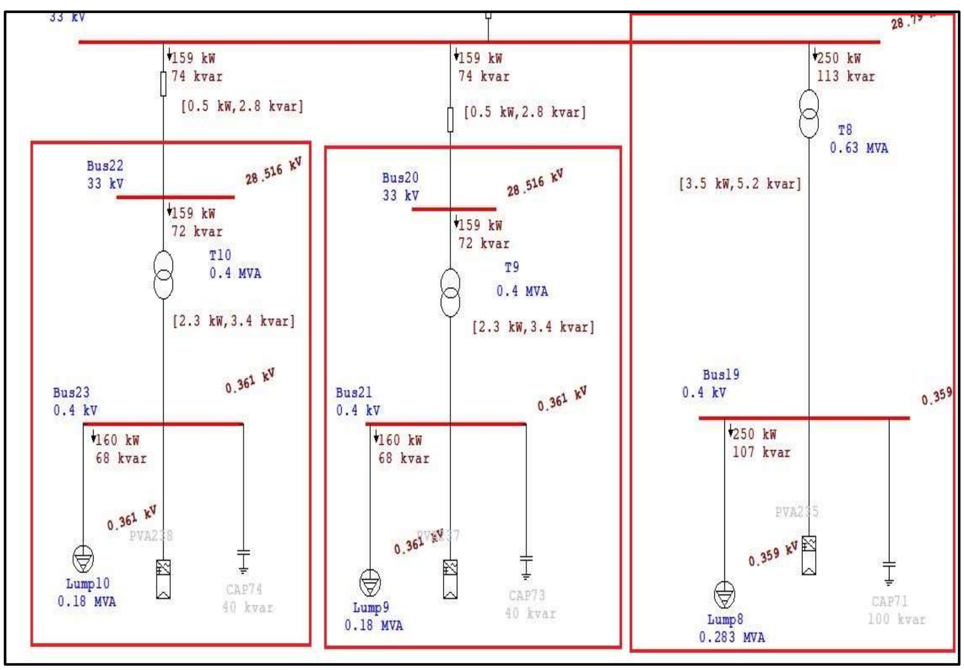


Figure A.1.4

Part4 of AL Maslakh Region before improvements

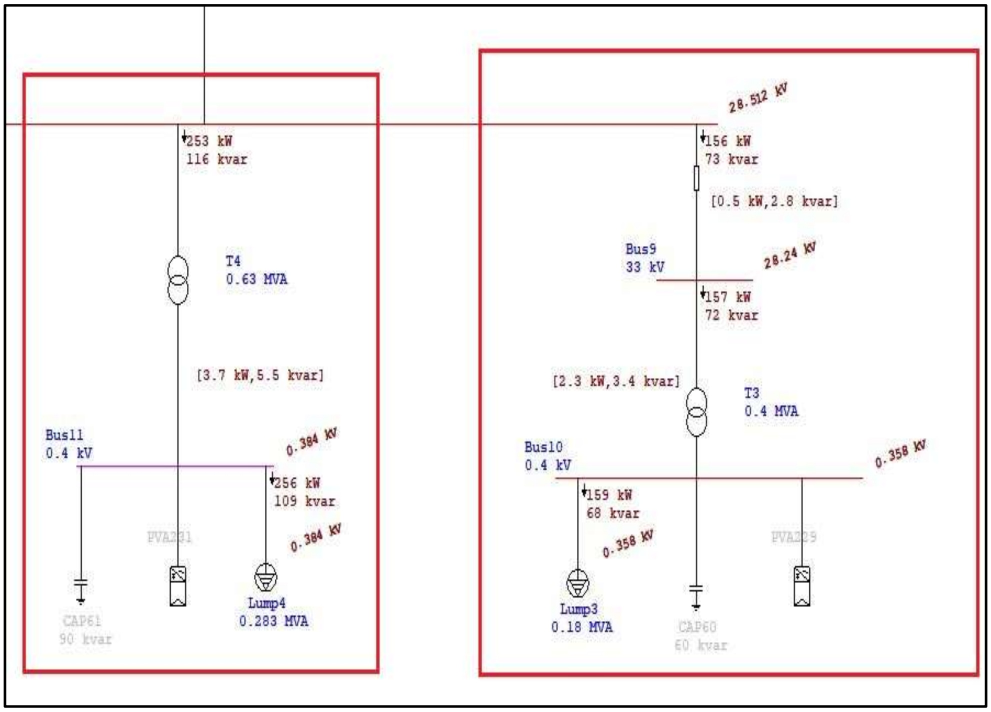


Figure A.1.5

Part5 of AL Maslakh Region before improvements

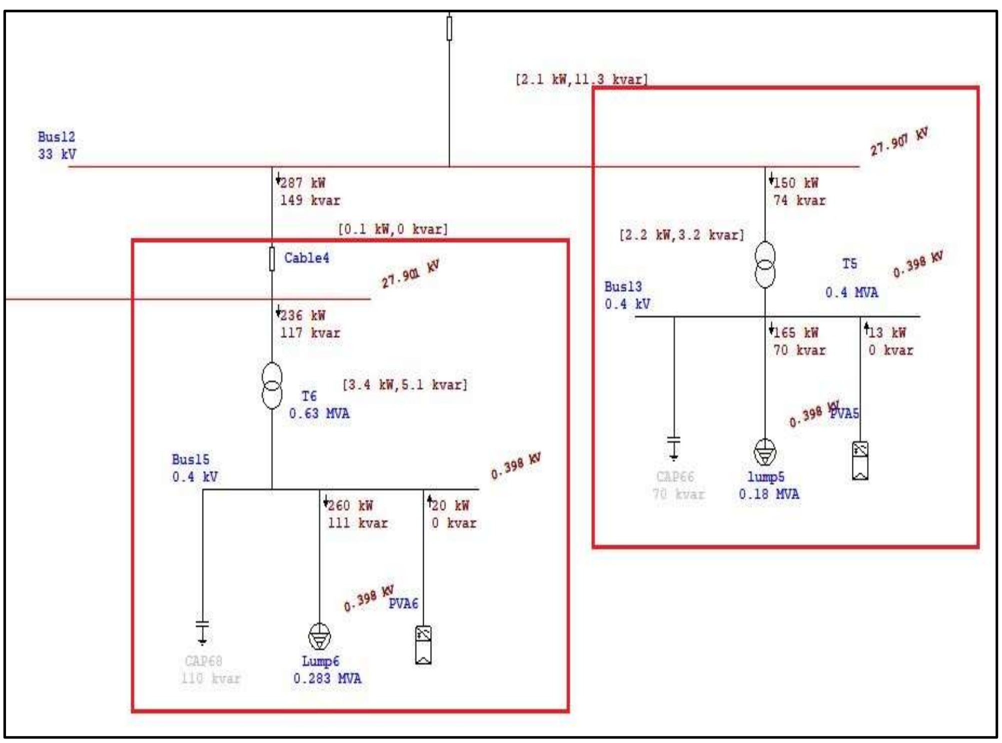


Table A.1.1

Load flow of AL Maslakh region before improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
		Origin network					
Bus3	203+113j	255+109j	52	0	2.3+3.5j	0.38	87.5
Bus6	255+114j	255+109j	0	0	3.4+5.1j	0.378	91..3
Bus10	157+72j	159+68j	0	0	2.3+3.4j	0.358	90.9
Bus11	253+116j	256+109j	0	0	3.7+5.5j	0.384	90.9
Bus 13	150+74j	165+70j	14	0	2.2+3.2j	0.398	89.6
Bus15	236+117j	260+111j	22	0	3.4+5.1j	0.398	88.7
Bus17	160+72j	160+68j	0	0	2.1+3.2j	0.363	91.2
Bus19	250+113j	250+107j	0	0	3.5+5.2j	0.359	91.1
Bus21	159+72j	160+68j	0	0	2.3+3.4j	0.361	90.6
Bus23	159+72j	160+68j	0	0	2.3+3.4j	0.361	90.6

A.2. Study AL Almanya region

Figure A.2.1

Part 1 of AL Almaniah region before improvements

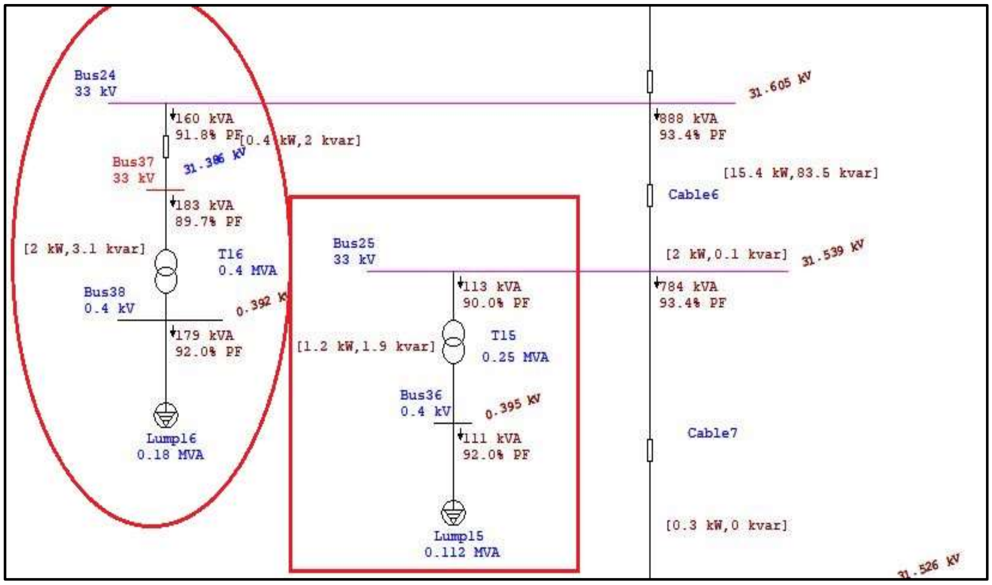


Figure A.2.2

Part 2 of AL Almaniah region before improvements

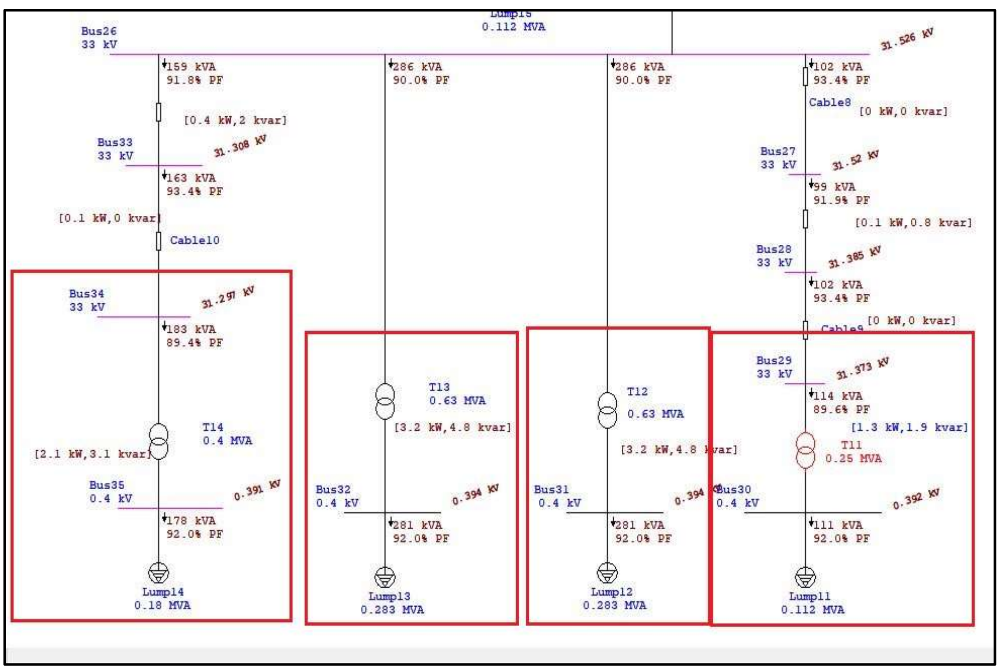


Table A.2.1

Load flow of AL Almaniah region before improvement

			Origin network				
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus30	102+50j	102+44j	0	0	1.3+1.9j	0.392	89.6
Bus31	258+125j	259+110j	0	0	3.2+4.8j	0.394	90
Bus32	258+125j	259+110j	0	0	3.2+4.8j	0.394	90
Bus35	164+82j	164+70j	0	0	2.1+3.1j	0.391	91.8
Bus36	102+49j	102+44j	0	0	1.2+1.9j	0.395	92
Bus38	164+81j	164+70j	0	0	2+3.1j	0.392	92

A.3. study Haddad Region

Figure A.3.1

Part 1 of Haddad region before improvements

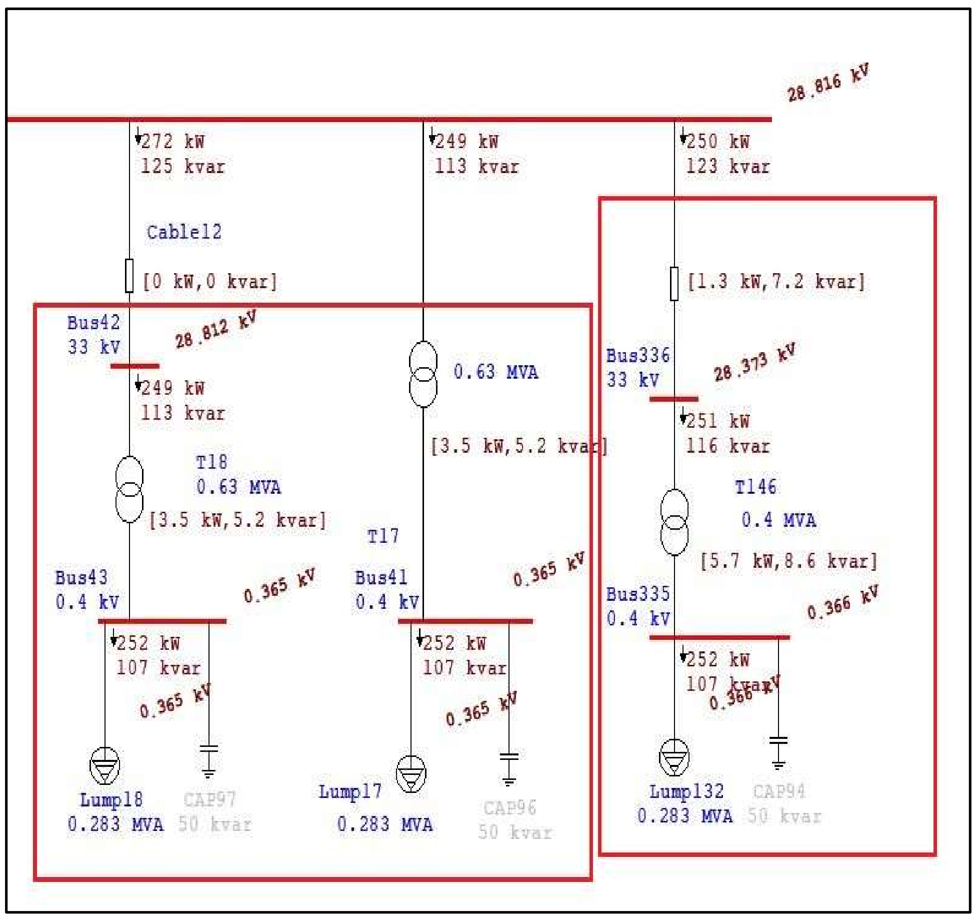


Figure A.3.2

Part 2 of Haddad region before improvements

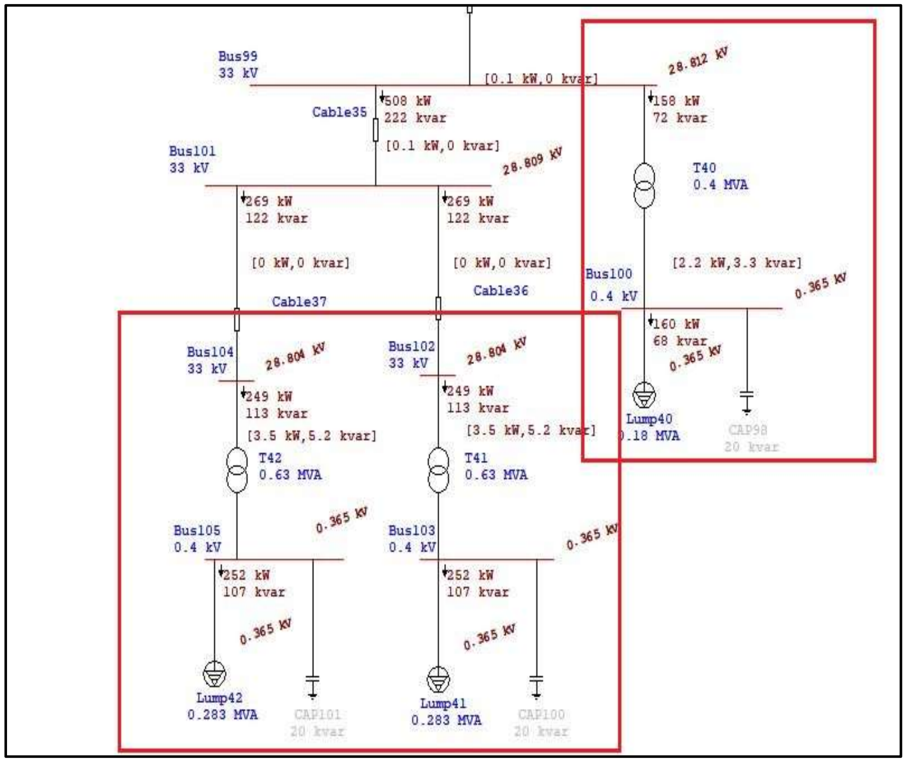


Figure A.3.3

Part 3 of Haddad region before improvements

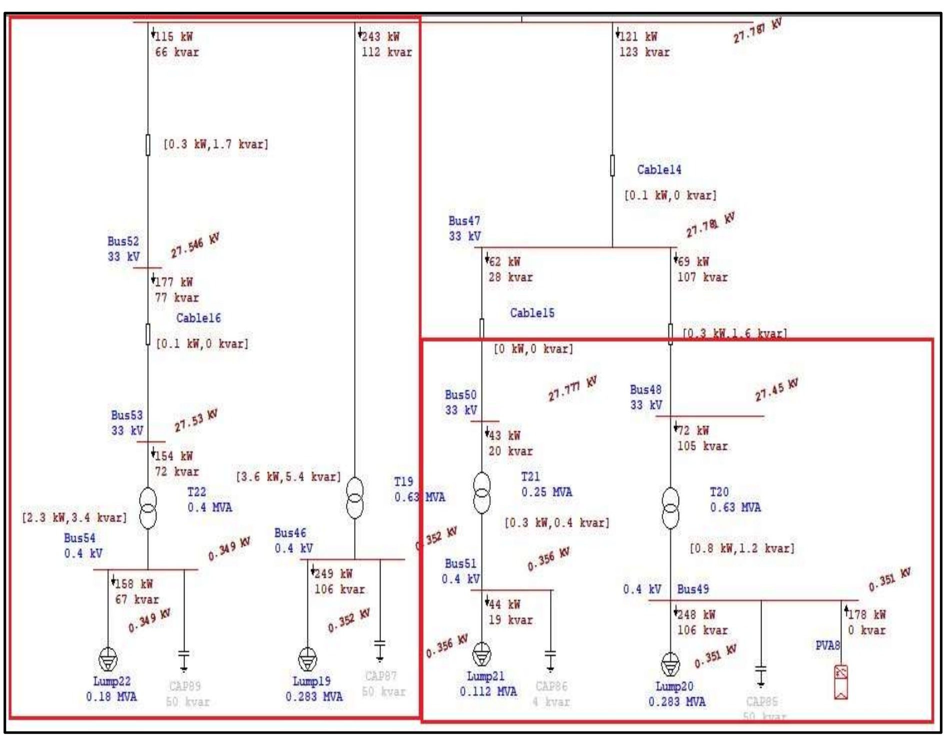


Figure A.3.4

Part 4 of Haddad region before improvements

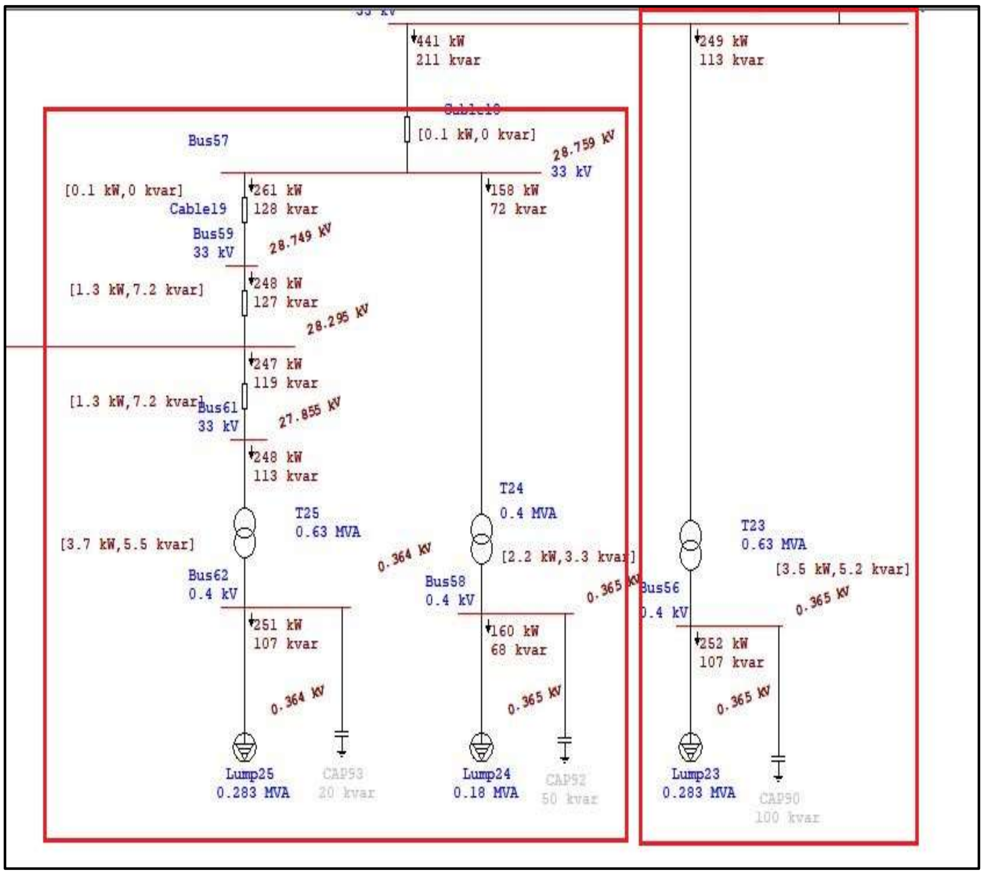


Table A.3.1

Load flow of Haddad region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus 335	251+116j	252+107j	0	0	5.7+8.6j	0.366	90.7
Bus41	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus 43	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus100	158+72j	160+68j	0	0	2.2+3.3j	0.365	91.1
Bus103	249+113j	252+107j	0	0	3.5+5.2j	0.365	91.1
Bus105	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus49	72+105j	248+106j	178	0	0.8+1.2j	0.351	56.4
Bus51	43+20j	44+19j	0	0	0.3+0.4j	0.356	91
Bus46	243+112j	249+106j	0	0	3.6+5.4j	0.352	90.8
Bus54	154+72j	158+67j	0	0	2.3+3.4j	0.349	90.7
Bus56	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus58	158+72j	160+68j	0	0	2.2+3.3j	0.365	91
Bus62	248+113j	251+107j	0	0	3.7+5.5j	0.364	91

A.4. Study of Ayash Region

Figure A.4.1

Part 1 of Ayash region before improvements

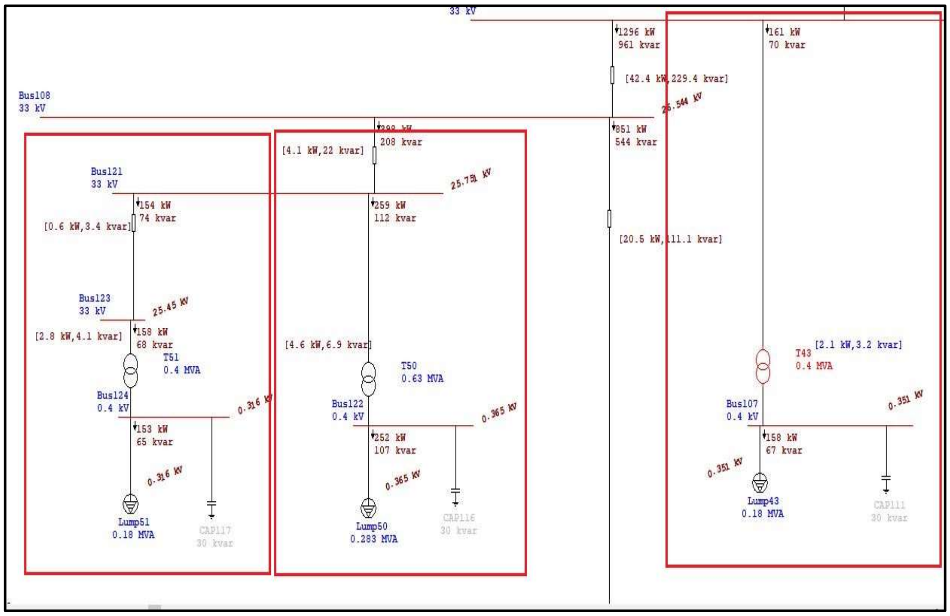


Figure A.4.2

Part 2 of Ayash region before improvements

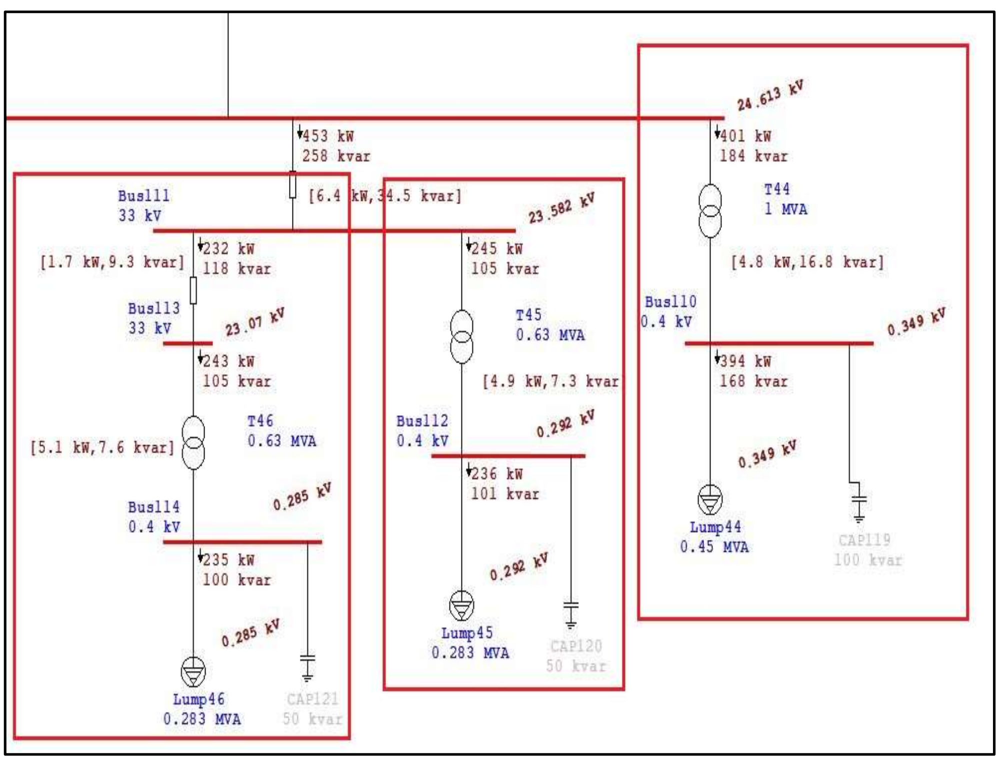


Table A.4.1

Load flow of Ayash region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus107	161+70j	158+67j	0	0	2.1+3.2j	0.351	91.7
Bus122	259+112j	252+107j	0	0	4.6+6.9j	0.365	91.7
Bus124	154+74j	153+65j	0	0	2.8+4.1j	0.316	90.1
Bus110	401+184j	394+168j	0	0	4.8+16.8j	0.349	90.8
Bus112	245+105j	236+101j	0	0	4.9+7.3j	0.292	91.9
Bus114	243+105j	235+100j	0	0	5.1+7.6j	0.285	91.7

A.5. Study of AL Nasreh Street Region

Figure A.5.1

Part 1 of AL Nasreh Street region before improvements

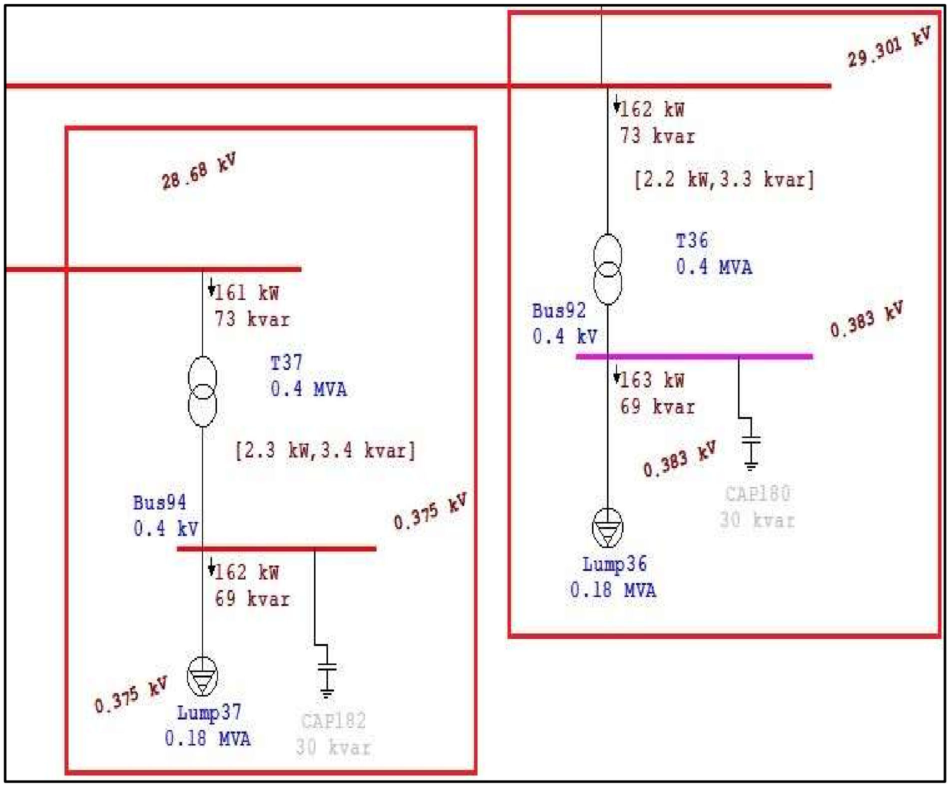


Figure A.5.2

Part 2 of AL Nasreh Street region before improvements

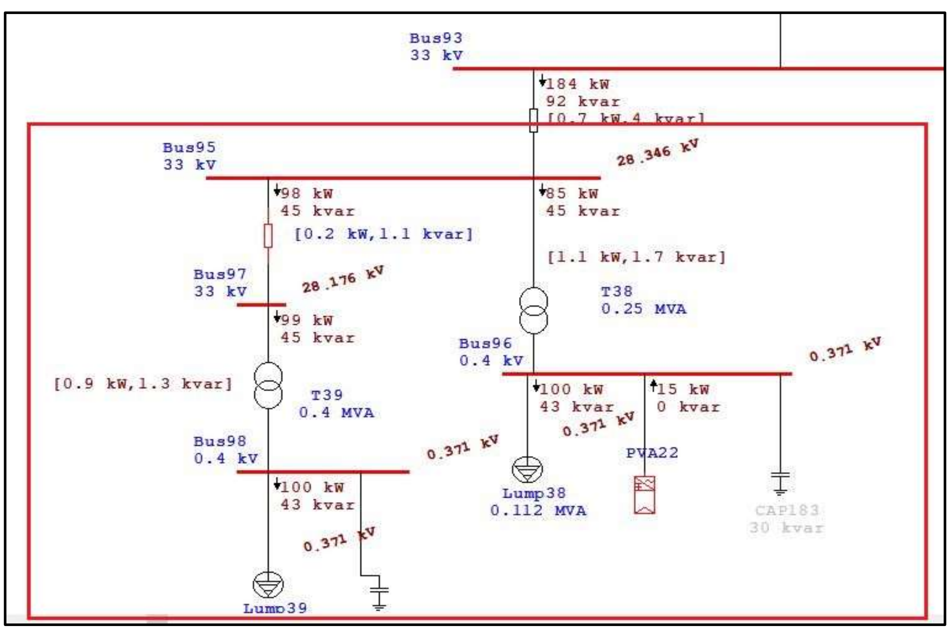


Figure A.5.3

Part 3 of AL Nasreh Street region before improvements

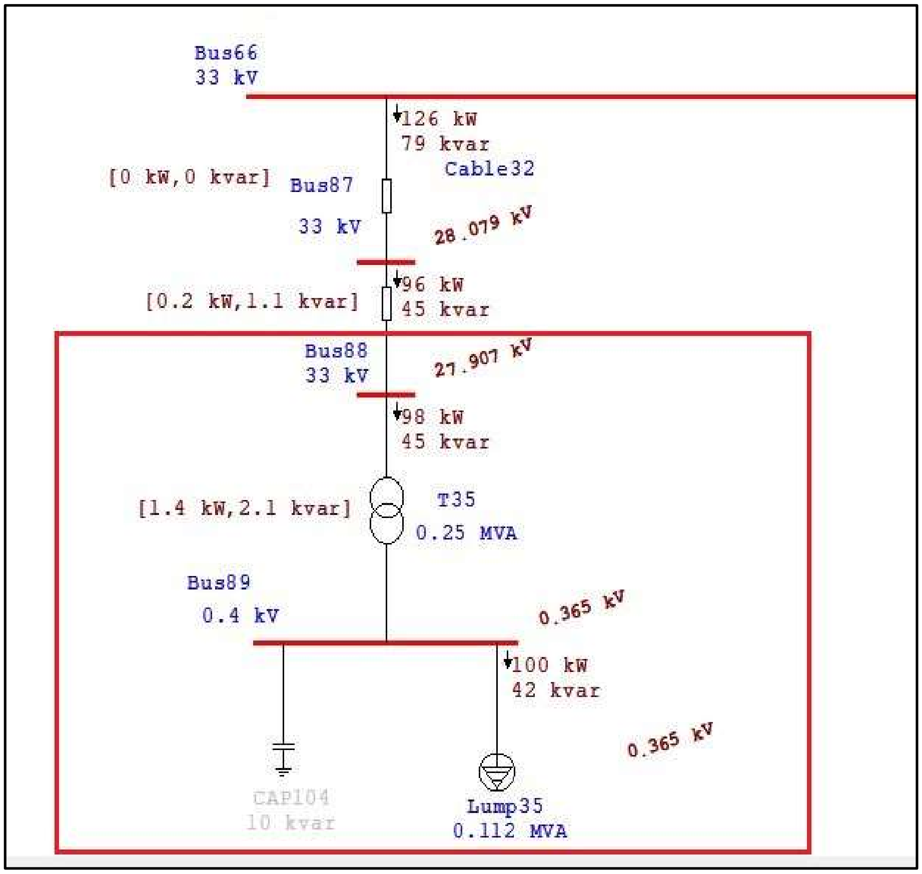


Figure A.5.4

Part 4 of AL Nasreh Street region before improvements

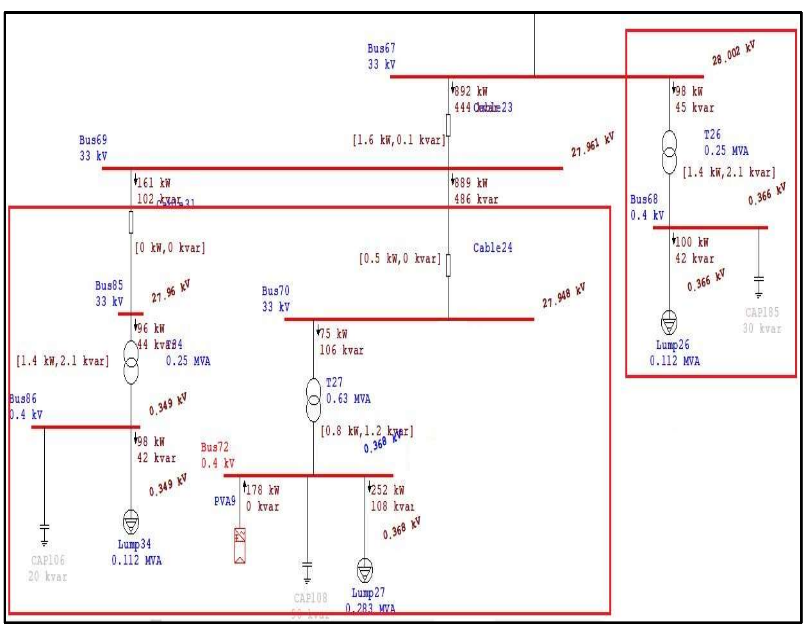


Figure A.5.5

Part 5 of AL Nasreh Street region before improvements

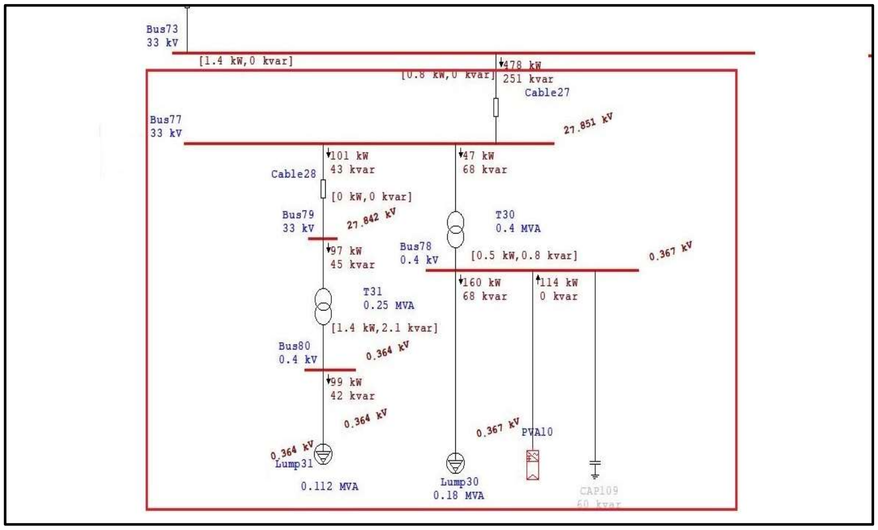


Figure A.5.6

Part 6 of AL Nasreh Street region before improvements

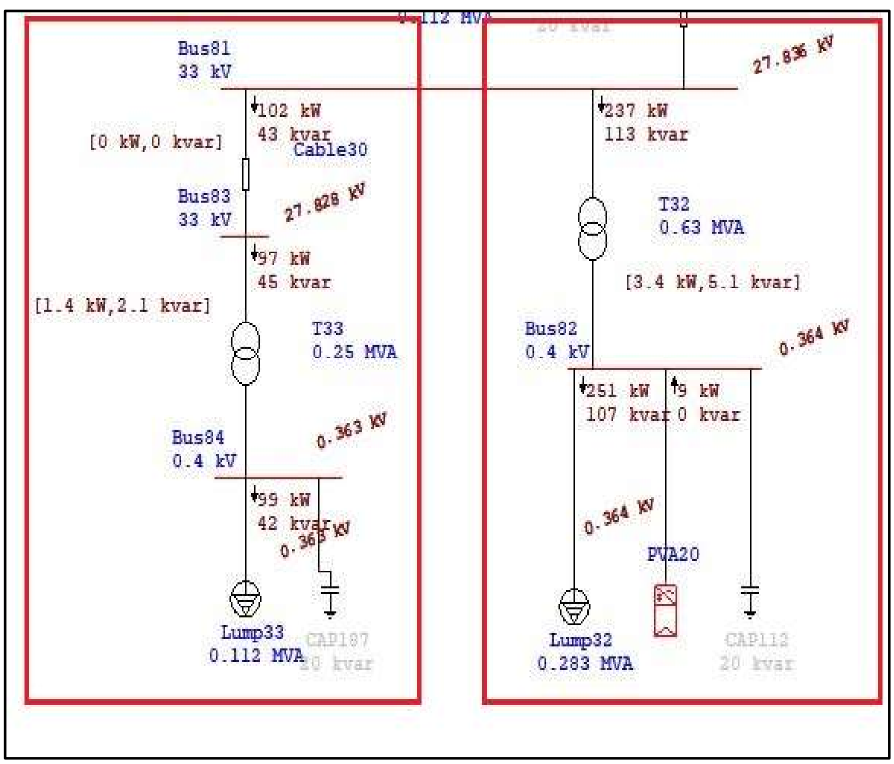


Table A.5.1

Load flow of AL Nasreh Street region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus92	162+73j	163+69j	0	0	2.2+3.3j	0.383	91.2
Bus94	161+73j	162+69j	0	0	2.3+3.4j	0.375	91.2
Bus96	85+45j	100+43j	15	0	1.1+1.7j	0.371	88.3
Bus98	99+45j	100+43j	0	0	0.9+1.3j	0.371	91
Bus88	98+45j	100+42j	0	0	1.4+2.1j	0.365	90.8
Bus68	98+45j	100+42j	0	0	1.4+2.1j	0.336	90.8
Bus72	75+106j	252+108j	178	0	0.8+1.2j	0.368	57.7
Bus86	96+44j	98+42j	0	0	1.4+2.1j	0.349	90.9
Bus78	47+68j	160+68j	114	0	0.5+0.8j	0.367	56.8
Bus80	97+45j	99+42j	0	0	1.4+2.1j	0.364	90.7
Bus82	237+113j	251+107j	9	0	3.4+5.1j	0.364	90.2
Bus84	97+45j	99+42j	0	0	1.4+2.1j	0.363	90.7

A.6. Study of Sinan Region

Figure A.6.1

Part 1 of Sinan region before improvements

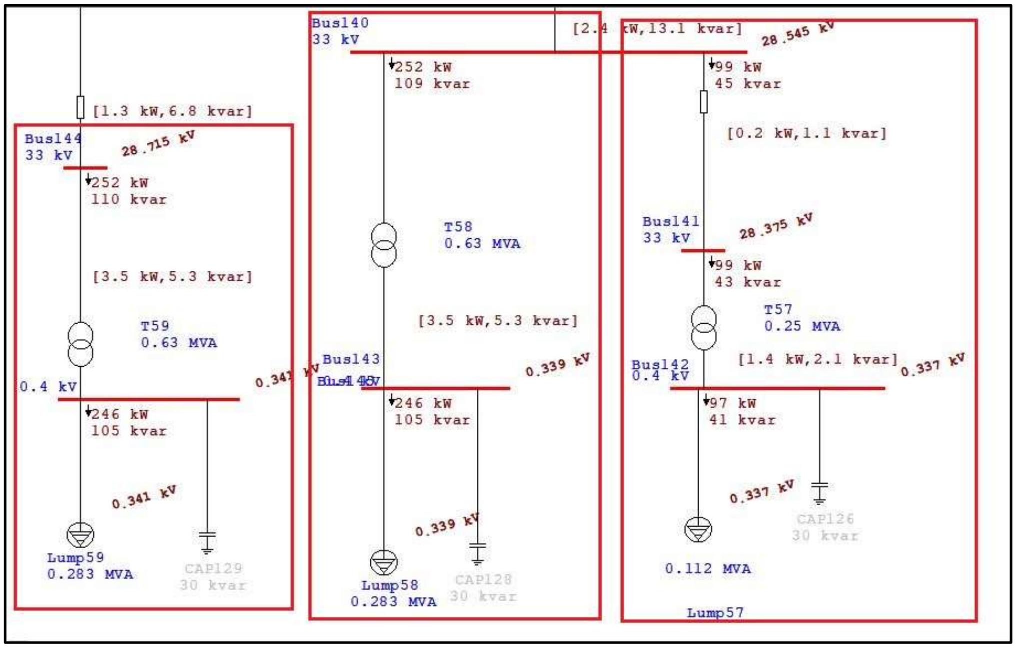


Figure A.6.2

Part 2 of Sinan region before improvements

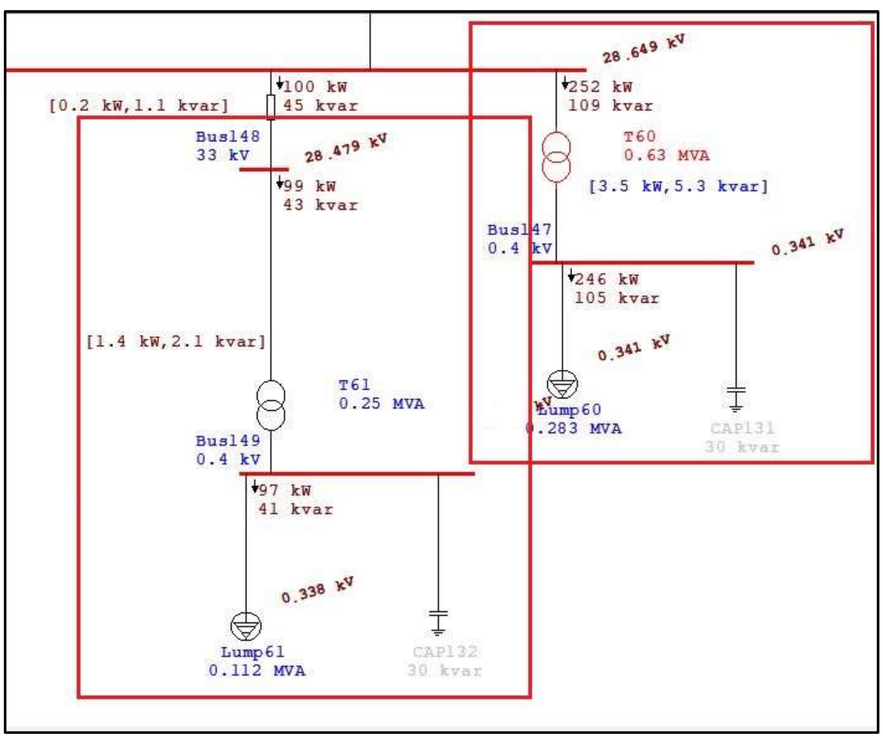


Figure A.6.3

Part 3 of Sinan region before improvements

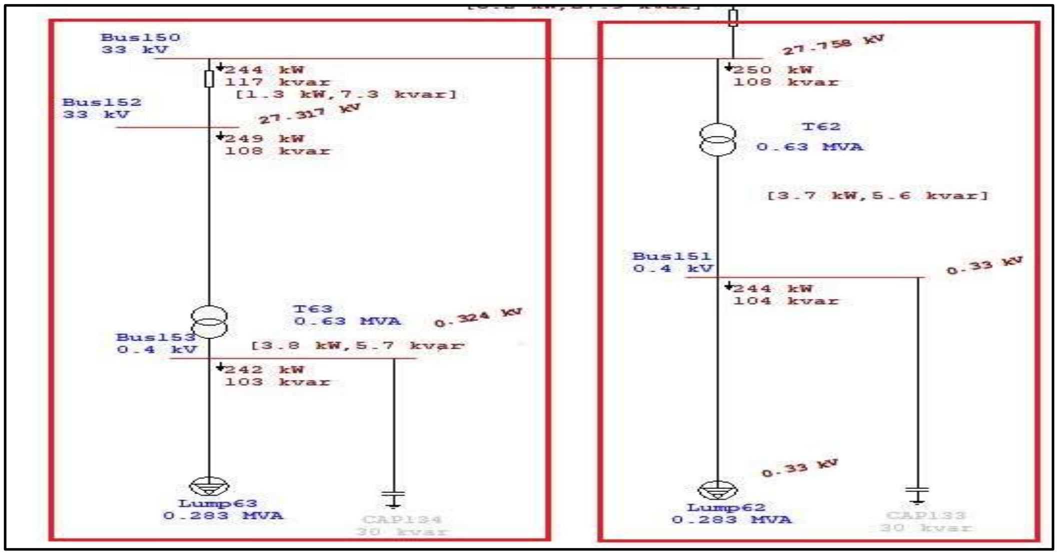


Table A.6.1

Load flow of Sinan region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus142	99+43j	97+41j	0	0	1.4+2.1j	0.337	91.7
Bus145	252+109j	246+105j	0	0	3.5+5.3j	0.339	91.7
Bus143	252+110j	246+105j	0	0	3.5+5.3j	0.339	91.6
Bus147	252+109j	246+105j	0	0	3.5+5.3j	0.341	91.7
Bus149	99+43j	97+41j	0	0	1.4+2.1j	0.338	91.7
Bus151	250+108j	244+104j	0	0	3.7+5.6j	0.33	91.8
Bus152	249+108j	242+103j	0	0	3.8+5.7j	0.324	91.7

A.7. Study of AL Jabriat Region

Figure A.7.1

Part 1 of AL Jabriat region before improvements

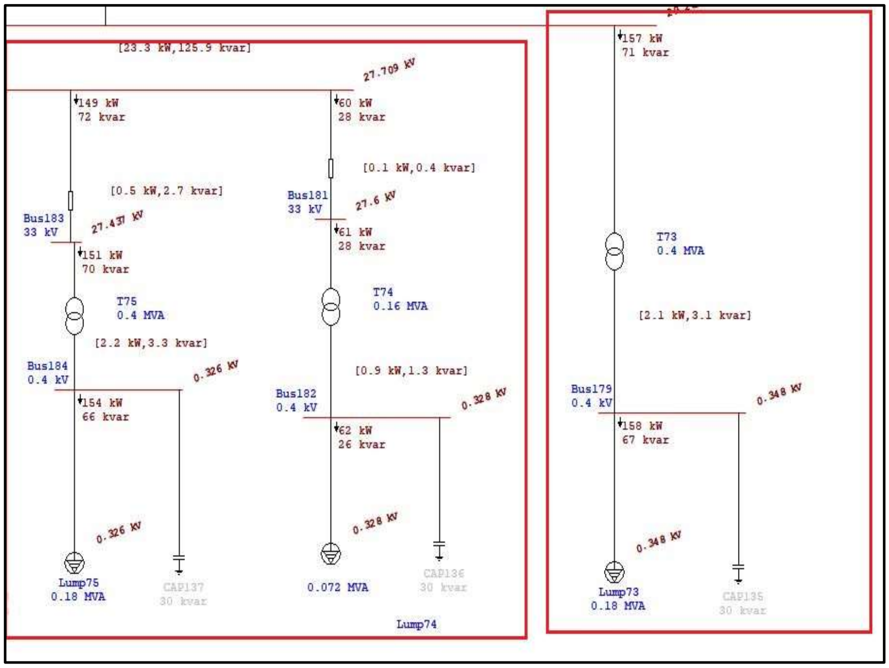


Figure A.7.2

Part 2 of AL Jabriat region before improvements

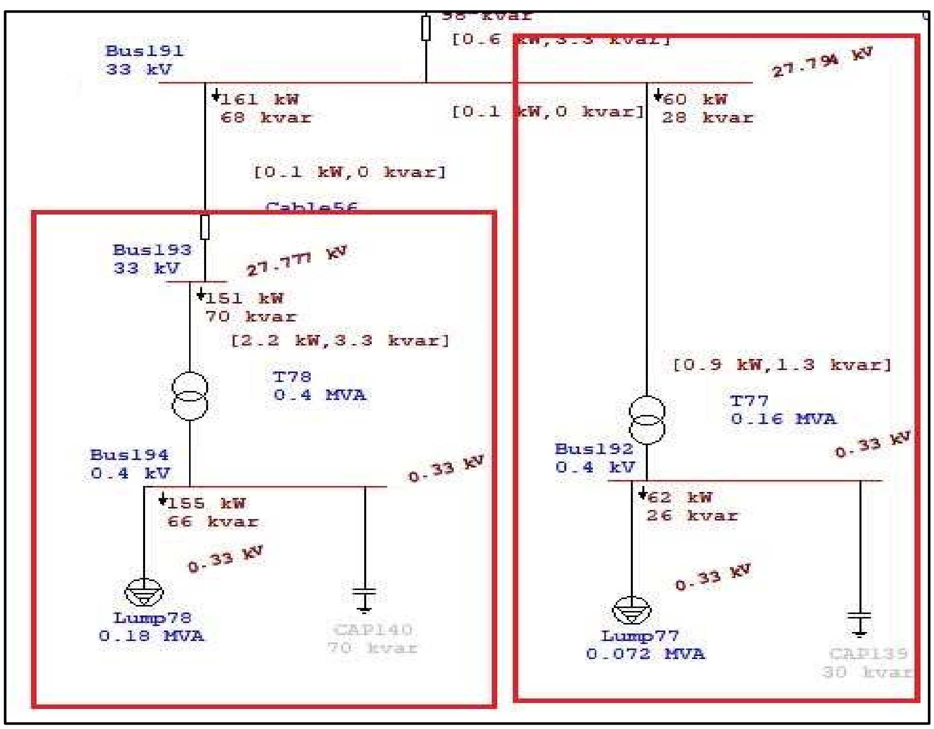


Figure A.7.3

Part 3 of AL Jabriat region before improvements

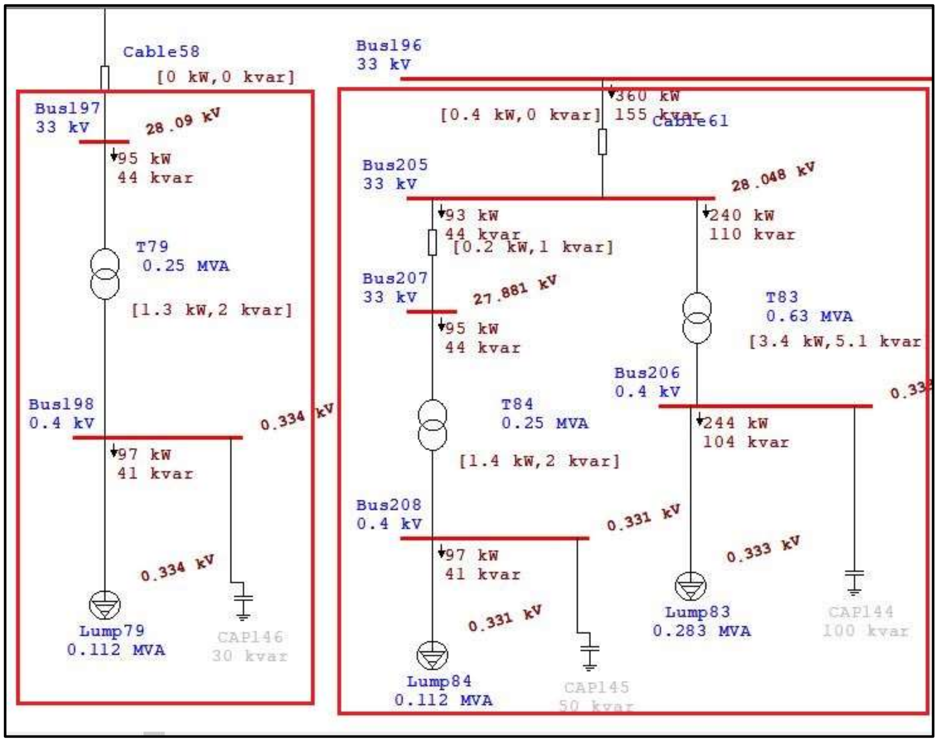


Table A.7.1

Load flow of AL Jabriat region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus179	157+71j	158+67j	0	0	2.1+3.1j	0.348	91.1
Bus182	61+28j	62+26j	0	0	0.9+1.3j	0.328	90.8
Bus184	151+70j	154+66j	0	0	2.2+3.3j	0.326	90.7

Bus192	60+28j	62+26j	0	0	0.9+1.3j	0.33	90.6
Bus194	151+70j	155+66j	0	0	2.2+3.3j	0.33	90.7
Bus206	240+110j	244+104j	0	0	3.4+5.1j	0.333	90.9
Bus208	95+44j	97+41j	0	0	1.4+2j	0.331	90.7
Bus198	95+44j	97+41j	0	0	1.3+2j	0.334	90.7

A.8. Study of AL Cinema Region

Figure A.8.1

Part 1 of Cinema region before improvements

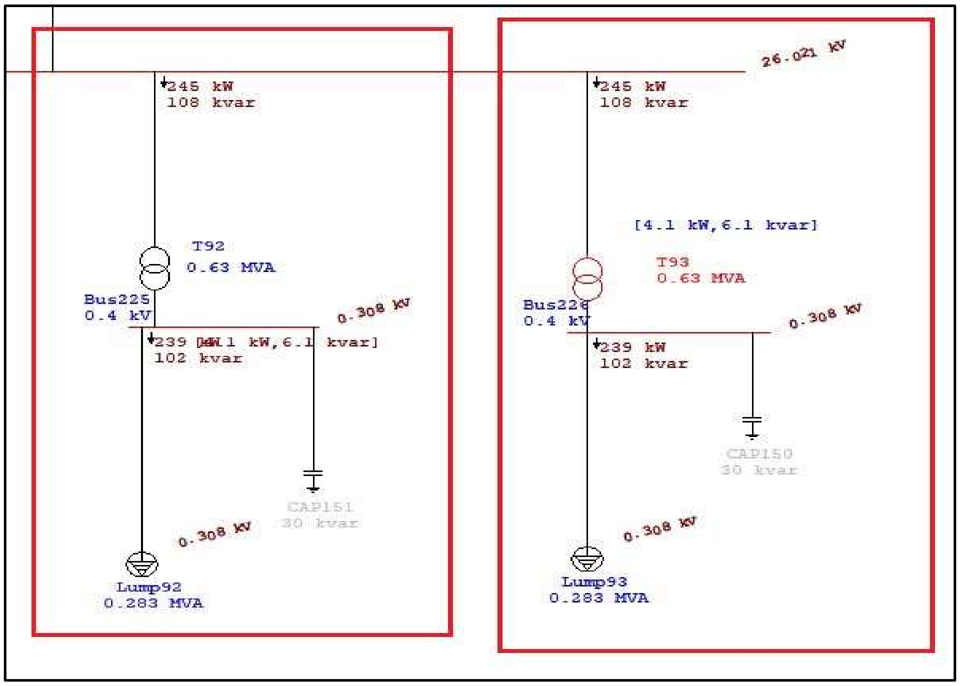


Figure A.8.2

Part 2 of Cinema region before improvements

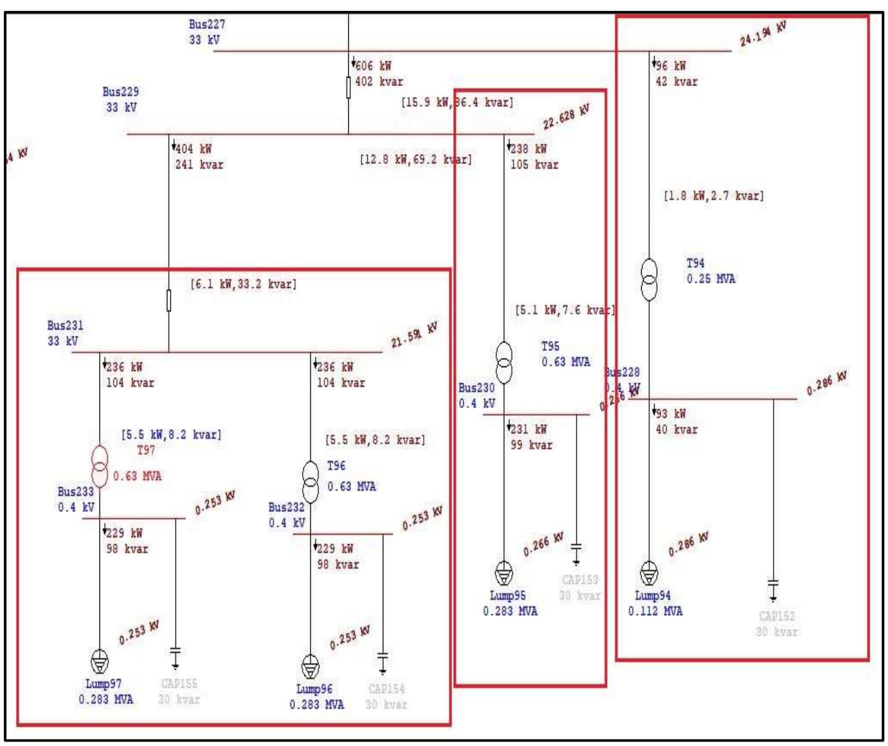


Figure A.8.3

Part 3 of Cinema region before improvements

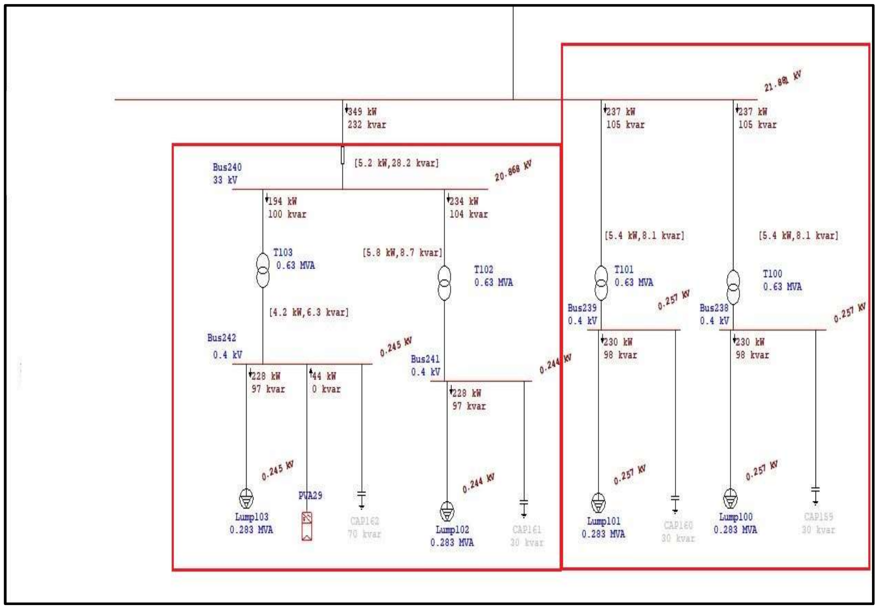


Table A.8.1

Load flow of Cinema region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus226	245+108j	239+102j	0	0	4.1+6.1j	0.308	91.5
Bus225	245+108j	239+102j	0	0	4.1+6.1j	0.308	91.5
Bus228	96+42j	93+40j	0	0	1.8+2.7j	0.286	94.8
Bus230	238+105j	231+99j	0	0	5.1+7.6j	0.266	91.5
Bus232	236+104j	229+98j	0	0	5.5+8.2j	0.253	91.5
Bus233	236+104j	229+98j	0	0	5.5+8.2j	0.253	91.5
Bus238	237+105j	230+98j	0	0	5.4+8.1j	0.257	91.4
Bus239	237+105j	230+98j	0	0	5.4+8.1j	0.257	91.4
Bus241	234+104j	228+97j	0	0	5.8+8.7	0.244	91.3
Bus242	194+100j	228+97j	44	0	4.2+6.3	0.245	88.8

A.9. Study of Haifa Street Region

Figure A.9.1

Part 1 of Haifa Street region before improvements

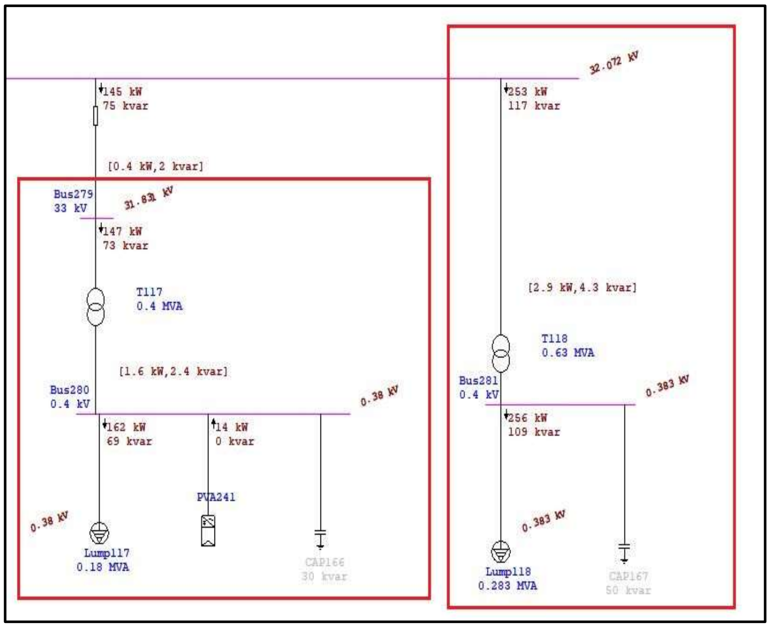


Figure A.9.2

Part 2 of Haifa Street region before improvements

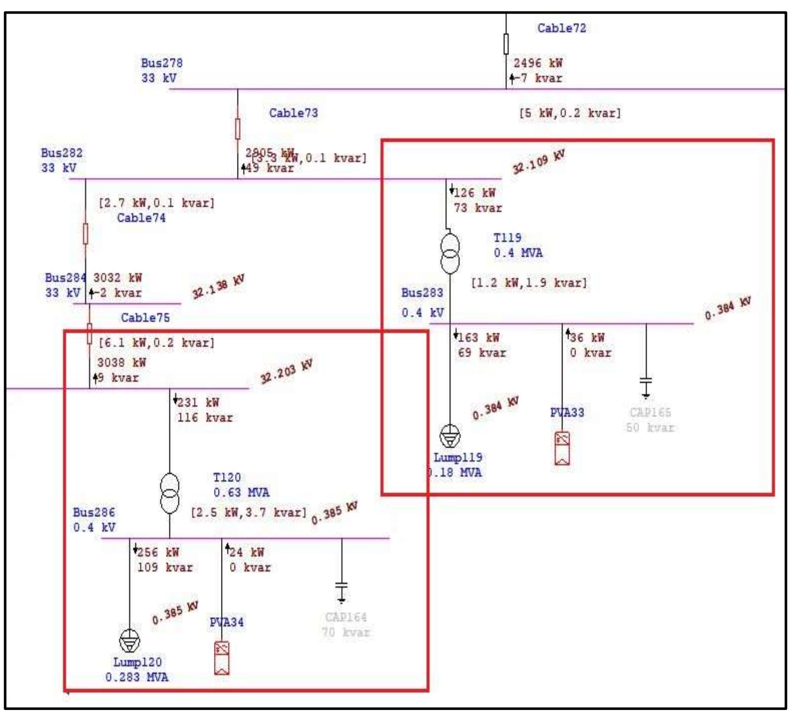


Figure A.9.3

Part 3 of Haifa Street region before improvements

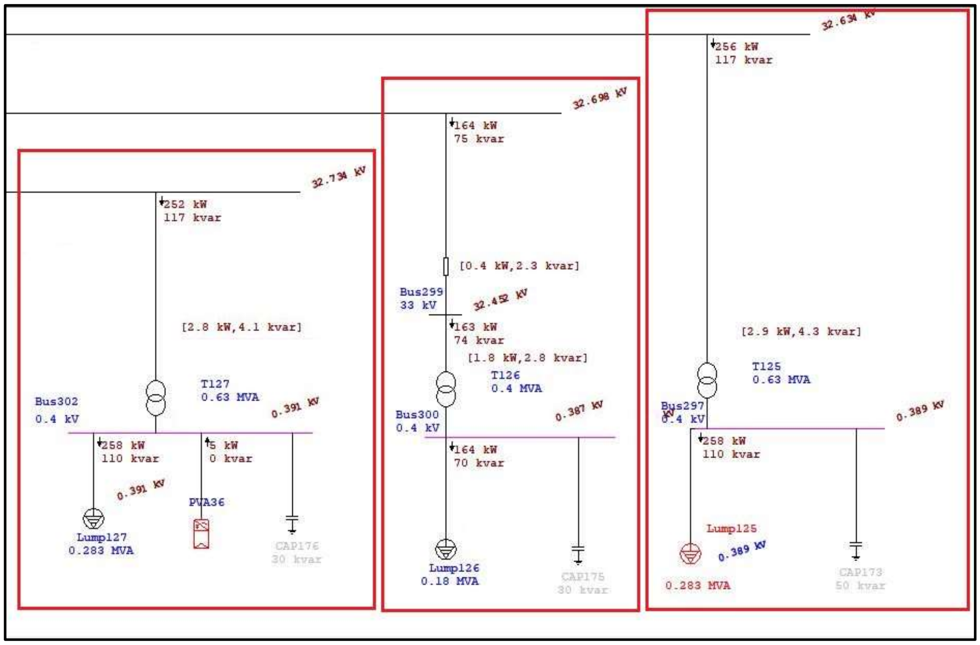


Figure A.9.4

Part 4 of Haifa Street region before improvements

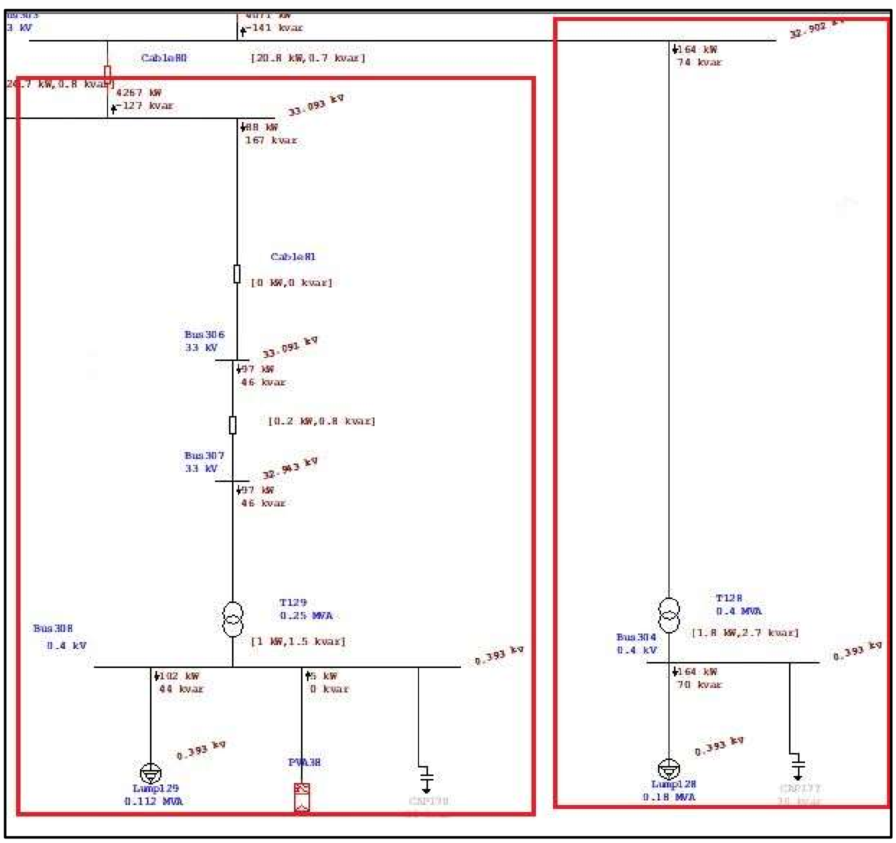


Table A.9.1

Load flow of Haifa Street region before improvement

Origin network							
Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KVA	Bus voltage KV	PF%
Bus281	253+117j	256+109j	0	0	2.9+4.3j	0.383	90.7
Bus280	147+43j	162+69j	14	0	1.6+2.4j	0.38	95.9
Bus283	126+73j	163+69j	36	0	1.2+1.9j	0.384	86.5
Bus286	231+116j	256+109j	24	0	2.5+3.7j	0.385	89.3
Bus297	256+117j	258+110j	0	0	2.9+4.3j	0.389	90.9
Bus300	163+74j	164+70j	0	0	1.8+2.8j	0.387	91
Bus302	252+117j	258+110j	5	0	2.8+4.1j	0.391	90.7
Bus304	164+74j	164+70j	0	0	1.8+2.7j	0.393	91.1
Bus308	97+46j	102+44j	5	0	1+1.5j	0.393	90.3

Appendix B

Solutions of Jenin electrical network.

B.1. Solutions of AL Maslakh Region

Figure B.1.1

Part 1 of AL Maslakh region after improvements

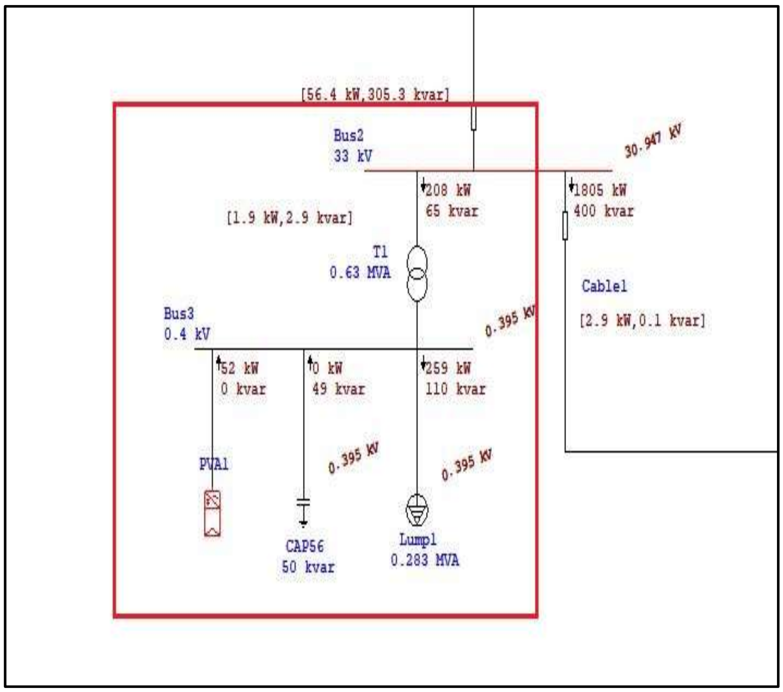


Figure B.1.2

Part 2 of AL Maslakh region after improvements

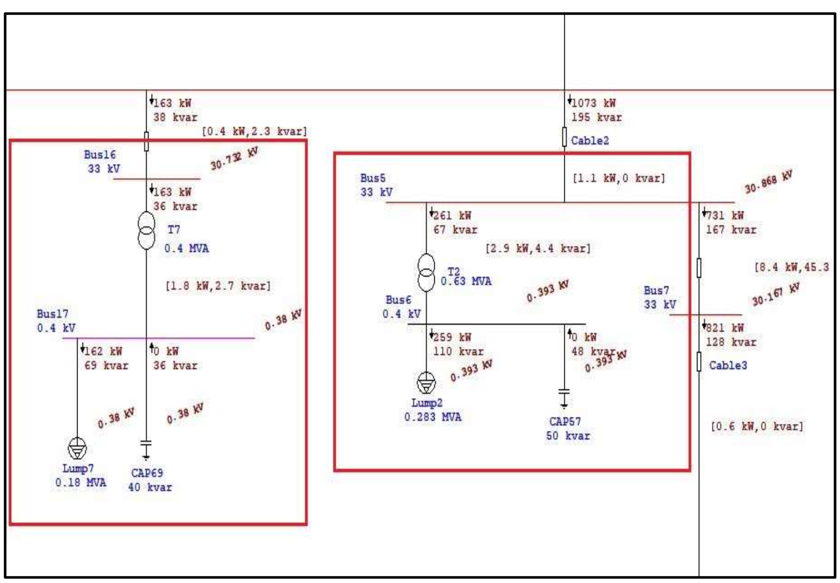


Figure B.1.3

Part 3 of AL Maslakh region after improvements

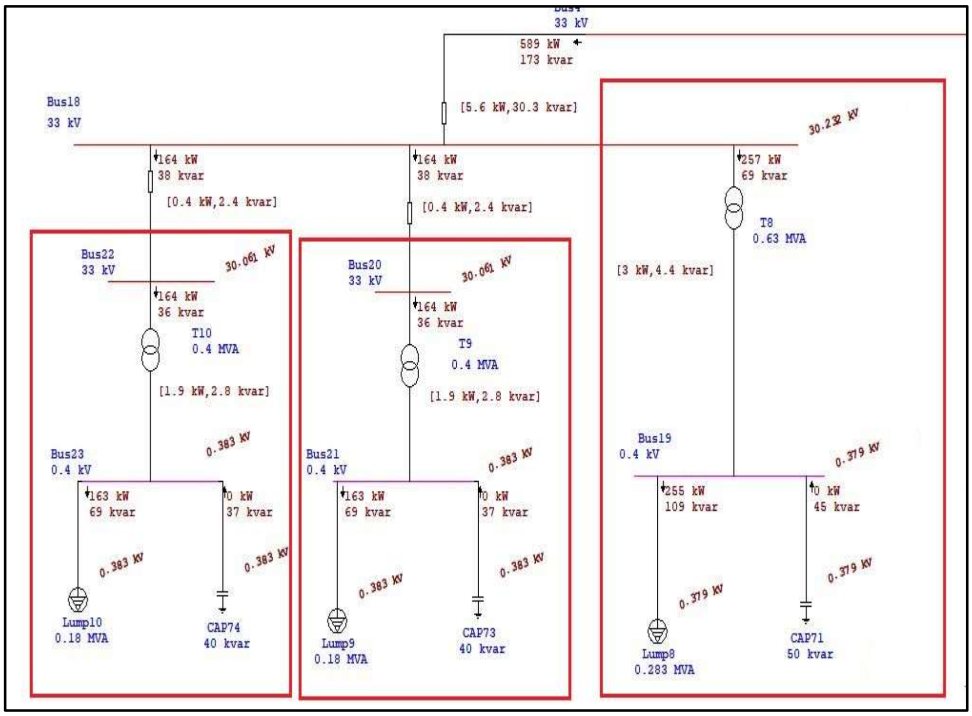


Figure B.1.4

Part 4 of AL Maslakh region after improvements

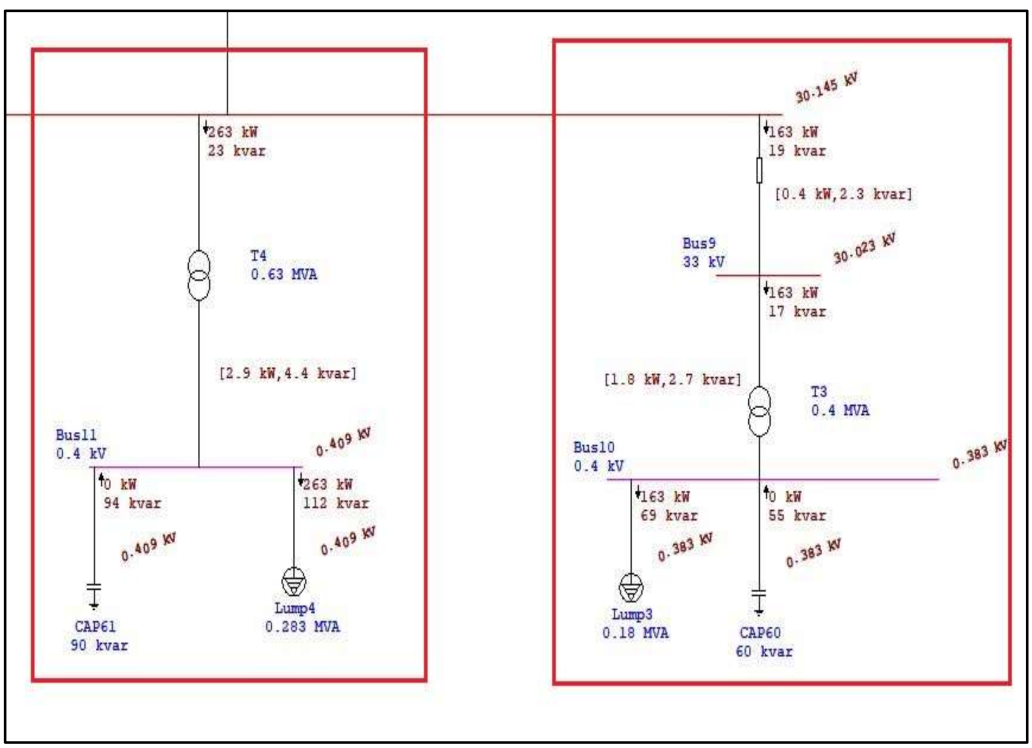


Figure B.1.5

Part 5 of AL Maslakh region after improvements

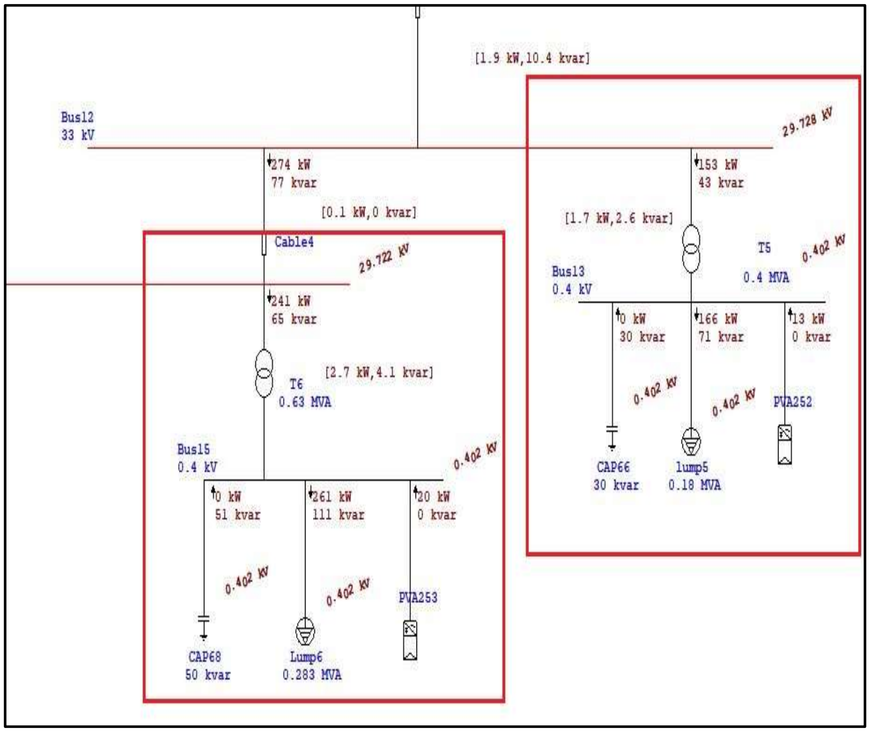


Table B.1.1

Load flow of AL Maslakh region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KW	Bus voltage KV	PF%
Bus3	203+113j	255+109j	52	0	2.3+3.5j	0.38	87.5
Bus6	255+114j	255+109j	0	0	3.4+5.1j	0.378	91..3
Bus10	157+72j	159+68j	0	0	2.3+3.4j	0.358	90.9
Bus11	253+116j	256+109j	0	0	3.7+5.5j	0.384	90.9
Bus 13	150+74j	165+70j	14	0	2.2+3.2j	0.398	89.6
Bus15	236+117j	260+111j	22	0	3.4+5.1j	0.398	88.7
Bus17	160+72j	160+68j	0	0	2.1+3.2j	0.363	91.2
Bus19	250+113j	250+107j	0	0	3.5+5.2j	0.359	91.1
Bus21	159+72j	160+68j	0	0	2.3+3.4j	0.361	90.6
Bus23	159+72j	160+68j	0	0	2.3+3.4j	0.361	90.6
Edited network							
Bus3	208+65j	259+110j	52	49	1.9+2.9j	0.396	95.5
Bus6	261+66j	259+110j	0	48	2.9+4.4j	0.394	96.9
Bus10	163+17j	163+69j	0	55	1.8+2.7j	0.383	99.4
Bus11	263+23j	263+112j	0	94	2.9+4.4j	0.409	99.6
Bus 13	153+43	166+71j	13	30	1.7+2.6j	0.403	96.2
Bus15	241+65j	261+111j	20	51	2.7+4.1j	0.402	96.5
Bus17	164+36j	162+69j	0	36	1.8+2.7j	0.38	97.7
Bus19	257+69j	255+109j	0	45	3+4.4j	0.379	96.6
Bus21	164+36j	163+69j	0	37	1.9+2.8j	0.383	97.4
Bus23	164+36j	163+69j	0	37	1.9+2.8j	0.383	97.4

B.2. Solutions of AL Almanya Region

Figure B.2.1

Part 1 of AL Almanyah region after improvements

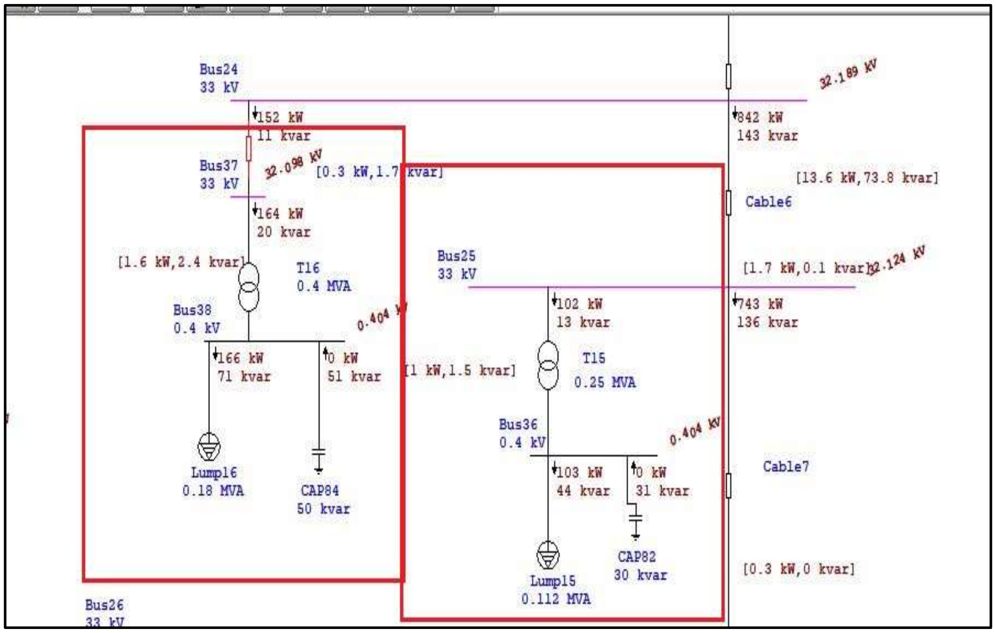


Figure B.2.2

Part 2 of AL Almanyah region after improvements

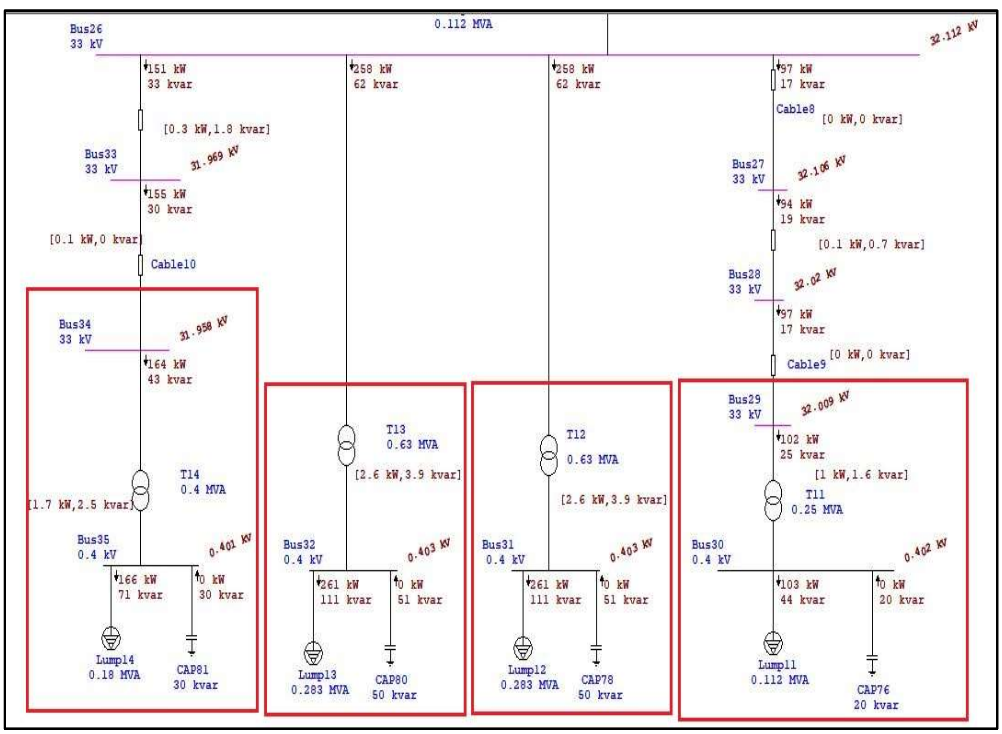


Table B.2.1

Load flow of AL Almaniah region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KW	Bus voltage KV	PF%
Origin network							
Bus30	102+50j	102+44j	0	0	1.3+1.9j	0.392	89.6
Bus31	258+125j	259+110j	0	0	3.2+4.8j	0.394	90
Bus32	258+125j	259+110j	0	0	3.2+4.8j	0.394	90
Bus35	164+82j	164+70j	0	0	2.1+3.1j	0.391	91.8
Bus36	102+49j	102+44j	0	0	1.2+1.9j	0.395	92
Bus38	164+81j	164+70j	0	0	2+3.1j	0.392	92
Edited network							
Bus30	102+25j	103+44j	0	20	1+1.6j	0.402	97.1
Bus31	258+62j	261+111j	0	50	2.6+3.9j	0.403	97.3
Bus32	258+62j	261+111j	0	50	2.6+3.9j	0.403	97.3
Bus35	164+43j	166+71j	0	30	1.7+2.5j	0.401	96.7
Bus36	102+13j	103+44j	0	30	1+1.5j	0.404	99.2
Bus38	164+20j	166+71j	0	50	1.6+2.4j	0.404	99.3

B.3. Solutions of Haddad Region

Figure B.3.1

Part 1 of Haddad region after improvements

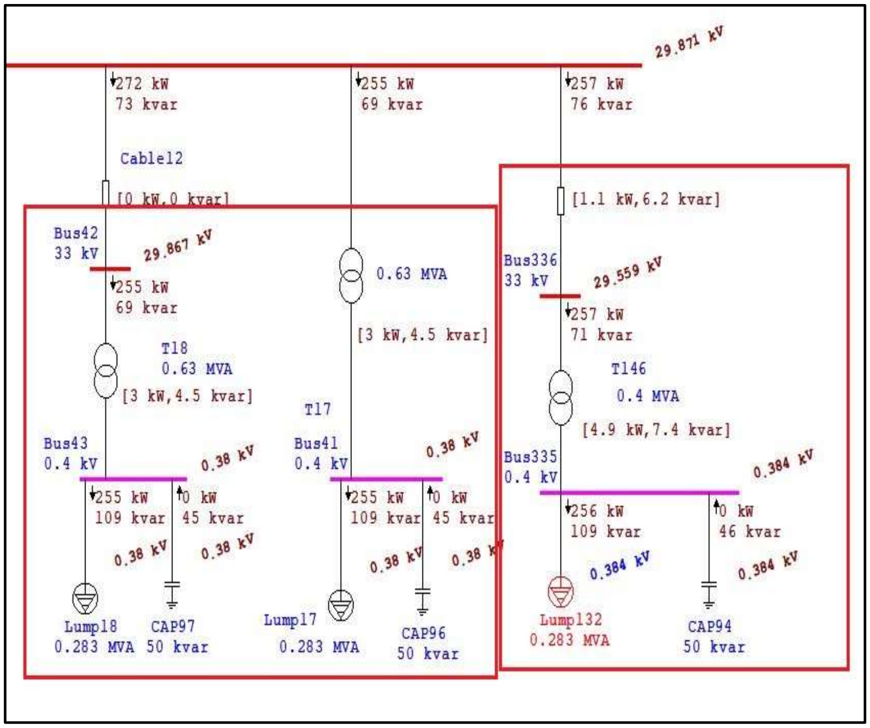


Figure B.3.2

Part 2 of Haddad region after improvements

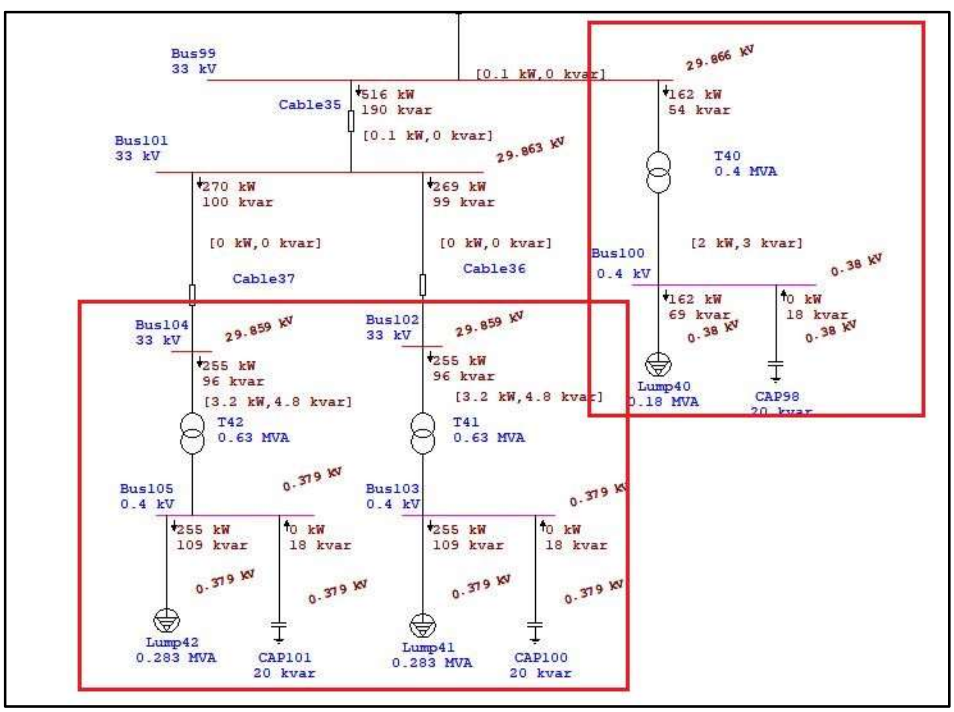


Figure B.3.3

Part 3 of Haddad region after improvements

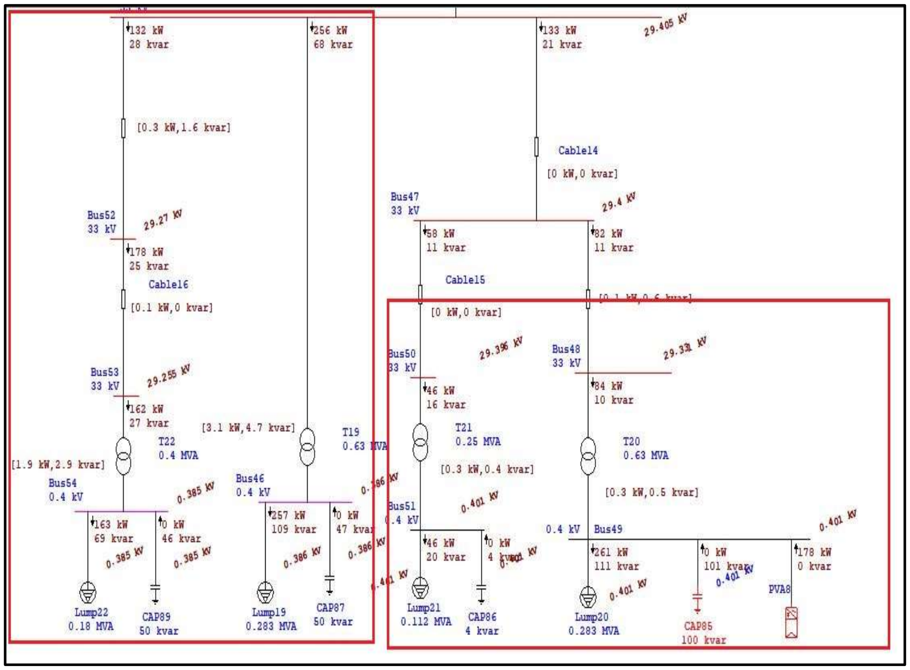


Figure B.3.4

Part 4 of Haddad region after improvements

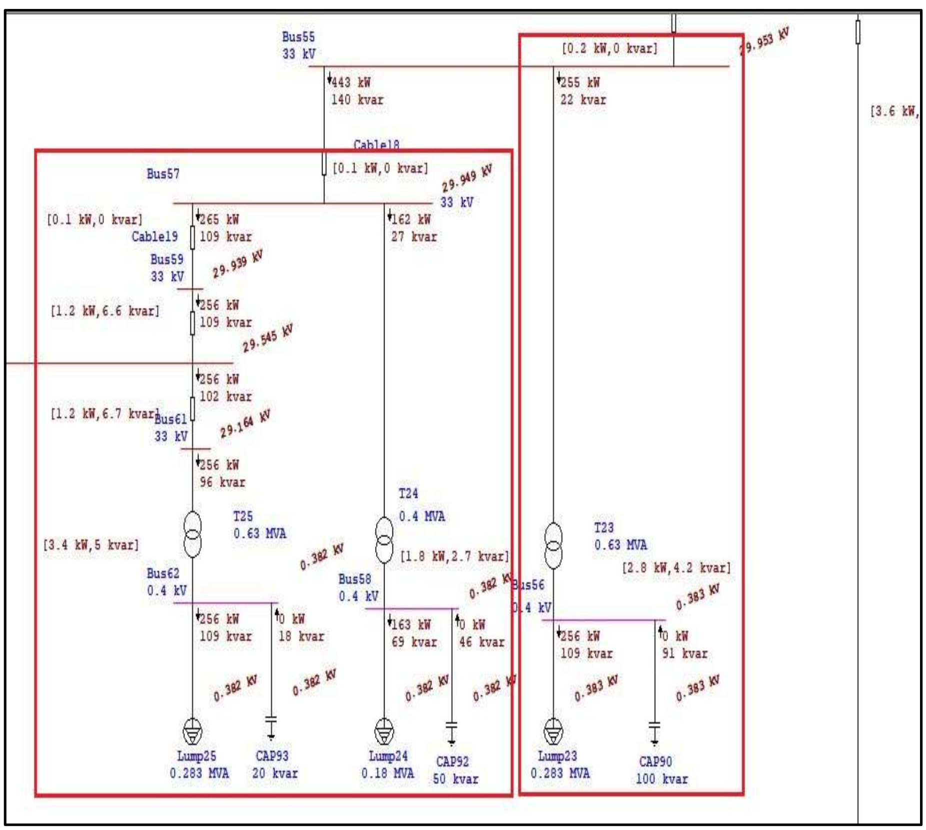


Table B.3.1

Load flow of Haddad region after improvement

Bus number	complex Power (Transformer) KVA	complex Power (Load) KVA	Real Power (PV) KW	Reactive Power (Capacitor) KVAR	Losses through transformer KW	Bus voltage KV	PF%
Origin network							
Bus 335	251+116j	252+107j	0	0	5.7+8.6j	0.366	90.7
Bus41	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus 43	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus100	158+72j	160+68j	0	0	2.2+3.3j	0.365	91.1
Bus103	249+113j	252+107j	0	0	3.5+5.2j	0.365	91.1
Bus105	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus49	72+105j	248+106j	178	0	0.8+1.2j	0.351	56.4
Bus51	43+20j	44+19j	0	0	0.3+0.4j	0.356	91
Bus46	243+112j	249+106j	0	0	3.6+5.4j	0.352	90.8
Bus54	154+72j	158+67j	0	0	2.3+3.4j	0.349	90.7
Bus56	249+113j	252+107j	0	0	3.5+5.2j	0.365	91
Bus58	158+72j	160+68j	0	0	2.2+3.3j	0.365	91
Bus62	248+113j	251+107j	0	0	3.7+5.5j	0.364	91
Edited network							
Bus 335	257+71j	256+109j	0	46	4.9+7.4j	0.384	96.4
Bus41	255+69j	255+109j	0	45	3+4.5j	0.38	96.6
Bus 43	255+69j	255+109j	0	45	3+4.5j	0.38	96.6
Bus100	162+54j	162+69j	0	18	2+3j	0.38	94.8
Bus103	255+96j	255+109j	0	18	3.2+4.8j	0.379	93.6
Bus105	255+96j	255+109j	0	18	3.2+4.8j	0.379	93.6
Bus49	84+10j	261+111j	178	101	0.3+0.5j	0.401	99.3
Bus51	46+16j	46+20j	0	4	0.3+0.4j	0.401	94.3
Bus46	256+68j	257+109j	0	47	3.1+4.7j	0.386	96.7
Bus54	162+27j	163+69j	0	46	1.9+2.9j	0.385	98.7
Bus56	255+22j	25+109j	0	91	2.8+4.2j	0.383	99.6
Bus58	162+27j	163+69j	0	46	1.8+2.7j	0.382	98.7
Bus62	256+96j	256+109j	0	18	3.4+5j	0.382	93.6

B.4. Solutions of Ayash Region

Figure B.4.1

Part 1 of Ayash region after improvements

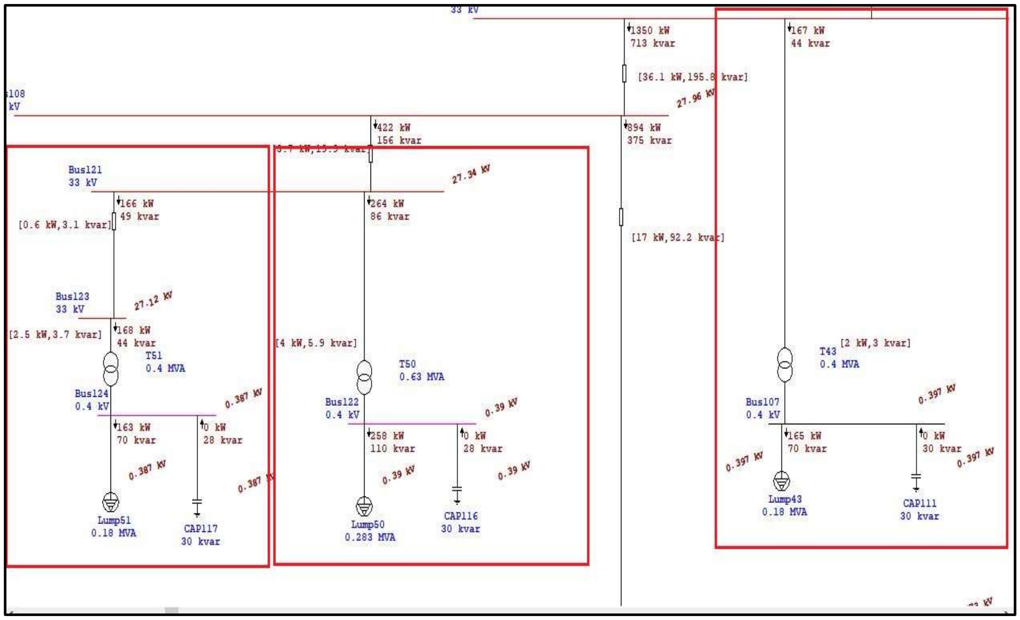
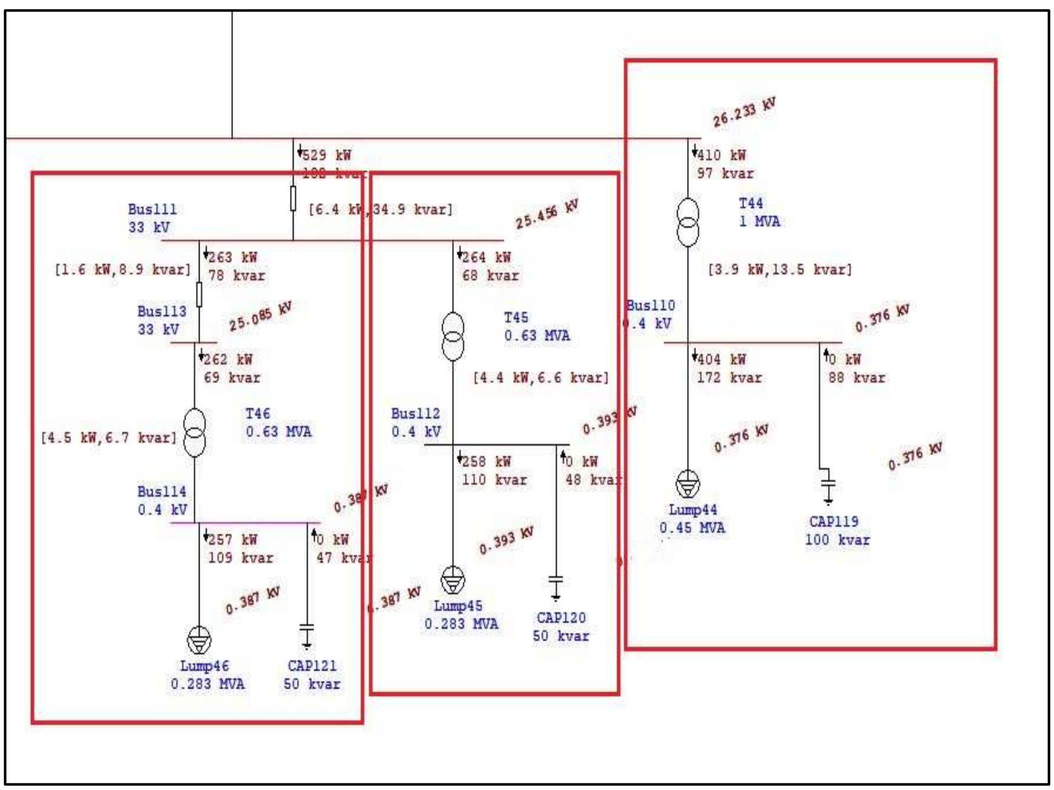


Figure B.4.2

Part 2 of Ayash region after improvements



B.5. Solutions of AL Nasreh Street Region

Figure B.5.1

Part 1 of AL Nasreh Street region after improvements

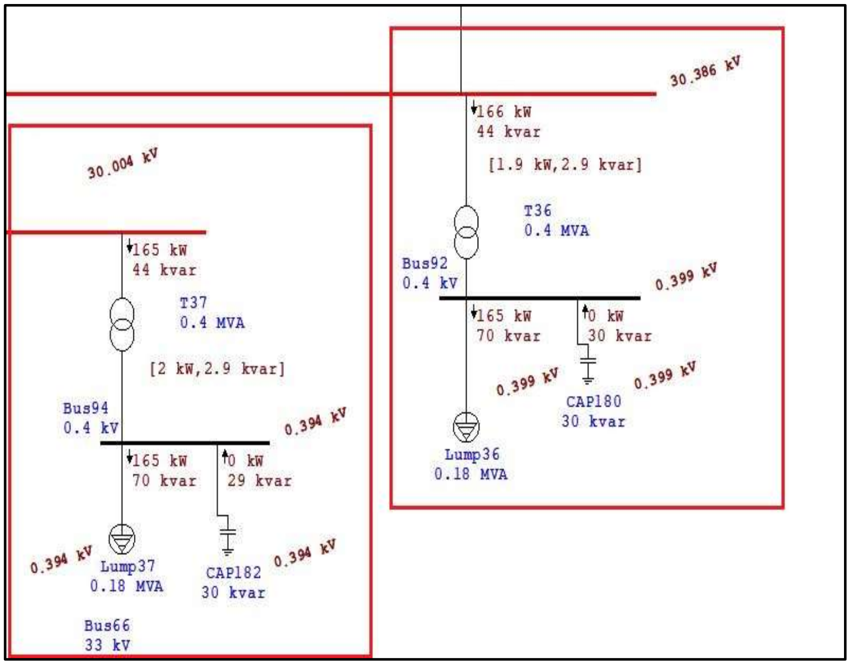


Figure B.5.2

Part 2 of AL Nasreh Street region after improvements

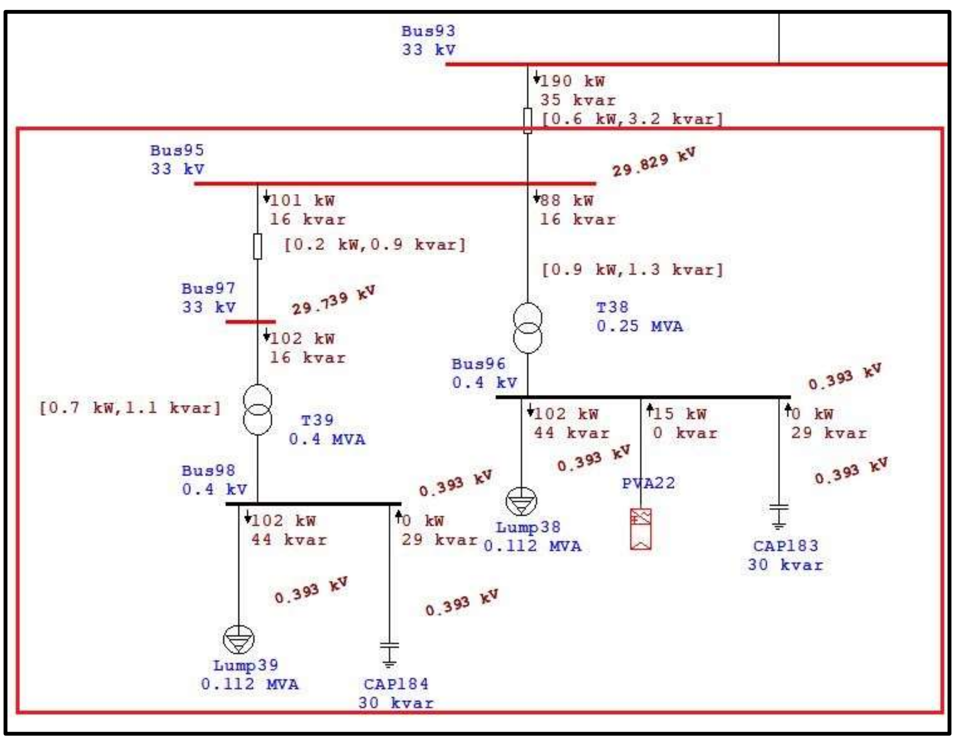


Figure B.5.3

Part 3 of AL Nasreh Street region after improvements

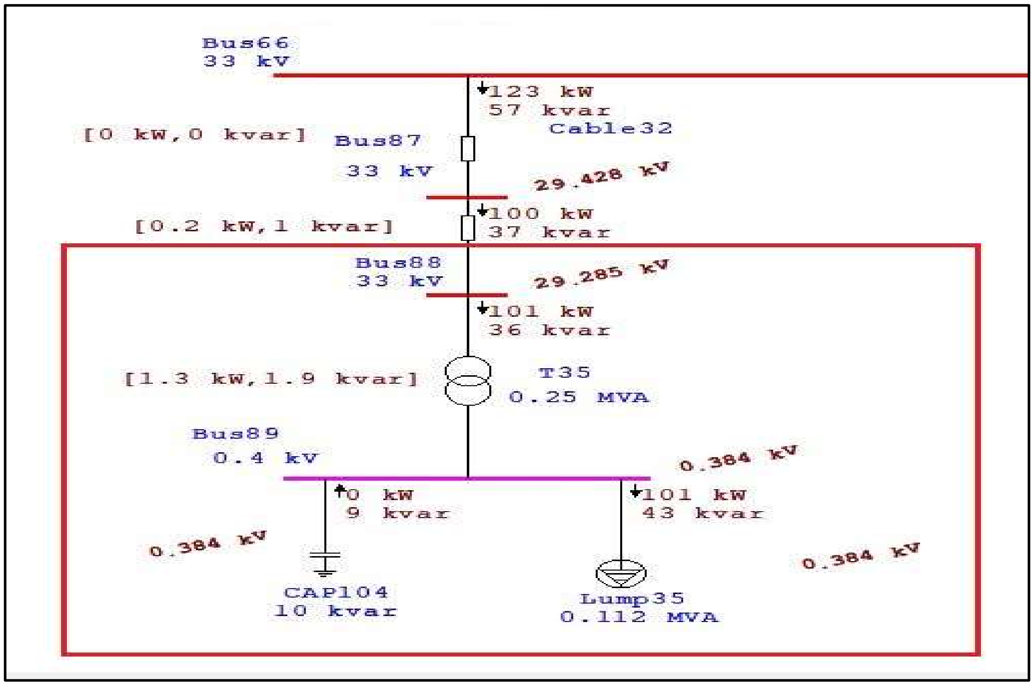


Figure B.5.4

Part 4 of AL Nasreh Street region after improvements

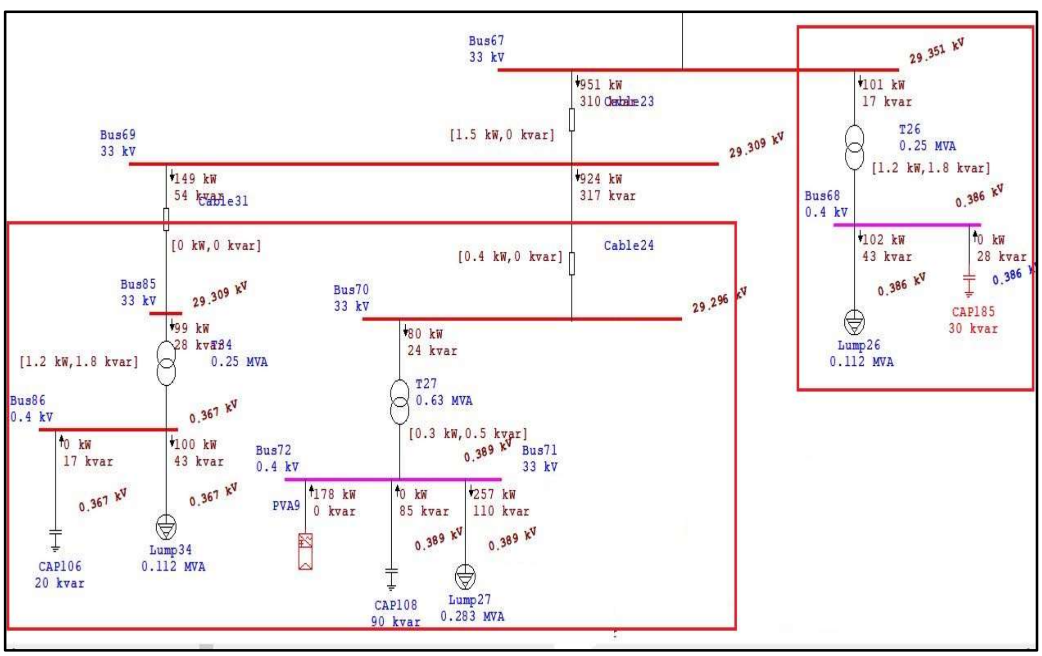


Figure B.5.5

Part 5 of AL Nasreh Street region after improvements

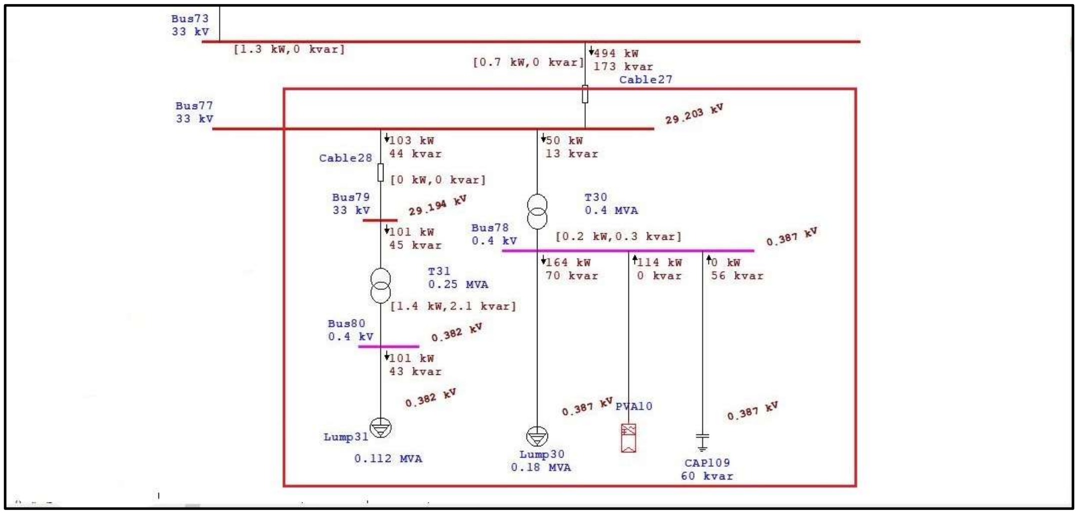
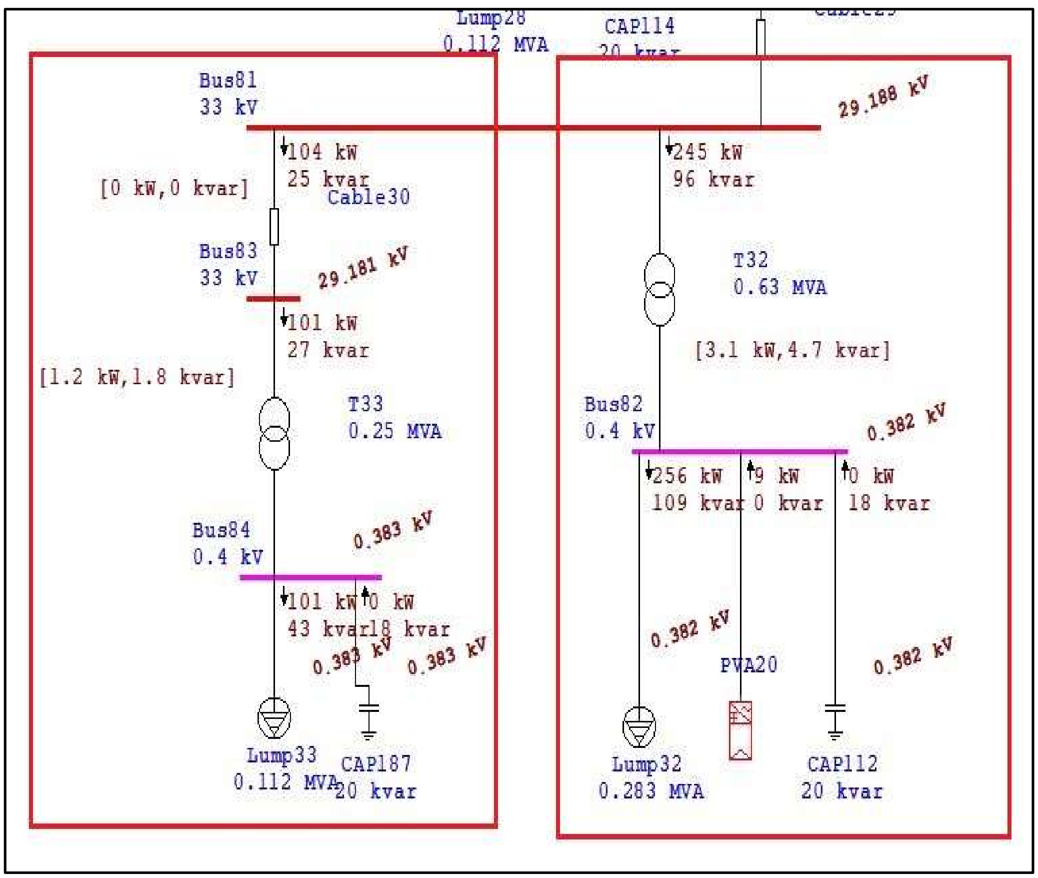


Figure B.5.6

Part 6 of AL Nasreh Street region after improvements



B.6. Solutions of Sinan Region

Figure B.6.1

Part 1 of Sinan region after improvements

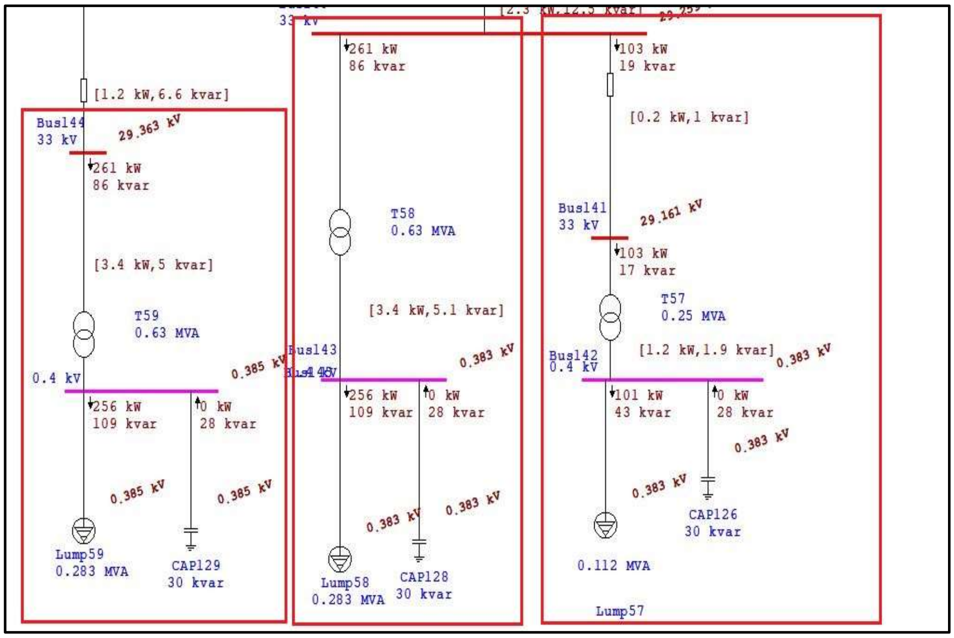


Figure B.6.2

Part 2 of Sinan region after improvements

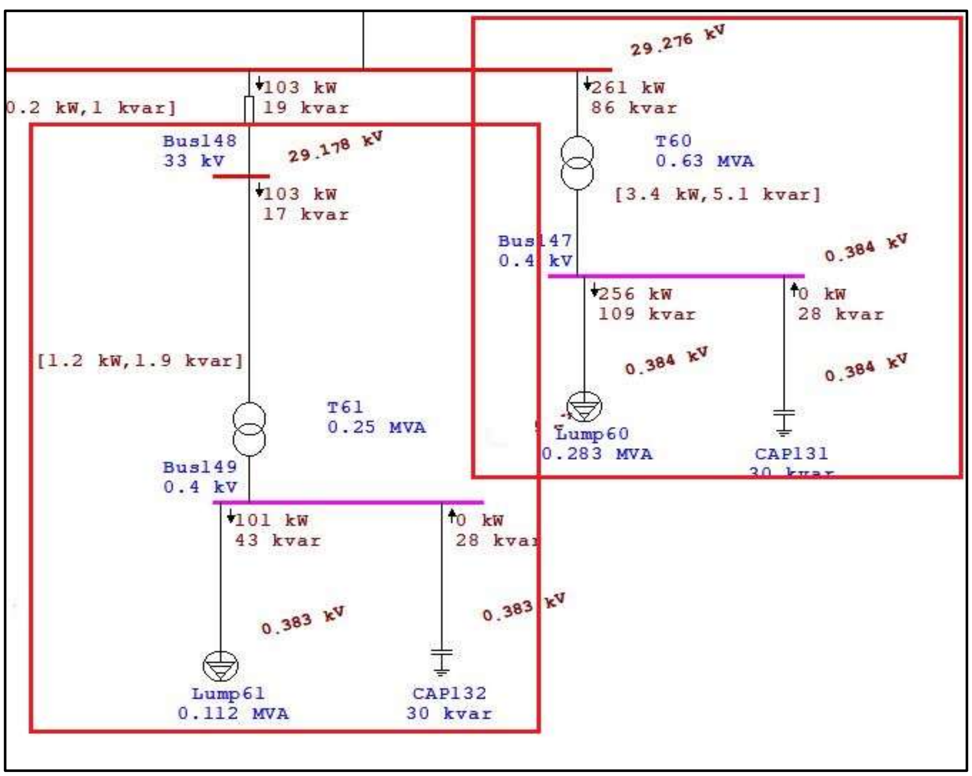
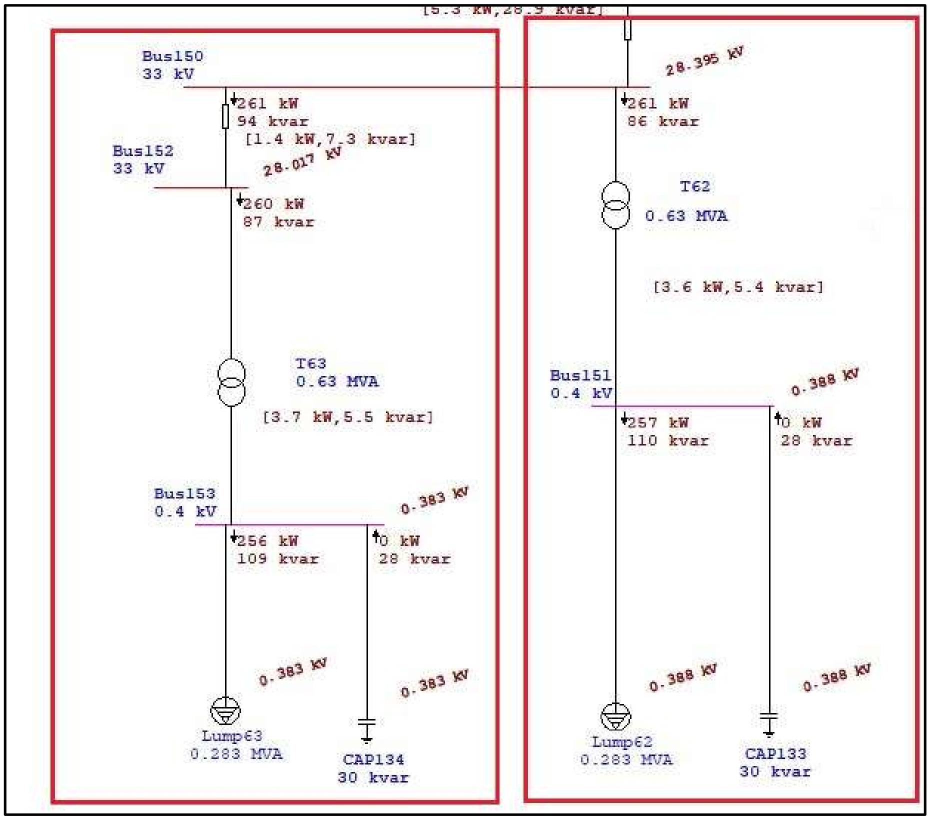


Figure B.6.3

Part 3 of Sinan region after improvements



B.7. Solutions of AL Jabriat Region

Figure B.7.1

Part 1 of AL Jabriat region after improvements

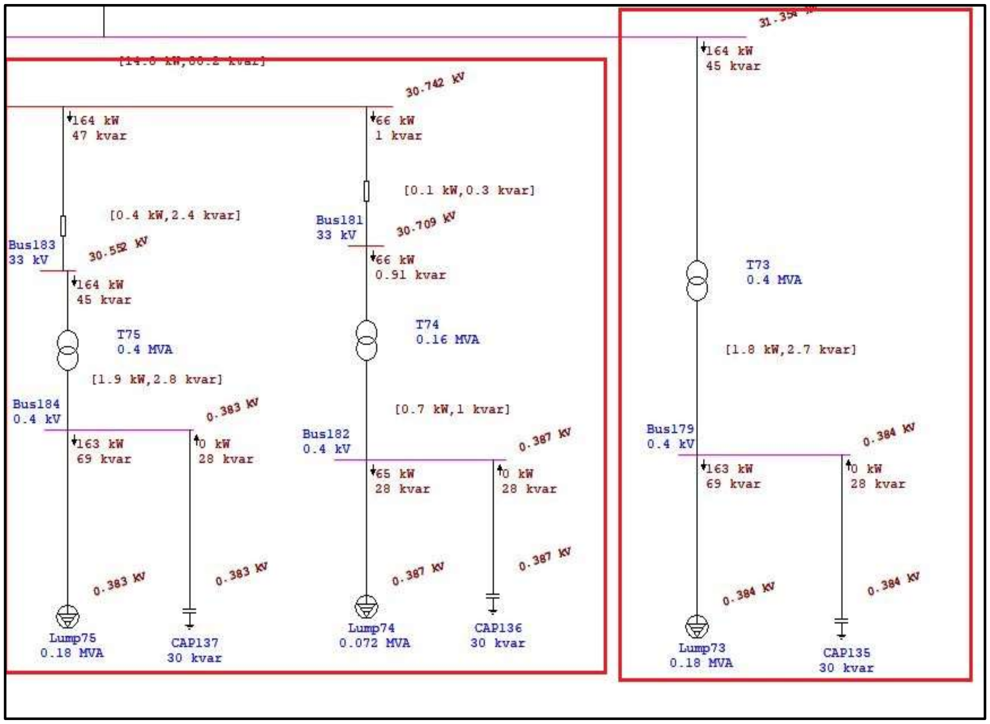


Figure B.7.2

Part 2 of AL Jabriat region after improvements

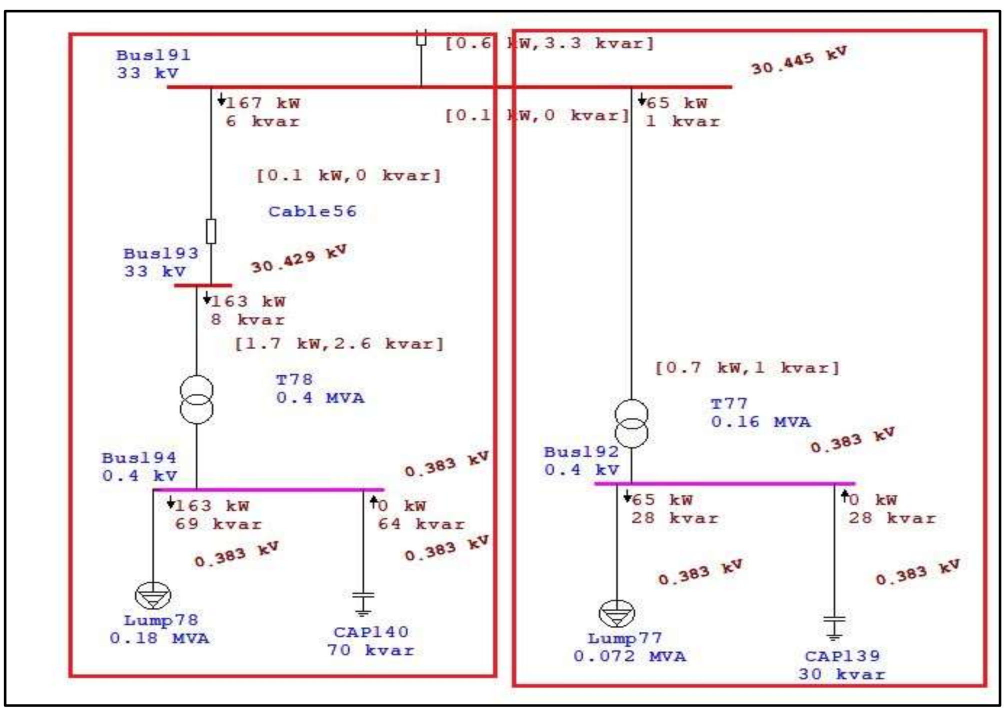
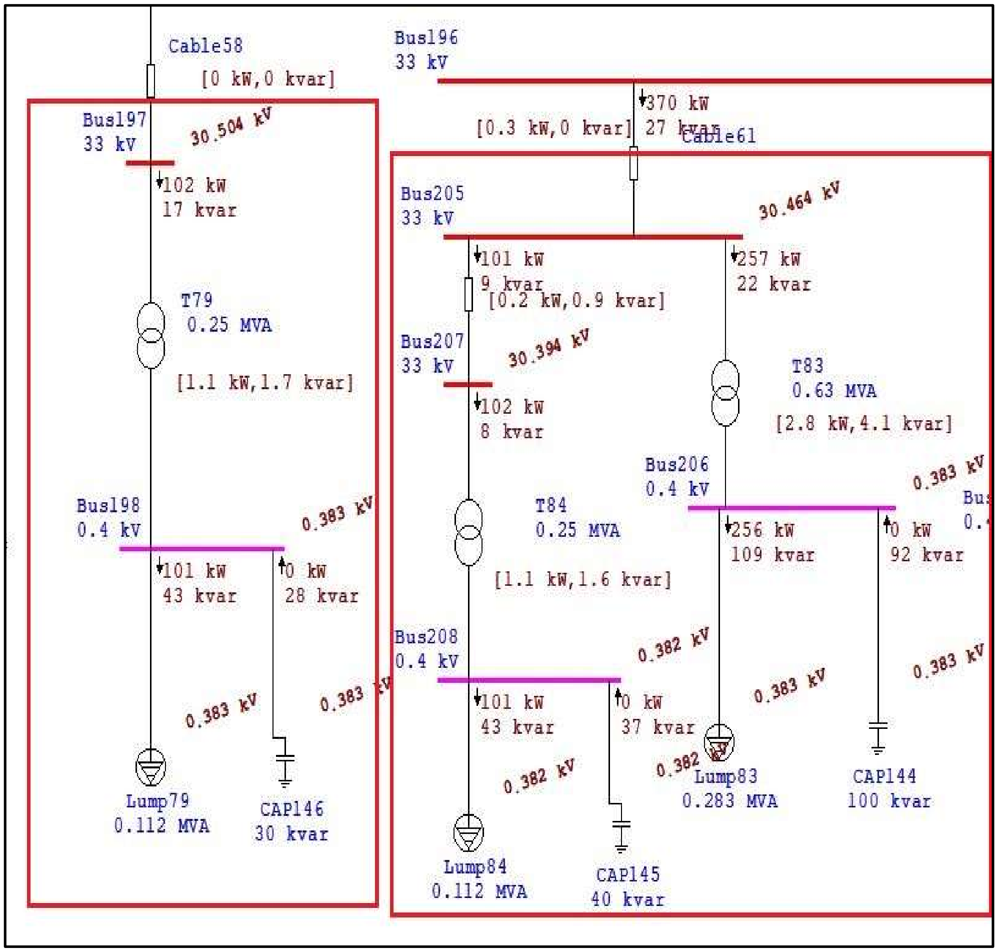


Figure B.7.3

Part 3 of AL Jabriat region after improvements



B.8.Solutions of AL Cinema Region

Figure B.8.1

Part 1 of Cinema region after improvements

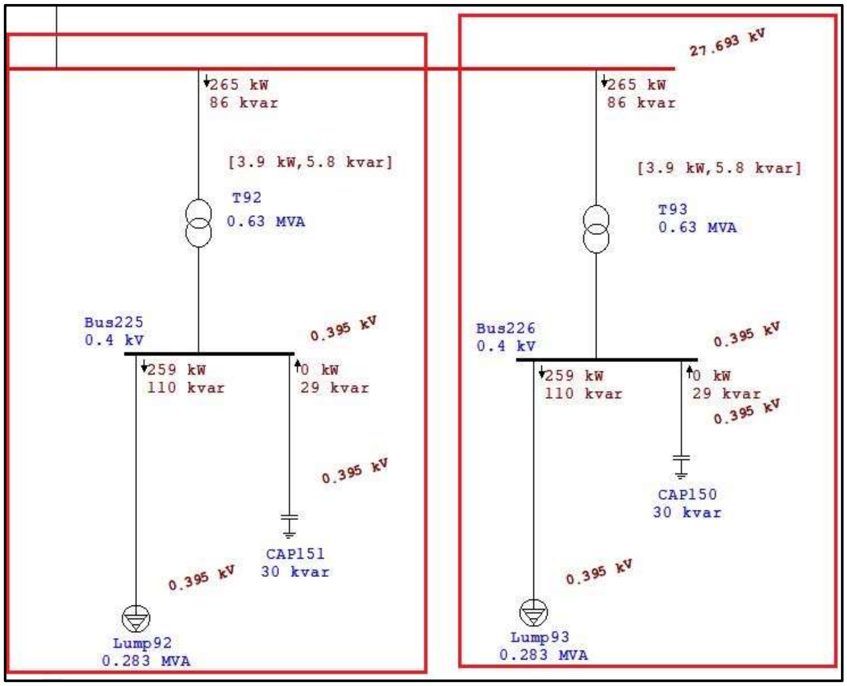


Figure B.8.2

Part 2 of Cinema region after improvements

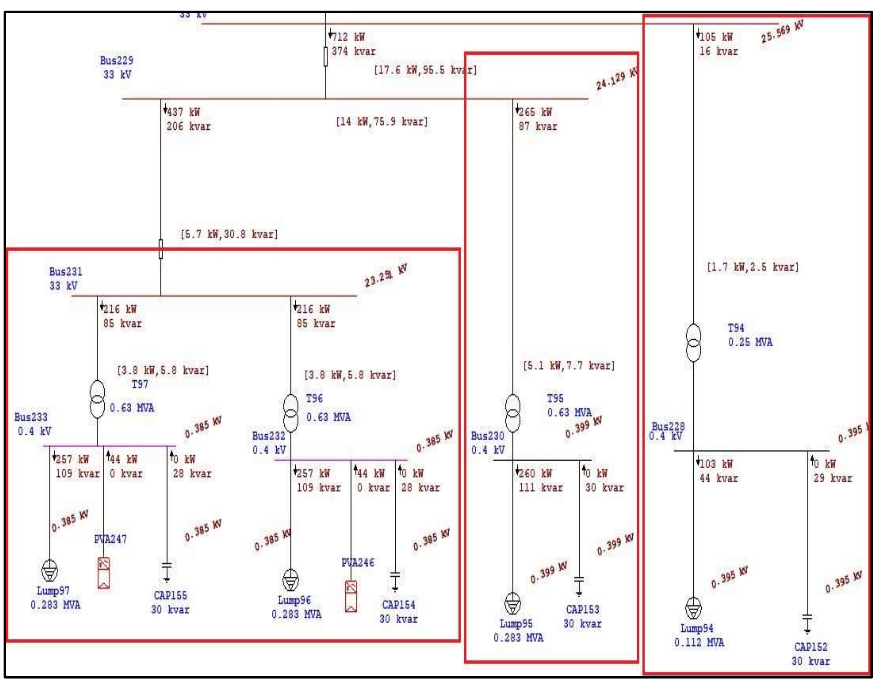
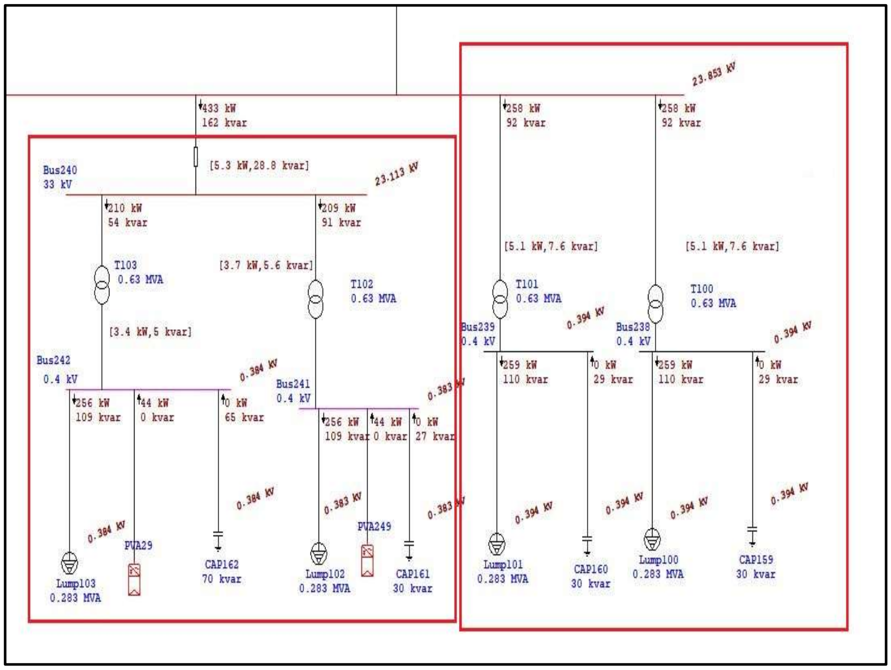


Figure B.8.3

Part 3 of Cinema region after improvements



B.9. Solutions of Haifa Street Region

Figure B.9.1

Part 1 of Haifa Street region after improvements

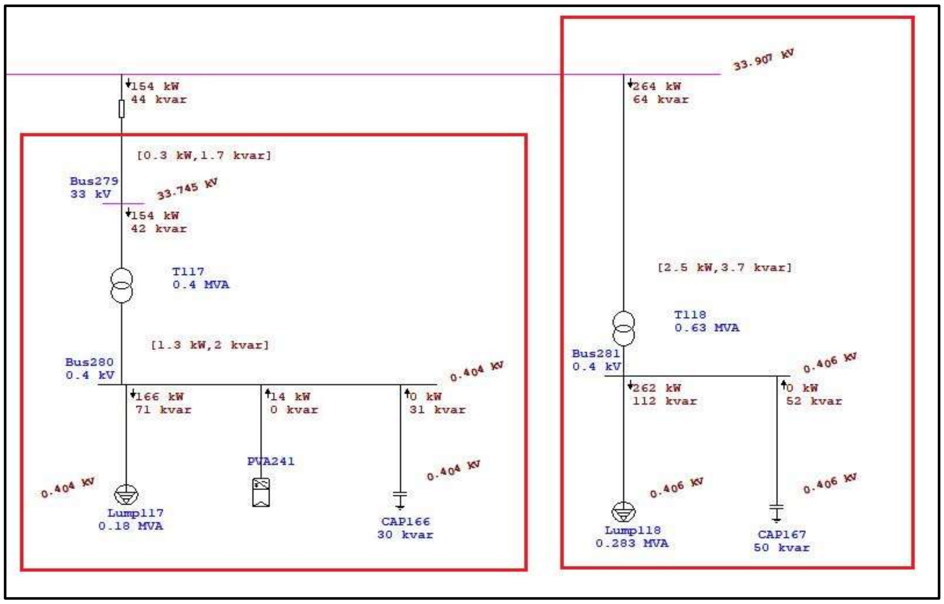


Figure B.9.2

Part 2 of Haifa Street region after improvements

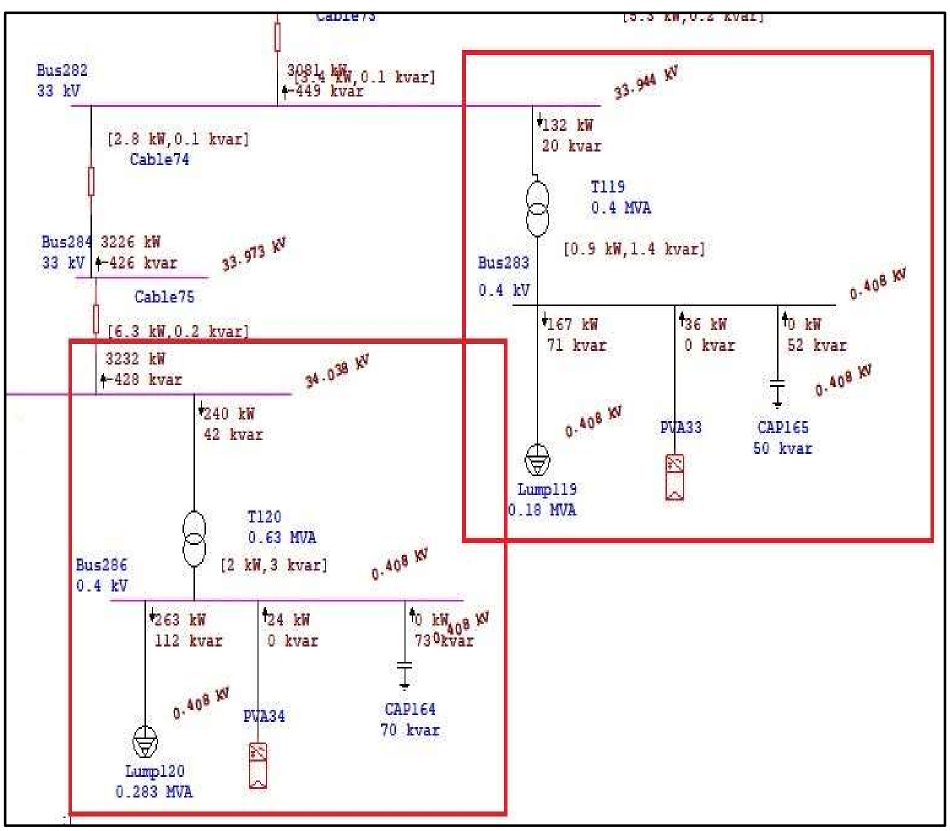


Figure B.9.3

Part 3 of Haifa Street region after improvements

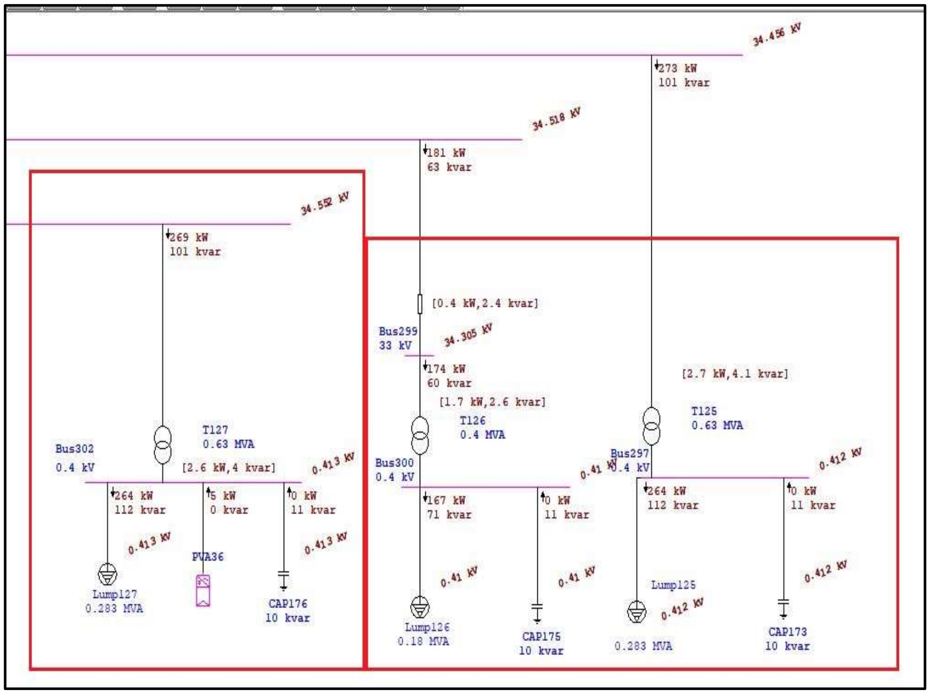
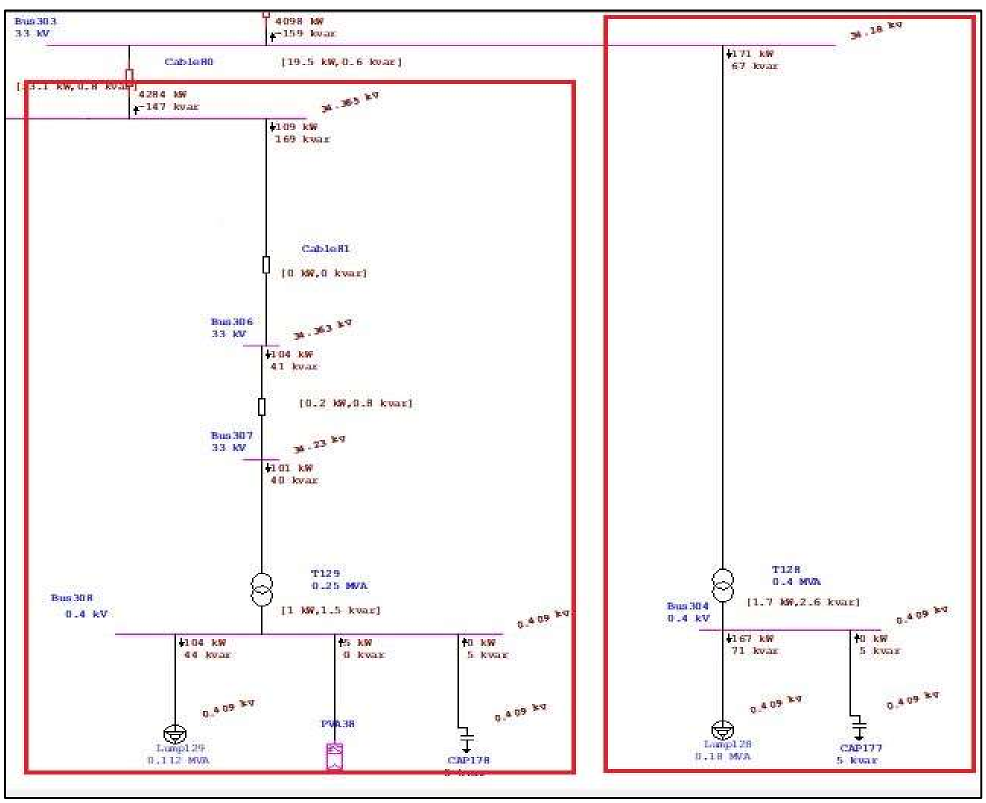


Figure B.9.4

Part 4 of Haifa Street region after improvements



Appendix C

Effect of PV Penetration Level on the network

C.1. Brief introduction of PV penetration level

Figure C.1.1

Electrical power consumption in Palestine

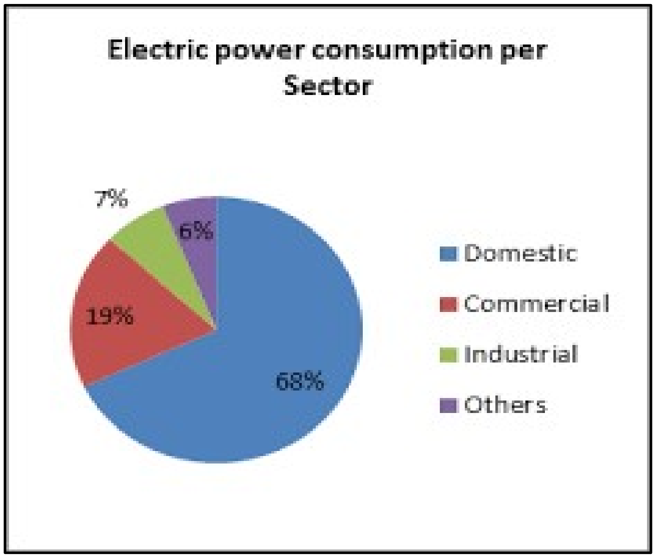
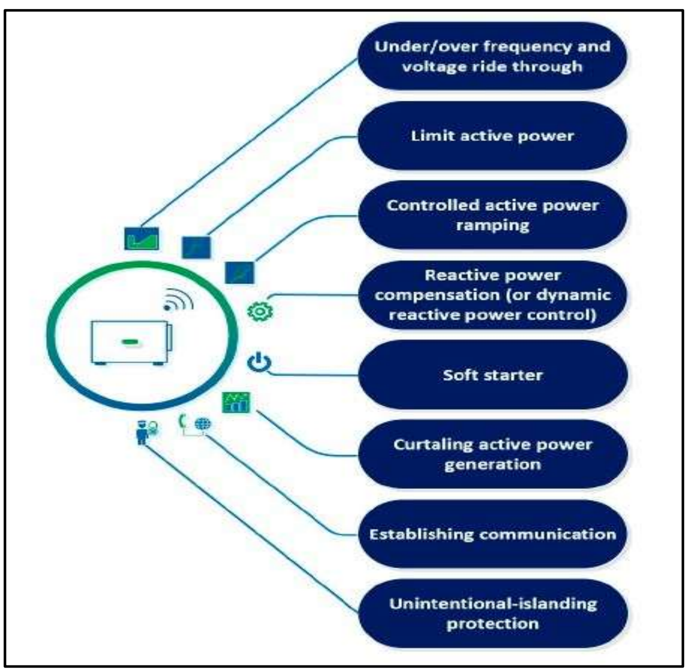


Figure C.1.2

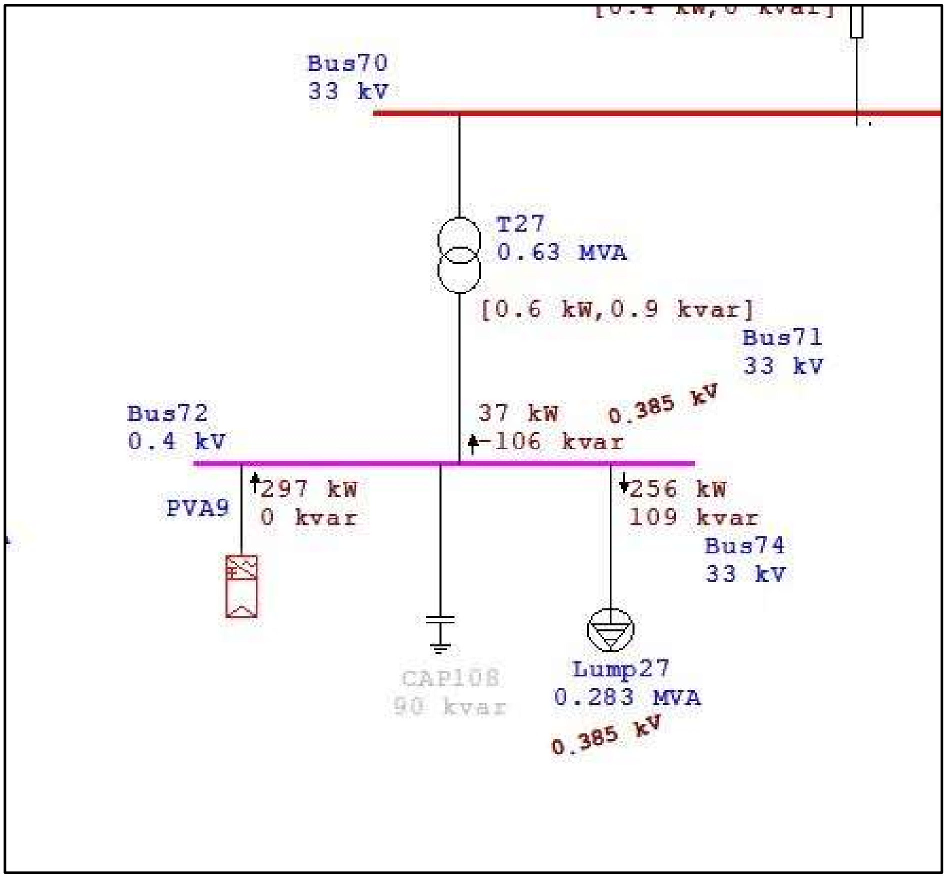
Advantages of smart inverter



C.2. Case study of PV penetration of Jenin Electrical Network:

Figure C.2.1

RPF problem at bus 72



C.3. Case study of harmonics effect on power quality due to Photovoltaic System

Figure C.3.1

Harmonic filter editor

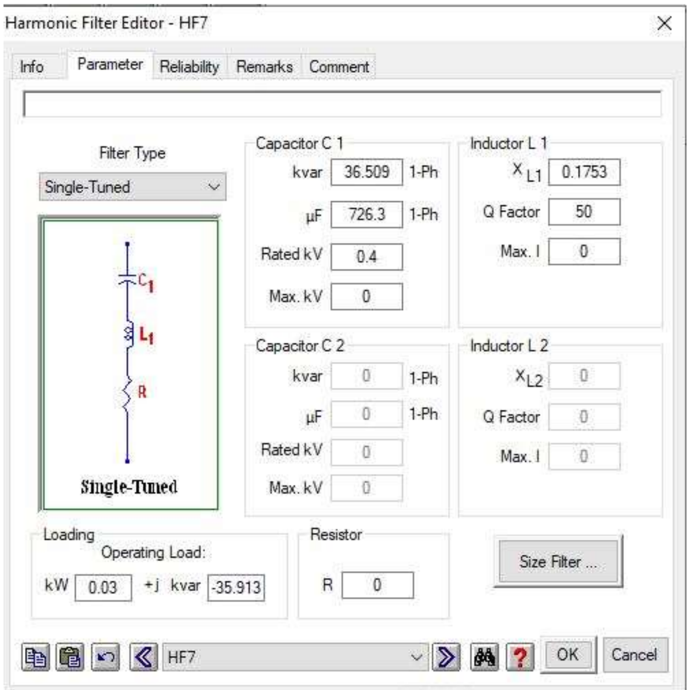
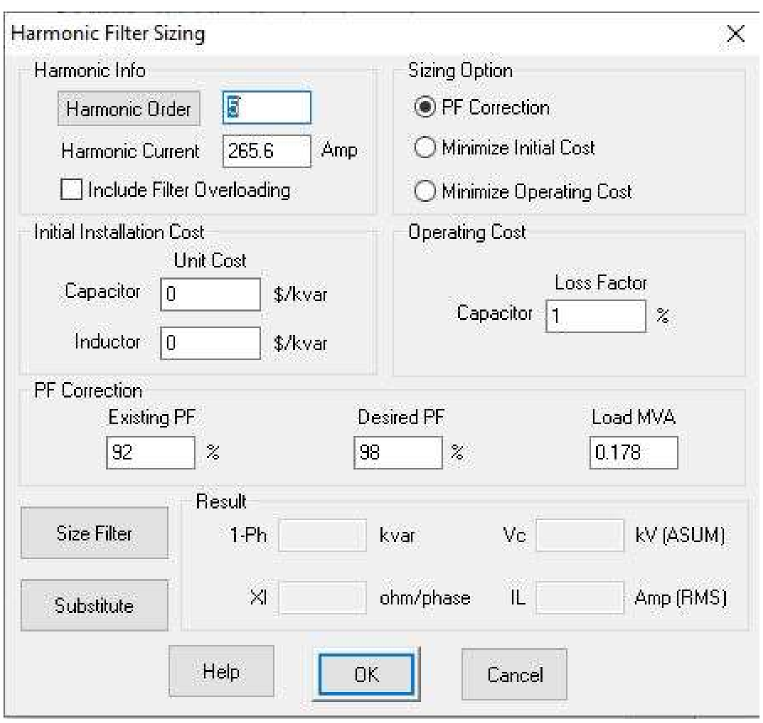


Figure C.3.2

Harmonic filter sizing



Appendix D

Details information about the Jenin Electrical Network

D.1.PV Systems Distributions

Table D.1.1

PV system distributed in Jenin

قدرة المشروع الشمسي	المدينة	جهد الربط مع الشبكة	اسم المحول المغذي
45	جنين	0.4 KV	محول مصنع التنك
999	جنين	33 KV	محول الزغيبي- داخلي
200	جنين	0.4 KV	محول جسر خروبة
8	جنين	0.4 KV	محول التنك
5	جنين	0.4 KV	خروبه المهدي
15	جنين	0.4 KV	خروبه المهدي
8	جنين	0.4 KV	خروبه المهدي
45	جنين	0.4 KV	خروبه المهدي
5	جنين	0.4 KV	خروبه المهدي
5	جنين	0.4 KV	خروبه المهدي
17	جنين	0.4 KV	خروبه المهدي
20	جنين	0.4 KV	خروبه المهدي
8	جنين	0.4 KV	خروبه المهدي
5000	جنين	33 KV	نور جنين 1 و 2 و 3
30	جنين	0.4 KV	محول البنك الاسلامي- السمودي
40	جنين	0.4 KV	محول شز حيفا(خمايسة) حي الظاهر
80	جنين	0.4 KV	الرازي
50	جنين	0.4 KV	البلدية القديمة 2
20	جنين	0.4 KV	شارع حيفا- الزهراء
5	جنين	0.4 KV	شارع حيفا- الزهراء
150	جنين	0.4 KV	محول مدارس الجنان
5	جنين	0.4 KV	جبل ابو ظهير 1
6	جنين	0.4 KV	عمارة الريماس/ الصوحة
5	جنين	0.4 KV	واد برقين- الكينا
5	جنين	0.4 KV	اسكان الجمعيات- الشماس
10	جنين	0.4 KV	عمارة الريماس/ الصوحة
10	جنين	0.4 KV	المستشفى الحكومي- المستوصف
10	جنين	0.4 KV	بوابة الشمال
5	جنين	0.4 KV	بوابة الشمال
10	جنين	0.4 KV	السينما 2
17	جنين	0.4 KV	احمد جبارين
10	جنين	0.4 KV	صباح الخير
6	جنين	0.4 KV	موال
15	جنين	0.4 KV	المسلخ البلدي
25	جنين	0.4 KV	المسلخ البلدي
200	جنين	0.4 KV	اعلاف الفقوعي

Connection point: AL- ALmanya 33Kv To ALMASLAKH 33KV

From bus	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
1	2	cable1	150m	50mm	cu							
2	3					TR1	630	Can factory	Load1	283.5	45+8	PVA1,PVA4
2	4	TL1	225m	50mm								
4	5	TL2	245m	50mm								
5	6					TR2	630	Mun.stadium	Load2	283.5		
5	7	Cable2	235m	95mm	AL							
7	8	TL3	220m	50mm								
8	9	Cable3	110m	240mm	AL							
9	10					TR3	400	Korianinst	Load3	180		
8	11					TR4	630	Medical clinic	Load4	283.5		
8	12	Cable4	80m	240mm	AL							

12	13					TR5	400	Industrial1	Load5	180	15	PVA5
12	14	TL4	165m	50mm								
14	15					TR6	630	Industrial2	Load6	283.5	25	PVA6
14	44	TL5-**Ring**	140m	50mm								
4	16	Cable5	90m	240mm	AL							
16	17					TR7	400	Abu ghali stonecutter	Load7	180		
4	18	Cable6	460m	240mm	AL							
18	19					TR8	630	Balawneh	Load8	283.5		
18	20	Cable7	400m	240mm	AL							
20	21					TR9	400	Khaled bin al waleed mosque	Load9	180		
18	22	Cable8	500m	95mm	AL							
22	23					TR10	400	Halima al sa'dya	Load10	180		

D.2. Elements Specification of Jenin Electrical Network

Table D.2.1

specification of every element used to build network using ETAP

Connection point: <u>AL- ALmanya 33Kv</u> To <u>AL- ALmanya 33Kv</u>

From bus	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
1	24	Cable9	40m	95mm	AL							
24	25	TL6	685m	50mm								
25	26	TL7	145m	50mm								
26	27	TL8	550m	50mm								
27	28	Cable10	80m	240mm	Al							
28	29	TL9	1050m	50mm								
29	30					Tr11	250	A'baestren	Load11	112.5		
26	31					Tr12	630	Faqo'e 2	Load12	283.5		
26	32					Tr13	630	Faqo'e1	Load13	283.5		

26	33	Cable11	400m	95mm	AL					
33	34	TL10	615m	50mm						
34	35					Tr14	400	Korian school	Load14	180
25	36					Tr15	250	Abu ghali	Load15	112.5
24	37	Cable12	510m	95mm	AL					
37	38					Tr16	400	Kadim	Load16	180

Connection point: AL- ALmanya 33Kv To Haddad 33Kv

	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
1	39	Cable13	200m	50mm	cu							
39	40	TL11	360m	50mm								
40	41					Tr17	630	Haddad2	Load17	283.5		
40	319					Tr135	1000	zughybe			999	PVA45
40	42	TL12	105m	50mm								
42	43					Tr18	630	Haddad1	Load18	283.5		
40	44	TL13	345m	50mm								
44	45	Cable14	315m	50mm	cu							
45	46					Tr19	630	Vegetable market	Load19	283.5		
45	47	TL14	360m	50mm								
47	48	Cable15	100m	120mm	AL							
48	49					Tr20	630	Faqo'e feed factory	Load20	283.5	200	PVA8
47	50	TL15	535m	50mm								
50	51					Tr21	250	Water wells	Load21	112.5		
45	52	Cable16	60m	120mm	AL							
52	53	TL16	680m	50mm								
53	54					Tr22	400	Slaughterhouse	Load22	180		
44	55	TL17	85m	50mm								
55	56					Tr23	630	Dynamo meter	Load23	283.5		
55	57	TL18	60m	95mm								

57	58					Tr24	400	No'manjabareen	Load24	180		
57	59	TL19	310m	95mm								
59	60	Cable17	80m	95mm	Cu							
60	61	Cable8	45m	50mm	Cu							
61	62					Tr25	630	Sinan complex	Load25	283.5		
60	63	TL20	30m	95mm								
63	64	Cable19	30m	95mm								
64	65	Cable20	30m	95mm								
65	66	TL21	175m	75mm								
66	67	TL22	600m	70mm								
67	68					Tr26	250	vianna	Load26	112.5		
67	69	TL23	350m	70mm								
69	70	TL24	110m	70mm								
70	71	TL25	125m	70mm								
70	72					Tr27	630	Kharobeh bridge	Load27	283.5	200	PVA9
71	73	TL26	470m	70mm								
71	74	Cable21	70m	240mm	AL							
74	75					Tr28	250	Abu farahanasreh street	Load28	112.5		
73	76					Tr29	630	Alhithnawi police	Load29	283.5		
73	77	TL27	585m	95mm								
77	78					Tr30	400	Kharobeh al mahdi	Load30	180	5+15+8+45+5+5+17+20+8	PVA10,11,12,13,14,15,16,17,18,19
77	79	TL28	686m	95mm								

79	80					Tr31	250	Kharobeharraneh road	Load31	112.5		
73	81	TL29	337m	150mm								
81	82					Tr32	630	Sabah al khair	Load32	283.5	10	PVA20
81	83	TL30	566m	150mm								
83	84					Tr33	250	Mawaal	Load33	112.5	6	PVA21
69	85	TL31	180m	95mm								
85	86					Tr34	250	Al sayeh al arz	Load34	112.5		
66	87	TL32	25m	95mm								
87	88	Cable22	90m	240mm								
88	89					Tr35	250	Ma'mon Al Sa'd	Load35	112.5		
64	90	Cable23	30m	95mm	cu							
90	91	TL33	160m	50mm								
91	92					Tr36	400	Jaradat	Load36	180		
91	93	Cable24	550m	95mm	AL							
93	94					Tr37	400	Jenin health directorate	Load37	180		
94												
93	95	Cable25	215m	120mm	AL							
95	96					Tr38	250	Abdul hadi&jabareen	Load38	112.5	17	PVA22
95	97	Cable26	190m	120mm	AL							
97	98					Tr39	250	Abu Hazeem	Load39	112.5		
64	126	Cable27-**Ring**	60m	95mm	AL							
40	99	TL34	55m	50mm								

99	100				Tr40	400	Abu al abed bricks factory	Load40	180
99	101	TL35	50m	50mm					
101	102	TL36	125m	50mm					
102	103				Tr41	630	Abu AL sba'a	Load41	283.5
101	104	TL37	120m	50mm					
104	105				Tr42	630	AL ghoul	Load42	283.5

Connection point: AL- ALmanya 33Kv To Ayash 33Kv

From bus	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
1	106	Cable28	1600m	120mm	Cu							
106	107					TR43	400	Ryad AL daher	Load43	180		
107												
106	108	Cable29	150m	120mm	Cu							
108	109	Cable30	200m	95mm	AL							
109	110					Tr44	1000	Western viliges complex	Load44	450		
110												
109	111	Cable31	180m	95mm	AL							
111	112					Tr45	630	Al sa'ed building	Load45	283.5		
112												
111	113	Cable32	130m	95mm	AL							
113	114					Tr46	630	Aboushi	Load46	283.5		
109	115	Cable33	250m	95mm	AL							
115	116					Tr47	1000	AL nafa'a 1	Load47	450		
115	117	Cable34	160m	95mm	AL							
117	118					Tr48	630	AL nafa'a 2	Load48	283.5		
117	119	Cable35	40m	95mm	Cu							
119	120					Tr49	400	AL sa'sd&Khalaf	Load49	180		
108	121	Cable36	360m	95mm	AL							
121	122					Tr50	630	Palestinian housing	Load50	283.5		

121	123	Cable37	200m	95mm	AL							
123	124					Tr51	400	AL Lahlouh	Load51	112.5		
123	125	TL38	60m	95mm								
125	126	Cable38	400m	95mm	AL							
126	127					Tr52	400	AL hirbawi	Load52	180		
126	128	TL39	230m	50mm								
125	129	TL40	383m	50mm								
129	130	TL41	67m	50mm								
130	131					Tr53	630	Water treatment old	Load53	283.5		
130	132	TL42	277m	50mm								
132	133	Cable39	100m	240mm	AL							
133	134					Tr54	630	AL Jinan school	Load54	283.5	150	PVA23
129	135	Cable40	100m	50mm	Cu							
135	136					Tr55	1500	Water treatment	Load55	675		
125	137					Tr56	630	AL Maslamani	Load56	283.5		
123	270	TL ring 43	70m	95mm								
108	243	Cable41-**ring**	45m	95mm	AL							

Connection point: AL- ALmanya 33Kv To Sinan 33Kv

From bus	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
1	138	Cable42	1050m	120mm	cu							
138	139	Cable 43	190m	95mm	cu							
139	140	Cable 44	170m	95mm	cu							
140	141	Cable 45	150m	95mm	cu							
141	142					Tr57	250	Ragheb AL Nader	Load57	112.5		
140	143					Tr58	630	Chamber of commerce	Load58	283.5		
139	144	Cable 46	215m	95mm	AL							
144	145					Tr59	630	Khanfar	Load59	283.5		
145												
138	146	Cable 47	200m	120mm	cu							

146	147					Tr60	630	Wad ez al deen al byader	Load60	283.5		
146	148	Cable 48	660m	50mm	cu							
148	149					Tr61	250	Wad ez al deen 2	Load61	112.5		
146	150	Cable 49	340m	95mm	cu							
150	151					Tr62	630	Al marah1	Load62	283.5		
150	152	Cable 50	190m	95mm	Cu							
152	153					Tr63	630	AL Razi	Load63	283.5	80	PVA24
152	154	Cable 51	450m	120mm	cu							
154	155	Cable 52	300m	120mm	Cu							
155	156	TL44	400m	50mm								
156	157	TL45	560m	50mm								
157	158					Tr64	400	Al marah2	Load64	180		

156	159					Tr65	400	Malasian school	Load65	180
156	160	TL46	180m	50mm						
160	161					Tr66	630	Al swetat1	Load66	283.5
160	162	TL47	800m	50mm						
162	163					Tr67	400	Al swetat2	Load67	180
162	164	Cable 53	150m	120mm	Cu					
164	165	TL48	300m	50mm						
165	166	TL49	715m	50mm						
166	167					Tr68	160	Bala'ma water pump	Load68	72
165	168	TL50	345m	50mm						
168	169	Cable54	150m	95mm	AL					
169	170					Tr69	100	AL Jinan	Load69	45
168	171	TL51	150m	50mm						

171	172	TL52	455m	50mm						
172	173					Tr70	250	Teachers housing	Load70	112.5
173										
171	174	TL53	365m	50mm						
174	175					Tr71	400	Al worood housing	Load71	180
154	176					Tr72	630	Firefighting department	Load72	283.5
154	177	Cable 55	175m	95mm						
177	178	Cable 56	540m	95mm	AL					
178	179					Tr73	400	Al sekeh Nablus street	Load73	180
178	180	Cable 57	770m	95mm	AL					
180	181	Cable 58	1025m	95mm	Al					
181	182					TR74	160	Nablus street/plane	Load74	72

180	181	Cable 59	60m	95mm	cu					
183	184					TR75	400	AL Jamal	Load75	180
180	185	Cable 60	60m	95mm	cu					
185	186	Cable 61	220m	95mm	AL					
186	187					Tr76	630	Al ashqar	Load76	283.5
185	188	Cable 62	160m	95mm	AL					
188	189	TL54	120m	50mm						
189	190	Cable 63	190m	95mm	AL					
190	191	TL55	265m	50mm						
191	192					Tr77	160	Dahyet al hanoon	Load77	72
191	193	TL56	785m	50mm						
193	194					Tr78	400	Al jinan2	Load78	180
180	195	Cable 64	490m	95mm	AL					
195	196	TL57	467m	50mm						

195	197	TL58	430m	50mm						
197	198					Tr79	250	Al jabryat 1	Load79	112.5
196	199					Tr80	630	Aljabryat 2	Load80	283.5
196	200	TL59	715m	95mm						
200	201	TL60	170m	95mm						
201	202	Cable 65	265m	150mm	AL					
202	203					Tr81	400	Al ghubaz	Load81	180
200	204					Tr82	400	Abraj	Load82	180
196	205	TL61	590m	50mm						
205	206					Tr83	630	Abu dheer 2	Load83	283.5
205	207	Cable 66	460m	240mm	AL					
207	208					Tr84	250	Sae'edmare'i	Load84	112.5
177	209	TL62	175m	95mm						
209	210	TL63	115m	50mm						

210	211					Tr85	630	Abu dhaier1	Load85	162	5	PVA25
209	212	TL64	520m	95mm								
212	213	TL65	130m	50mm								
213	214	Cable 67	300m	120mm	AL							
214	215					TR86	400	Remas building	Load86	180	6	PVA26
213	216					Tr87	630	Khalet al soha	Load87	283.5		
212	217	TL66	140m	95mm								
217	218					Tr88	630	Hourse round about	Load88	283.5		
217	219	Cable 68	180m	95mm	AL							
219	220					Tr89	630	Al mostawsaf	Load89	283.5	10	PVA27
219	221	Cable 69	320m	95mm	AL							
221	288	TL67-**ring**	130m	95mm								
217	222	Cable 70	70m	50mm	cu							

222	223					Tr90	630	Gov.hospital1	Load90	283.5		
222	224					Tr91	630	Gov.hospital2	Load91	283.5		
219	225					Tr92	630	Cinema1	Load92	283.5		
219	226					Tr93	630	Cinema2	Load93	283.5	10	PVA28
219	227	Cable 71	50m	240mm	AL							
227	228					Tr94	250	Haddad building	Load94	112.5		
227	229	Cable 72	40m	240mm	AL							
229	230					TR95	630	Abu mwies	Load95	283.5		
229	231	Cable 73	40m	240mm	AL							
231	232					TR96	630	Al sa'adi1	Load96	283.5		
231	233					Tr97	630	AL sa'adi2	Load97	283.5		
219	234	Cable 74	200m	95mm	cu							
234	235					TR98	630	Galyoon1	Load98	283.5		
234	236					Tr99	400	Galyoon2	Load99	180		

234	237	Cable 75	160m	95mm	cu							
237	238					TR100	630	Abu baker1	Load100	283.5		
237	239					Tr101	630	Abu baker2	Load101	283.5		
237	240	Cable 76	320m	95mm	Cu							
240	241					TR102	630	Old.mun1	Load102	283.5		
240	242					Tr103	630	Old.mun2	Load103	283.5	50	PVA29
237	243	Cable 77	400m	95mm	cu							
243	244					Tr104	630	Ayash round about	Load104	283.5		
219	245	Cable 78	150m	95mm	AL							
245	246					Tr105	630	POB	Load105	283.5		
245	247	Cable 79	80m	95mm	AL							
247	248					Tr106	630	Abu al sba'a	Load106	283.5		
247	249	Cable 80	400m	95mm	AL							
249	250					Tr107	400	sammodi	Load107	180	30	PVA30

249	251	Cable 81	40m	95mm	AL					
251	252	Cable 82	100m	95mm	AL					
252	253					Tr108	400	Governorate out door	Load108	180
252	254	TL68	22m	50mm						
254	255					Tr109	630	Court house	Load109	283.5
254	256	TL69	50m	50mm						
256	257	Cable 83	20m	95mm	cu					
257	258	Cable 84	20m	95mm	cu					
258	259					Tr110	630	m.o.ijenin	Load110	283.5
257	260	Cable 85	170m	95mm	AL					
260	261	Cable 86	20m	240mm	AL					
261	262					Tr111	630	AL Ameer	Load111	283.5
261	263	Cable 87	20m	240mm	AL					
263	264	Cable 88	70m	95mm	AL					

264	265					Tr112	400	Abu AL Rub	Load112	180
264	266	Cable 89	190m	95mm	AL					
266	267					Tr113	630	Special police force	Load113	283.5
266	268	Cable 90	200m	240mm	AL					
268	269					Tr114	1000	Ma'ali	Load114	450
268	270	Cable 91	150m	240mm	AL					
270	271	Cable 92	120m	95mm	AL					
271	272					Tr115	400	Anan al sa'ed	Load115	180
271	284	TL70-**ring**	175m	95mm						
249	273	Cable 93	70m	240mm	AL					
273	274					Tr116	250	KFC	Load116	112.5

Connection point: AL- Al jalameh 33kv

From bus	To bus	TL/Cable#	Length	Diameter	AL/Cu	Tr#	(KVA)	Region name	Load#	Value(KW)	PV (KW)	Name of PV
309	275	Cable 94	50m	240mm	AL							
275	276	TL71	3910m	150mm								
276	277	Cable 95	695m	240mm	AL							
277	278	TL72	230m	95mm								
278	279	Cable 96	780m	240mm	AL							
279	280					Tr117	400	North gates	Load117	180	10+5	PVA31,PVA32
278	281					Tr118	630	AL Daher	Load118	283.5		
278	282	TL73	112m	95mm								
282	283					Tr119	400	Haifa street	Load119	180	40	PVA33
282	284	TL74	85m	95mm								

284	285	TL75	190m	95mm								
285	286					Tr120	630	Al zahra'a	Load120	283.5	20+5	PVA34,PVA35
285	287	TL76	295m	95mm								
287	288	Cable 97	70m	95mm	AL							
288	289	Cable 98	150m	95mm	AL							
289	290					Tr121	630	Camp1	Load121	283.5		
289	291					Tr122	250	Camp2	Load122	112.5		
289	292	Cable 99	400m	95mm	AL							
292	293					Tr123	630	Joraet al dahab	Load123	283.5		
292	294	Cable 100	260m	50mm	cu							
294	295					Tr124	400	Abdullah azzam	Load124	180		
288	296	Cable 101	470m	240mm	AL							
296	297					Tr125	630	Unrwa school	Load125	283.5		
296	298	TL77	160m	95mm								

298	299	Cable 102	480m	95mm	AL							
299	300					Tr126	400	Al shammas housing	Load126	180		
298	301	TL78	86m	95mm								
301	302					Tr127	630	Wad burqin kina	Load127	283.5	5	PVA36
301	303	TL79	375m	95mm								
303	304					Tr128	400	Al hadaf al bado	Load128	180		
303	305	TL80	410m	95mm								
305	306	TL81	205m	95mm								
305	314					Tr130	1500	Noor Jenin1			1500	PVA40
305	315					Tr131	1500	Noor Jenin2			1500	PVA42
305	316					Tr132	2000	Noor Jenin3			2000	PVA43
306	307	Cable 103	210m	50mm	cu							
307	308					Tr129	250	Al hadaf housing/al shammas	Load129	112.5	5	PVA38

جامعة النجاح الوطنية

كليـــة الدراسات العليا

تحليل وتحسين شبكة توزيع كهرباء الشمالNEDCO لمحافظة جنين وتوضيح تأثير تغلغل الطاقة الشمسية الكهروضوئية

إعداد

هيثم علاونـة

إشراف

د. ماهر خماش

قدمت هذه الرسالة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2022

تحليل وتحسين شبكة توزيع كهرباء الشمال NEDCO لمحافظة جنين وتوضيح تأثير تغلغل الطاقة الشمسية الكهروضوئية

إعداد

هيثم علاونة

إشراف

د. ماهر خماش

الملخص

تقدم هذه الأطروحة مجموعة من الحلول المقترحة لحل مجموعة من المشاكل الموجودة في شبكة كهرباء الشمال منطقة جنين، وقد تم اختيار هذه الحلول كأفضل حلول من حيث التطبيق العملي لكل من هذه الحلول. وتجدر الإشارة إلى أن شبكة كهرباء الشمال منطقة جنين يوجد بها عدة نقاط ربط بينها وبين والشبكة القطرية. وخلال هذه الأطروحة سيتم مناقشة كل هذه النقاط وتأثيرها على شبكة كهرباء الشمال منطقة جنين.

الأهداف المراد تحقيقها في هذه الرسالة، تحسين معايير الطاقة لشبكة كهرباء الشمال منطقة جنين من خلال اضافة مصادر طاقة شمسية جديدة لبعض الأحمال واضافة مكثفات لبعض الاحمال الاخرى كل حسب معطيات الشبكة لتحسين معامل القدرة وتقليل الفاقد في الشبكة.

كما سيتم اضافة محولات طاقة جديدة لبعض الاحمال لزيادة الاستقرار في استهلاك الكهرباء وتخفيف الضغط على المحولات البعيدة عن هذه الاحمال وبالتالي تقليل الفاقد أيضا.

كما سيتم توضيح الاثر السلبي لزيادة استخدام الطاقة الشمسية وتغلغلها في الشبكة من الارتفاع في الفولتيات وأثرها على الاجهزة وتأثيرها على معامل القدرة السلبي وغيرها من التأثيرات السلبية. كما سيتم توضيح الية معالجة هذا الاثر والوقاية منه من خلال طرق حديثة وذكية مثل استخدام العواكس الذكية وغيرها لضبط توليد الطاقة الى الشبكة حسب متطلبات الشبكة.

كلمات مفتاحية: أثر تغلغل الطاقة الشمسية، تأثير التوافقيات، تحسين جود الطاقة، تحسين جودة الجهد، تحسين شبكة كهرباء الشمال.