# *The Libyan Academy*




***School of Applied Sciences and Engineering***

***Department of Electrical and Computer Engineering***

# *Study And Design of A Power Grid Connected With PV Power Plant in BIN-WALED City*

***A Thesis Submitted To The Department of Electrical And Computer Engineering in Partial Fulfillment of The Requirements Master of Science***

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَحِيمِ

قُلْ إِنَّ صَلاَتِي وَنُسُكِي وَمَحْيَايْ وَمَمَاتِيَ لِلهِ رَبِّ اِلْعَالَمِينَ ﴿164﴾ لاَشَرِيكَ لَهُ وَبِذَلِكَ اُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ ﴿165﴾

# سورة الأنعام

## ***شكر وإهداء***

بسم الله أحمده تعالى وأشكره على توفيقه وبعد، أود أن أعبر عن خالص تقديري واحترامي إلى مشرفي ومرشدي الدكتور / ***عمر جمعة مريحيل***. على ما قدمه لي من توجيهات ومعلومات وملاحظات حول محتوى الرسالة من مادة علمية وطريقة للبحث والكتابة فيه. **كم اهدي العمل إلى:**

من كلله الله بالهيبة والوقار. إلى من علمني العطاء بدون انتظار. إلى من أحمل أسمه بكل افتخار. أرجوا من الله أن يمد في عمرك لترى ثماراً قد حان قطافها بعد طول انتظار وستبقى كلماتك نجوم أهتدي بها اليوم وفي الغد وإلى الأبد

***((والدي العزيز))***

إلى ملاكي في الحياة. إلى معنى الحب والحنان والتفاني. إلى بسمة الحياة وسر الوجود
إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى إنسان على قلبي.

***أطال الله عمرها***

***((والدتي العزيزة))***

إلي من تمنيت ان أكون لها شاعرا أو كاتبا ليس لشيء وانما لكي أعبر عن حبي لك بطريقتي وأُخرج لكي كلمات تليق بك لكن عجز لساني عن التفوه بها امام طيبتك وحبك الدي سكن في اعماق قلبي.

***((زوجتي الغالية))***

إلى من بوجودهم أكتسب قوة ومحبة لا حدود لها

***((أخوتي الأعزاء))***

إلى من تحلوا بالإخاء وتميزوا بالوفاء والعطاء، إلى ينابيع الصدق الصافي إلى من معهم سعدت، وبرفقتهم في دروب الحياة الحلوة والحزينة سرت، إلى من كانوا معي على طريق النجاح والخير.

***((أصدقائي))***

***ملخص الرسالة***

إن اختراق توليد التوزيع للشبكات الكهربائية هو التحدي الجديد لأنظمة الطاقة الكهربائية التقليدية. و حقن القدرة الكهربائية من التوليد التوزيع سوف يغيير في تحليل و حساب تدفق الأحمال و التشغيل و التحكم بالشبكات التوزيع الكهربائية مما يترتب عليه من التحسين الإقتصادي .

وتتمثل أهداف هذه الرسالة في بحث تصميم و دراسة ربط محطات كهروضوئية في الشبكة الكهربائية الليبية وتحديدا في حلقة بني وليد.

بالإضافة الي ذلك دراسة التأتيرات الناتجة عن ربط هذه المحطات علي حلقة بني وليد الكهربائية من حيت تدفق الحمل ، مستوي دائرة القصر و التوافقيات عند نقطة الربط .

وكذلك، تم عرض الفوائد الاقتصادية والبيئية الناتجة من إنشاء محطة توليد طاقة شمسية في مدينة بني وليد.

ان الدراسة التى اجريت في هذه الرسالة على حلقة فعلية من الشبكة الليبية التي تتمثل في نظام توزيع جهد 66 ك.ف في حالة الحد القصى من التحميل وتتكون من مجموعة محطات تحويل القدرة متصلة ببعضها عن طريق كوابل أرضية وخطوط هوائية .

تم تنفيذ المحاكاة تحت ظروف الحمل الكامل باستخدام برنامج PVSOL & NEPLAN

وقد تبين من النتائج ان انشاء محطة طاقة شمسية في مدينة بني وليد لديها فوائد ملحوظة في كل نقاط الدراسة التي ذكرت اعلاه .

***Abstract***

Penetration of distributed generation (DG) is a new challenge for traditional electric power systems. Power injections from DGs change network power flows, modifying energy losses and voltage profile of the system. Proper locations of DGs in power systems are important to obtain the maximum potential benefits.

The main objectives of this thesis are to Implement a large – scale (photovoltaic) PV power plant in Libyan network exactly at BIN-WALID city, as a chosen location.

In addition to study the impacts of these large – scale PV system on bin-walid electrical network loop, in which the load flow analysis, and short circuit level were analyzed with the penetration of photovoltaic (PV) power plant as well as, the total harmonic distortion (THD) at PCC will be investigated.

Also, the economic and environmental benefits from building a solar power plant were presented.

System study is a real part of the Unified Libyan Grid represented by distribution system of 66 KV it consists a group of substations, and feeder circuits considering, the maximum load connected to system buss.

The simulation is performed under full load condition using NEPLAN & PVSOL software

The simulation results show that, the presents of PV power plant in BIN-WALID has a notable benefits, to the city electrical network that increase the system reliability and enhance its operation.

# Contents


**ملخص الرسالة** ..... II

**Abstract** ..... III

**List of abbreviation** ..... XI

**CHAPTER I Introduction** ..... 1

1.1 Background ..... 2

1.2 Motivation Of The Study ..... 3

1.3 Objective Of The Project ..... 3

1.4 Problem Statement ..... 4

1.5 Project Outlines ..... 4

**CHAPTER II PV Systems** ..... 5

2.1 Introduction ..... 6

2.2 Major Solar System Components ..... 7

2.3 Solar System Parameters Definitions Abbreviations and Relations ..... 9

2.4 Photovoltaic Power System Off Grid ..... 12

2.5 Grid-Connected Photovoltaic Power System ..... 13

2.6 DC -AC Power Inverter ..... 15

2.6.1 Size of Inverter ..... 15

**CHAPTER III Site Survey & Make the Design Process** ..... 19

3.1 Introduction ..... 20

3.2 Location Determination ..... 20

3.3 City Temperature Calculation ..... 21

3.4 Solar Radiation Calculation ..... 22

3.5 Sun Path Position: ..... 23

3.6 Determine The Appropriate PV Module ..... 24

3.6.1 Module1 ..... 25

3.6.2 Module2 ..... 26

3.7 The Panel Design ..... 27

3.7.1 Using Module 1 ..... 27

3.7.2 Using Module 2 ..... 31

3.8 The Result of All Design ..... 34

3.9 Losses Calculation ..... 37
**CHAPTER IV Load Flow & Short Circuit** ..... 50
4.1 Introduction ..... 51
4.2 Network Description ..... 51
4.3 Studies Cases ..... 54
4.3.1 Scenario 1:Normal Network ..... 55
4.3.2 Scenario 2:PV Power Plant Connected To 66KV Substation ..... 56
4.3.3 Scenario 3:Connect PV (1,2,4) Power Station To The Network Bin-Walid 66 KV & Connect PV3 To Bus Bar Bin-Walid 220 KV ..... 58
4.3.4 Scenario 4: Connecting PVS (1,2,3,4) To 220 KV Meddle Region ..... 61
4.3.5 Scenario 5:Reduce 163 MW From Koms Power Station And Add 163 MW PV ..... 66
**CHAPTER V Harmonics Analysis** ..... 70
5.1 Definitions ..... 71
5.2 Total Harmonic Distortion (THD) ..... 71
5.2.1 Total Harmonic Distortion of Voltage (THDv) ..... 72
5.2.2 Total Harmonic Distortion of Current (THDi) ..... 72
5.3 Point of Common Coupling (or Point of Common Connection) ..... 73
5.4 Standard G5/4 ..... 73
5.5 Harmonic Analysis ..... 76
5.5.1 Scenario 1 : With PVS Connected To 66KV ..... 76
5.5.2 Scenario 2:PVS(1,2,4) Connected To 66 KV And PV3 Connected To 220 KV ..... 86
4.2.1 Comparison Between The Two Scenarios In Term Of THDv Values ..... 95
**CHAPTER VI Economic & Environmental Study** ..... 96
6.1 Introduction ..... 97
6.2 Input Data ..... 97
6.3 Energy & Fuel Consumption ..... 98
6.4 Analysis & Dictation ..... 98
**Conclusion** ..... 102
**Recommendations** ..... 104
**References** ..... 105
**APPENDICES** ..... 107

# Figure

Fig2. 1: Solar Cells ..... 7
Fig2. 2: Solar Array ..... 7
Fig2. 3: Inverter ..... 8
Fig2. 4: Charge Controller ..... 8
Fig2. 5: Batteries ..... 8
Fig2. 6: Wiring ..... 9
Fig2. 7: Relationship between Voltage, Current and Temperature ..... 11
Fig2. 8: Relationship Between Voltage, Current and Irradiance ..... 11
Fig2. 9: Photovoltaic Power System Off Grid ..... 12
Fig2. 10: Grid-Connected Photovoltaic Power System ..... 13
Fig2. 11: Grid-Connected Photovoltaic Power System ..... 16
Fig2. 12: String Inverters ..... 16
Fig2. 13: Micro Inverter ..... 17
Fig2. 14: Size Inverter ..... 18

Fig3. 1: The Proposed Sites for the Design and Study ..... 21
Fig3. 2: The Average Maximum Temperature ..... 22
Fig3. 3: Solar Radiation Calculated Using “Ret Screen International “ ..... 22
Fig3. 4: Writing Solar Radiation and Temperature for Each Month ..... 23
Fig3. 5: Height of Bottom Edge ..... 28
Fig3. 6: Single Line Diagram for Module 1 in Vertical ..... 29
Fig3. 7: Single Line Diagram for Module 1 in Horizontal ..... 29
Fig3. 8: Single Line Diagram for Module 1 In (2* Horizontal) ..... 29
Fig3. 9: Module 1 in Vertical ..... 30
Fig3. 10: Module 1 in Horizontal ..... 30
Fig3. 11: Module 1 in (2*Horizontal) ..... 30
Fig3. 12: Single Line Diagram for Module 2 in Vertical ..... 32
Fig3. 13: Single Line Diagram for Module 2 in Horizontal ..... 33
Fig3. 14: Single Line Diagram for Module 2 In (2* Horizontal) ..... 33
Fig3. 15: Module 2 in Vertical ..... 33
Fig3. 16: module 2 in horizontal ..... 34
Fig3. 17: Module 2 in (2*Horizontal) ..... 34
Fig3. 18: Production Forecast for Year ..... 35
Fig3. 19: Production Forecast for Each Inverter ..... 36
Fig3. 20: Performance Ratio (BR) ..... 36
Fig3. 21: Irradiance ..... 37
Fig3. 22: Deviation from Standard Spectrum ..... 38

Fig3. 23: Orientation and Inclination of the Module Surface ..... 38
Fig3. 24: Reflection on the Module Interface ..... 39
Fig3. 25: Module-Specific Partial Shading ..... 40
Fig3. 26: Partial Load ..... 40
Fig3. 27: Temperature ..... 41
Fig3. 28: Temperature Panel Losses ..... 41
Fig3. 29: Losses in Diodes ..... 42
Fig3. 30: Mismatch (Manufacturer Information) ..... 42
fig3. 31: Mismatch (Configuration/Shading) ..... 43
Fig3. 32: Regulation on Account of the MPP Voltage Range ..... 44
Fig3. 33: MPP Matching ..... 44
Fig3. 34: Energy at the Inverter Input ..... 45
Fig3. 35: Input Voltage Deviates From Rated Voltage ..... 45
Fig3. 36: DC/AC Conversion ..... 46
Fig3. 37: Own Consumption ..... 46
Fig3. 38: Regulation of Radiation Peaks ..... 47
Fig3. 39: Total Cable Losses ..... 47

Fig5. 1: Example of Voltage/Current Waveform With Harmonics ..... 71
Fig5. 2: Example of Voltage/Current Harmonic Spectrum ..... 71
Fig5. 3: Harmonic Voltage Distortion at Bin- Walid 66kv-1st Scenario without Filter ..... 77
Fig5. 4: Harmonic Voltage Distortion at Al-Sof 66kv-1st Scenario Without Filter ..... 77
Fig5. 5: Harmonic Voltage Distortion at Al-Fuqhaa 66kv-1st Scenario Without Filter ..... 77
Fig5. 6: Harmonic Voltage Distortion at Alantena 66kv-1st Scenario without Filter ..... 78
Fig5. 7: Harmonic Voltage Distortion at Pv1- 23.2944kv -1st Scenario without Filter ..... 78
Fig5. 8: Harmonic Voltage Distortion at Pv2- 6.75 KV -1st Scenario without Filter ..... 78
Fig5. 9: Harmonic Voltage Distortion at Pv3- 5.064 KV -1st Scenario Without Filter ..... 79
Fig5. 10: harmonic voltage distortion at pv4- 135.04 kV -1st scenario without filter ..... 79
Fig5. 11: Harmonic Voltage Distortion At Bin- Walid 66kV-1st Scenario With Filter ..... 81
Fig5. 12: Data of Filter on Bus Bar Bin- Walid 66 KV -1st Scenario With Filter ..... 81
Fig5. 13: Harmonic Voltage Distortion at Al-Sof 66kv-1st Scenario with Filter ..... 82
Fig5. 14: Data of Filter on Bus Bar Alsof 66 KV -1st Scenario With Filter ..... 82
Fig5. 15: Harmonic Voltage Distortion at Al-Fuqhaa 66kv-1st Scenario with Filter ..... 83
Fig5. 16: Data of Filter on Bus Bar Al-Fuqhaa 66 KV-1st Scenario with Filter ..... 83
Fig5. 17: Harmonic Voltage Distortion at Alantena 66kv-1st Scenario with Filter ..... 84
Fig5. 18: Data of Filter on Bus Bar Alantena 66 KV -1st Scenario with Filter ..... 84
Fig5. 19: Harmonic Voltage Distortion at PV1- 23.2944KV -1st Scenario with Filter ..... 85
Fig5. 20: Harmonic Voltage Distortion at Pv2- 6.75 KV -1st Scenario with Filter ..... 85
Fig5. 21: Harmonic Voltage Distortion at Pv3- 5.064 KV -1st Scenario with Filter ..... 85
Fig5. 22: Harmonic Voltage Distortion at Pv4- 135.04 KV -1st Scenario with Filter ..... 86
Fig5. 23: Harmonic Voltage Distortion at Bin- Walid 66kv- Scenario 2 without Filter ..... 87

Fig5. 24: Harmonic Voltage Distortion at Al-Sof 66kv- Scenario 2 without Filter ..... 87
Fig5. 25: Harmonic Voltage Distortion at Al-Fuqhaa 66kv- Scenario 2 without Filter ..... 87
Fig5. 26: Harmonic Voltage Distortion at Alantena 66kv- Scenario 2 without Filter ..... 88
Fig5. 27: Harmonic Voltage Distortion at Pv1- 23.2944kv- Scenario 2 without Filter ..... 88
Fig5. 28: Harmonic Voltage Distortion at Pv2- 6.75 KV- Scenario 2 without Filter ..... 88
Fig5. 29: Harmonic Voltage Distortion at Pv3- 5.064 KV – Scenario 2 without Filter ..... 89
Fig5. 30: Harmonic Voltage Distortion at Pv4- 135.04 KV – Scenario 2 without Filter. ..... 89
Fig5. 31: Harmonic Voltage Distortion at Bin- Walid 66kv- Scenario 2 with Filter ..... 90
Fig5. 32: Data of Filter on Bus Bar Bin- Walid 66 KV ..... 90
Fig5. 33: Harmonic Voltage Distortion at Al-Sof 66kv- Scenario 2 with Filter ..... 91
Fig5. 34: Data of Filter on Bus Bar Alsof 66 KV ..... 91
Fig5. 35: Harmonic Voltage Distortion at Al-Fuqhaa 66kv- Scenario 2 with Filter ..... 92
Fig5. 36: Data of Filter on Bus Bar Alfogha 66 KV ..... 92
Fig5. 37: Harmonic Voltage Distortion at Alantena 66kv- Scenario 2 with Filter ..... 93
Fig5. 38: Data of Filter on Bus Bar Alantena 66 KV ..... 93
Fig5. 39: Harmonic Voltage Distortion at Pv1 66kv- Scenario 2 with Filter ..... 94
Fig5. 40: Harmonic Voltage Distortion at Pv2 66kv- Scenario 2 with Filter ..... 94
Fig5. 41: Harmonic Voltage Distortion at Pv3 66kv- Scenario 2 with Filter ..... 94
Fig5. 42: Harmonic Voltage Distortion at Pv4- 135.04 KV – Scenario 2 with Filter ..... 95
Fig5. 43: Comparison between the Two Scenarios in Term of THDv Values ..... 95

# Tables

Table3. 1: The Proposed Sites for the Design and Study ..... 20
Table3. 2: The Maximum Temperature $C^0$ ..... 21
Table3. 3: Azimuth and Elevation for Location ..... 23
Table3. 4: Sun Position Calculations ..... 24
Table3. 5: Data Sheet for Clearline PV 30/500 ..... 25
Table3. 6: Data Sheet for Trina Solar TSM-PA14 ..... 26
Table3. 7: Data for Design Module 1 ..... 27
Table3. 8: Data for Inverter Module 1 ..... 28
Table3. 9: Data for Design Module 2 ..... 31
Table3. 10: Data for Inverter Module 2 ..... 32
Table3. 11: the result of all design ..... 34
Table3. 12: Production Account the Total Area Of Sites ..... 49

Table4. 1: Loading Rate for Each Transformer 66KV ..... 51
Table4. 2: Data of the Cable Network Used in Bin-Walid 220 KV System ..... 52
Table4. 3: Bus Bar Data and the Percentage of Load for Bin-Walid 66KV ..... 53
Table4. 4: Bus Bar Data and the Percentage of Load for Bin-Walid 11KV ..... 53
Table4. 5: Loads During the Year 2015 ..... 54
Table4. 6: Result Load Flow for Network Bin-Walid 220kv in 2015 ..... 55
Table4. 7: Short Circuit Current Value in Network Bin-Walid 66 KV At 2015 ..... 55
Table4. 8: Bus Bar Data and the Percentage of Load For Bin-Walid 66kv For The Scenario 2 ..... 56
Table4. 9: Result for (N) When Connect PV (1, 2, 3, 4) To Network Bin-Walid 66 KV ..... 57
Table4. 10: Result For (N-1) When Connect PV (1, 2, 3, 4) To Network Bin-Walid 66 KV ..... 57
Table4. 11: Short Circuit Current Value66 KV in Network Bin-Walid When Connect PV (1, 2, 3, 4) To Busses Bin-Walid 66 KV ..... 58
Table4. 12: Bus Bar Data and the Percentage of Load for Bin-Walid 66kv For the Scenario 3 ..... 59
Table4. 13: Result for (N) From Scenario 3 ..... 59
Table4. 14: Result for (N-1) From Scenario 3 ..... 60
Table4. 15: Short Circuit Current Value 66kv in Network Bin-Walid from Scenario 3 ..... 60
Table4. 16: Substation Name 220 KV in Meddle Region ..... 61
Table4. 17: Unit in Power Station ..... 62
Table4. 18: Conductor in Meddle Region ..... 62
Table4. 19: Summary for Electrical Power Network of 220kv to Meddle Region for the Year 2015(N) ..... 63
Table4. 20: Summary for Electrical Power Network of 220 KV to the Meddle Region for (N-1) ..... 63
Table4. 21: Bus Bar Data and the Percentage of Load for 220 KV to the Meddle Region ..... 64
Table4. 22: Short Circuit in Network of 220 KV to the Meddle Region for the Year 2015 ..... 64

Table4. 23: Bus Bar Data and the Percentage of Load for 220 KV to the Meddle Region..... 66
Table4. 24: Summary When Reduce 163 MW from Koms Power Station and Add 163 Mw PV (N) ..... 67
Table4. 25: Summary When Reduce 163 MW from Koms Power Station and Add 163 Mw PV (N-1)..... 67
Table4. 26: Short Circuit When Reduce 163 MW from Koms Power Station and Add 163 Mw PV ..... 68

Table5. 1: THD Planning Levels ..... 74
Table5. 2::Maximum Allowable Harmonic Current For Aggregate Loads / Equipment Rated >16a Per Phase At 400v ..... 74
Table5. 3: Maximum Allowable Harmonic Current per Customer At HV In Amps RMS Per Phase ..... 75
Table5. 4: Results Of THDv in the 1st Scenario Without Filter ..... 76
Table5. 5: Results of THDv in the 1st Scenario After Filter..... 80
Table5. 6: Results Of THDv In The Second Scenario 2 Without Filter..... 86
Table5. 7: Results of THDv in the Scenario 2 With Filter..... 89

Table6. 1: Economic Feasibility Study for the Installation of Solar Power Plant Study (PV)..... 97
Table6. 2: Local And Global Fuel Prices (LD / m3) For the Year 2015..... 97
Table6. 3: The Cost of Transformers (Invertor)..... 97
Table6. 4: Other Ratios of Fuel..... 98
Table6. 5: The Amount of Energy Produced, Fuel Consumed and the Rate of Fuel Consumption by Fuel Type in 2014 ..... 98
Table6. 6: A Table Showing Analytical Data for Medium Voltage Stations and Linked to the Proposed Solar PV Stations As Well As the Savings Expected in the Fuel Bill for Fuel, Transportation and Carbon Emissions of Co2..... 99

## List of abbreviation

PV……. photovoltaic

GECOL…….…..…. general electrical company of Libya

PCC……..… point of common coupling

THDv…….……..…..... Total Harmonic Distortion of Voltage

THDi…….…… Total Harmonic Distortion of Current

MPP…….…….…….....maximum power point

Vmp ……Voltage maximum power

Voc…….……..Voltage open circuit

Isc…….…….…….. Amps short circuits

Imp……...Amps max power

IEC…….. International Electro technical Commission

# CHAPTER I
# Introduction

## 1.1 Background

Renewable energy is generally defined as energy that is collected resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat [1]. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services [2].

Based on REN21's 2014 report (renewable energy policy network for the 21st century), renewables contributed 19 percent to humans' global energy consumption and 22 percent to their generation of electricity in 2012 and 2013, respectively. This energy consumption is divided as 9% coming from traditional biomass, 4.2% as heat energy (non-biomass),3.8% hydroelectricity and 2% is electricity from wind, solar, geothermal, and biomass[3]. Worldwide investments in renewable technologies amounted to more than US$214 billion in 2013, with countries like China and the United States heavily investing in wind, hydro, solar and biofuels[4] [5] .

Renewable energy resources exist over wide geographical areas, concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits[6]. In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power[7].

## 1.2 Motivation Of The Study

The growth of the loads in the central region in specific and Libyan in general, as well as loss existing in the network because of the loads for generation centers of the most important reasons for this study.

The city of BANI WALID is selected .For this study for several reasons, including:

i. The possibility of easily obtaining information easily.
ii. The Study can be considered as a model for other similar Libyan cities.
iii. City is currently undergoing reconstruction and development.
iv. Can the work of field visits to the city when needed who knead.
v. Climate enjoyed by the city of the desert and the nature of the land open and flat.

## 1.3 Objective Of The Project

This research aims many objectives that some are imminent and others are farsighted such as:

i. Determine the possibility of feeding the city of BANI WALID using solar energy to feed the loads in that region.
ii. Taking the study of the city of BANI-WALID model for many similar Libyan cities
iii. Cover part of the loads of non-harmful to the environment sources
iv. Investigate the effect of the use of renewable energy sources on the public network
v. Know the extent improve network performance by using (Distributed Generation DG) and check of the impacts in the Libyan network and focus on periods of peaks loads.

vi. Prepping for the post-petroleum

vii. Contribute to the preservation of the environment and reduce carbon emissions produced by conventional power plants.

viii. Exploitation of renewable energy sources available in Libya to diversify its energy sources and to ensure its supply.

## 1.4 Problem Statement

Distance loads for generation stations and the growth of loads in the central region are the most important problems that make us do this study in addition to increasing emissions CO2.

## 1.5 Project Outlines

***Chapter two***: deal with PV module, specifications connected to the PV system and design guidelines with mathematical calculations

***Chapter three***: introduce the sit survey and analysis of the selected location with a study of beak load in region.

***Chapter four***: in these chapter the power system under study is simulated to investigate the impact of PV generation on PCC, load flow analysis and short circuit level.

***Chapter five*** investigates the effect of harmonic in the network which under studied.

***Chapter six***: In this chapter the economic and environmental impact, which produce an establishment of solar stations, where concerned.

# CHAPTER II
# PV Systems

## 2.1 Introduction

A photovoltaic system, also named solar PV power system, or PV system, is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS). Moreover, PV systems convert light directly into electricity and shouldn't be confused with other technologies, such as concentrated solar power or solar thermal, used for heating and cooling[8].

PV systems range from small, rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems only account for a small portion of the market[9].

Operating silently and without any moving parts or environmental emissions, PV systems have developed from being niche market applications into a mature technology used for mainstream electricity

Generation. A rooftop system recoups the invested energy for its manufacturing and installation within 0.7 to 2 years and produces about 95 percent of net clean renewable energy over a 30-year service lifetime[8, 9].

## 2.2 Major Solar System Components

The following subsections gives a brief overview of the main components of the solar systems[10]:

- **Solar Cells**

Solar cells capture the sun's energy and change it to electricity. Inside a solar panel, each cell contains silicon, an element found in sand that absorbs sunlight as shown in figure (2.1). The energy in this absorbed light produces a small electrical current. Metal grids around the solar cells direct the currents into wires that lead to the power controls.



Fig2. 1: Solar Cells

- **Solar Array**

The solar array is comprised of one or more solar PV modules (solar panels) as shown in figure (2.2) which convert sunlight into clean solar electricity. PV is the abbreviation for Photovoltaic, which means electricity from light. The solar modules need to be mounted facing the sun and avoiding shade for best results. Solar panels generate DC power



Fig2. 2: Solar Array

### ❖ Inverter

The Inverter changes the DC solar power into usable 240 Volt AC electricity which is the most common type used by most household appliances and lighting.

The inverter is a power electronic DC-AC converter module as shown in figure (2.3)



Fig2. 3: Inverter

### ❖ Charge Controller

As shown in figure (2.4), the main function of a charge controller is to prevent over charging which results in out-gassing of the batteries, as well as keeping electrical storage in the batteries from discharging to the solar modules at night.




Fig2. 4: Charge Controller

### ❖ Batteries

The batteries store the solar power generated and discharge the power as needed as shown figure (2.5). The battery bank consists of one or more solar deep-cycle type batteries. Depending on the current and voltages for certain applications the batteries are wired in series and/or parallel.

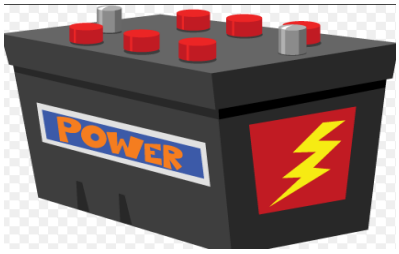


Fig2. 5: Batteries

❖ **Wiring**

Selecting the correct size and type of wire will enhance the performance and reliability of your PV system. The size of the wire must be large enough to carry the maximum current expected without undue voltage losses.

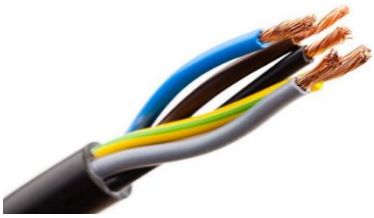

Fig2. 6: Wiring

System wires shown in figure (2.6)

## 2.3 Solar System Parameters Definitions Abbreviations and Relations

Solar energy system has its own parameters to design, calculations and corrections.

The most used parameter are defined as follows:

❖ **Irradiance**

Irradiance is the amount of solar radiation falling on a particular area at any given time. It's measured in watts per square meter[11].

❖ **Irradiation**

Irradiation is a measure of solar energy, the amount of irradiance that falls on a location over time. Irradiation is measured in kWh / square meter / day. Irradiation was formerly called insolation[11].

❖ **Horizontal Tilt**

The tilt angle from the sun, is the angle from the horizon to the sun. Solar PV modules will produce the most energy when the sun is shining directly onto them, from a 90 degree angle. Thus, all else equal, for fixed PV

modules the best tilt angle will be the same as the latitude of the site. For example, if the PV site is at 44 N, the best tilt will be 44 degrees[11].

❖ **Azimuth**

The azimuth is the number of degrees from true south that the sun, or another object, is facing. It's used when designing a solar PV system because due south will provide the best production, when PV arrays fixed.

❖ **Voltage Open Circuit (Voc)**

Volts open circuit is the maximum voltage a solar module can ever make when it has no load on it. Voc is used when sizing solar arrays along with temperature coefficients to determine worst case voltage scenarios.

❖ **Voltage Maximum Power (Vmp)**

Voltage maximum power is the reading of the maximum volts a module can produce when load understanding testing condition, STC, irradiance levels (1000 W / m2). The Vmp would be somewhere in curve on the right in the bend. It will be on the place in the curve creates the most power (volts times amps). The number is actually rather too difficult to calculate exactly and can change rapidly from second to second as the current changes.

❖ **Amps Short Circuits (Isc)**

Amps short circuits it the maximum amount of amps that a solar module could produce. You will find Isc on the x axis of the above graph where there is no voltage and thus no power being produced.

### ❖ Amps Max Power (Imp)

Amps max power, like volts max power, is the current point on the power curve when the module is producing maximum power.

### ❖ Temperature and Voltage

It's important to understand the relationship between temperature and voltage in solar modules for design purposes. While temperature does have a slight impact on current, it's considered to be negligible.

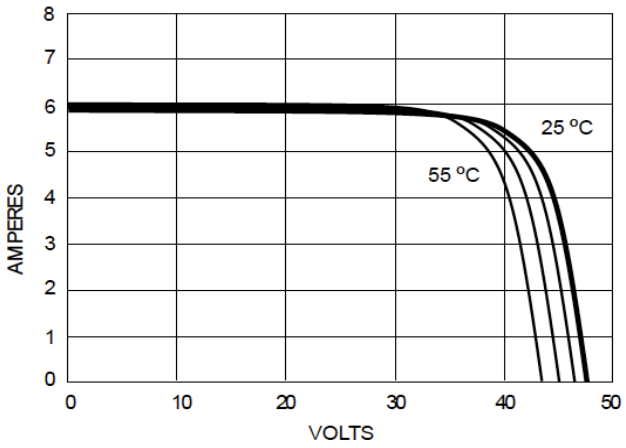


Fig2. 7: Relationship between Voltage, Current and Temperature

However, temperature has a large impact on voltage. When determining the maximum number of solar modules in a string, based on the inverters acceptable voltage, it's needed to take into account expected lowest temperature ranges that can increase voltage as shown in figure (2.7) [11].

### ❖ Irradiance and Current

Irradiance and current also have a direct relationship as shown in figure (2.8). The amount of irradiance falling on a solar PV module will directly impact the current that module is

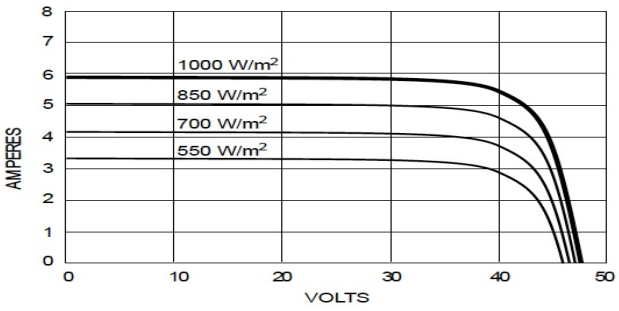


Fig2. 8: Relationship Between Voltage, Current and Irradiance

Producing. This is key for understand when performing designs, and troubleshooting systems.

## 2.4 Photovoltaic Power System Off Grid

This type of Photovoltaic (PV) system provides electricity in situations where utility power is not available. An off-grid system is ideal for locations where grid connections are not accessible, such as cottages and remote home locations, or for anyone craving greater energy independence. Typically the PV system has a fossil fueled generator connected for back-up purposes. As shown figure (2.9) a group or array of PV panels are connected together in groups or strings, usually 3 panels. These strings or groups are all connected together in a Combiner Box which is located near the array. The DC electricity from the PV panels flows through Combiner Box to a Controller/Regulator in the inverter system. The Controller regulates the DC power to the batteries. The Inverter converts the DC battery power to AC electricity which is normal household power (DC

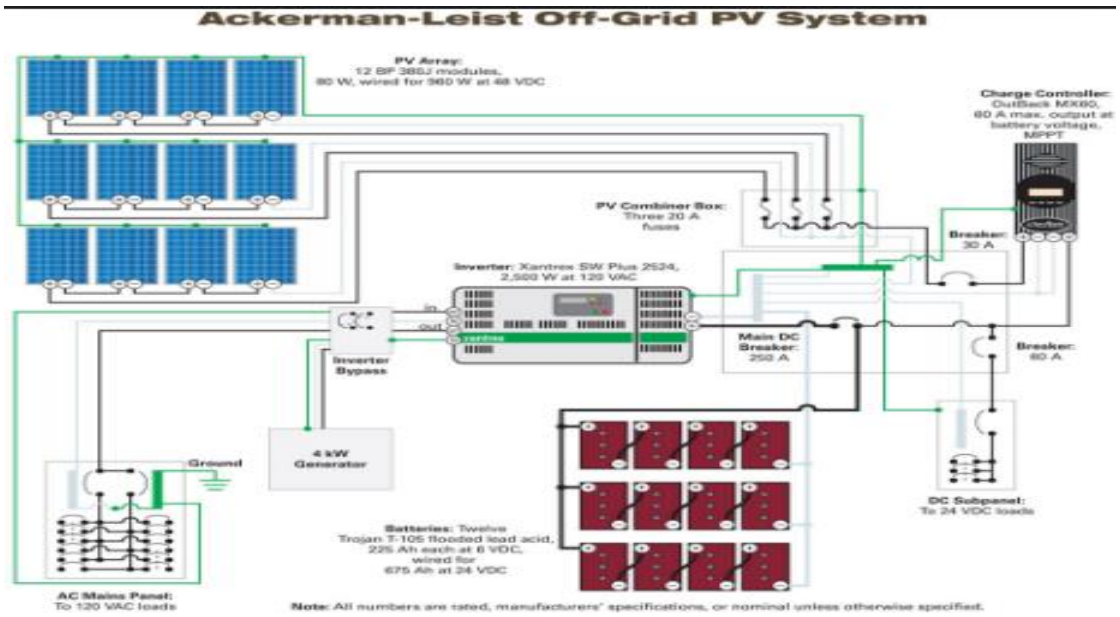


Fig2. 9: Photovoltaic Power System off Grid

Power is sometimes used for lights and small appliances in small camps or cottages). The AC electricity goes to the main electrical panel.

Once in the electrical panel, the electricity is used by the loads connected to the panel, such as lights or appliances. During periods of no sun the generator is used to provide power to the loads and charge the batteries. A wind turbine can be integrated into the system to provide power at night and cloudy days. When wind turbine and solar power systems are combined, it is called a hybrid system.

## 2.5 Grid-Connected Photovoltaic Power System

A grid-connected photovoltaic power system, or grid-connected PV system is an electricity generating solar PV system that is connected to the utility grid as shown in figure (2.10). A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right,

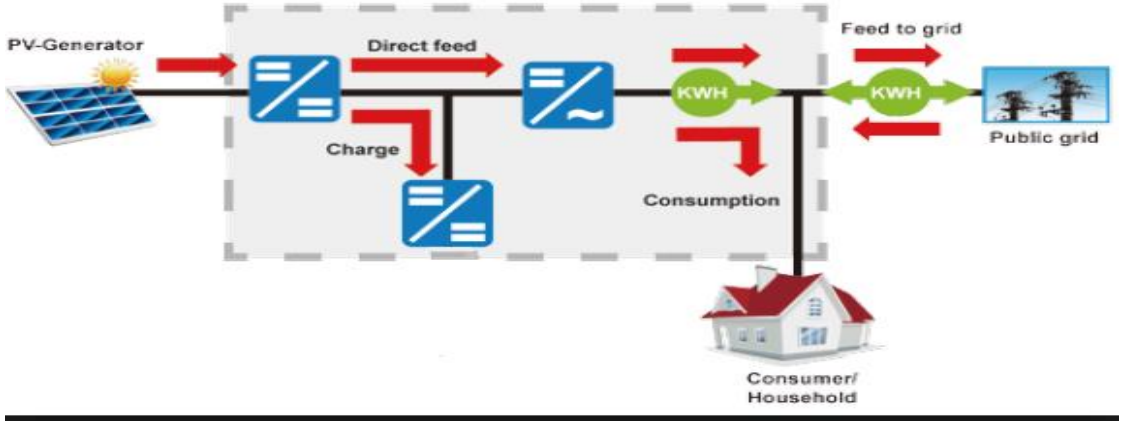


Fig2. 10: Grid-Connected Photovoltaic Power System

the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid[12].

### 2.5.1 Advantages and Disadvantage of Grid Connected PV System

Grid connected PV system have advantage and disadvantages as well, which some of them are summarized in the following:

❖ **Advantages**

i. Grid-connected PV systems are comparatively easier to install as they do not require a battery system[12].

ii. Grid interconnection of photovoltaic (PV) power generation systems has the advantage of effective utilization of generated power because there are no storage losses involved [13].

iii. A photovoltaic power system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon consumption.

iv. Systems such as Net Metering and Feed-in Tariff which are offered by some system operators, can offset a customer's electricity usage costs. In some locations though, grid technologies cannot cope with distributed generation feeding into the grid, so the export of surplus electricity is not possible and that surplus is earthed.

❖ **Disadvantages**

i. Grid-connected PV can cause issues with voltage regulation. The traditional grid operates under the assumption of one-way, or radial, flow. But electricity injected into the grid increases voltage, and can drive levels outside the acceptable bandwidth of ±5[14].

ii. Grid-connected PV can compromise power quality. PV's intermittent nature means rapid changes in voltage. This not only wears out voltage regulators due to frequent adjusting, but also can result in voltage flickers[15].

iii. Connecting to the grid poses many protection-related challenges. addition to islanding, as mentioned above, too high levels of grid-connected PV result in problems like relay desensitization, nuisance tripping, interference with automatic reclose, and Ferro resonance[15].

## 2.6 DC -AC Power Inverter

A power inverter is an electronic device that changes direct current (DC) to alternating current (AC).

Inverters are used in many applications including as part of any AC residential or commercial solar power system. An inverter converts direct current (DC) power coming from a solar panel or solar array into AC current which can be utilized to power loads that run on alternating current electricity. They are also used in utility-scale solar power generating plants[16].

A typical inverter requires a stable source of DC power capable of supplying power demands. There are two main commercially available types of inverters, modified sine wave and sine wave[16].

### 2.6.1 Size of Inverter

The three main types of inverters used in solar PV power plants are[17, 18]:

❖ **Central Inverters**

These perform the function of DC to AC conversion and other power management functions from one central device. A large solar farm could have multiple central inverters, but each of these could be of 1 MW size and above as shown in figure (2.11).



Fig2. 11: Grid-Connected Photovoltaic Power System[1]

Three types of solar inverters available are: micro inverters, string inverters, and central inverters. Micro inverters are typically attached directly to individual photovoltaic modules. String inverters are designed to be wired to a string of 8-15 solar modules connected in series. Central inverters are a type of string inverter used in large scale applications. They offer in general easier installation and higher efficiency than smaller string inverters, but at slightly higher installation cost.

❖ **String Inverters**

String inverters distribute the load of central inverters into multiple inverters. Typically, string inverters could be of sizes of a fourth of central inverters or even smaller. A 1 MW solar power plant could have as many as 40 string inverters, each 25 kW as shown in figure (2.12).



Fig2. 12: String Inverters[1]

Solar panels are wired together in series (a string of panels) which increases the voltage and keeps the current low so that wiring is simpler and wire size can be smaller. String inverters are designed to be wired to a single series string of 8-15 solar modules and are currently the most widely used inverter type.

❖ **Micro Inverters**

Micro-inverters are small sized inverters attached to individual solar panels. Micro inverter capacities could be as small as the solar panels they support, that is, as low as 240 W each as shown in figure (2.13).



Fig2. 13: Micro Inverter[1]

Micro inverters are typically attached directly to individual photovoltaic modules in order to extract the maximum power from each module. These are exceptionally reliable and typically come with a 15-year warranty. They are highly efficient and can potentially produce more power than a string inverter; however they can add substantial cost to a solar project.

The following illustration shows the appropriate size of inverters in figure (2.14).

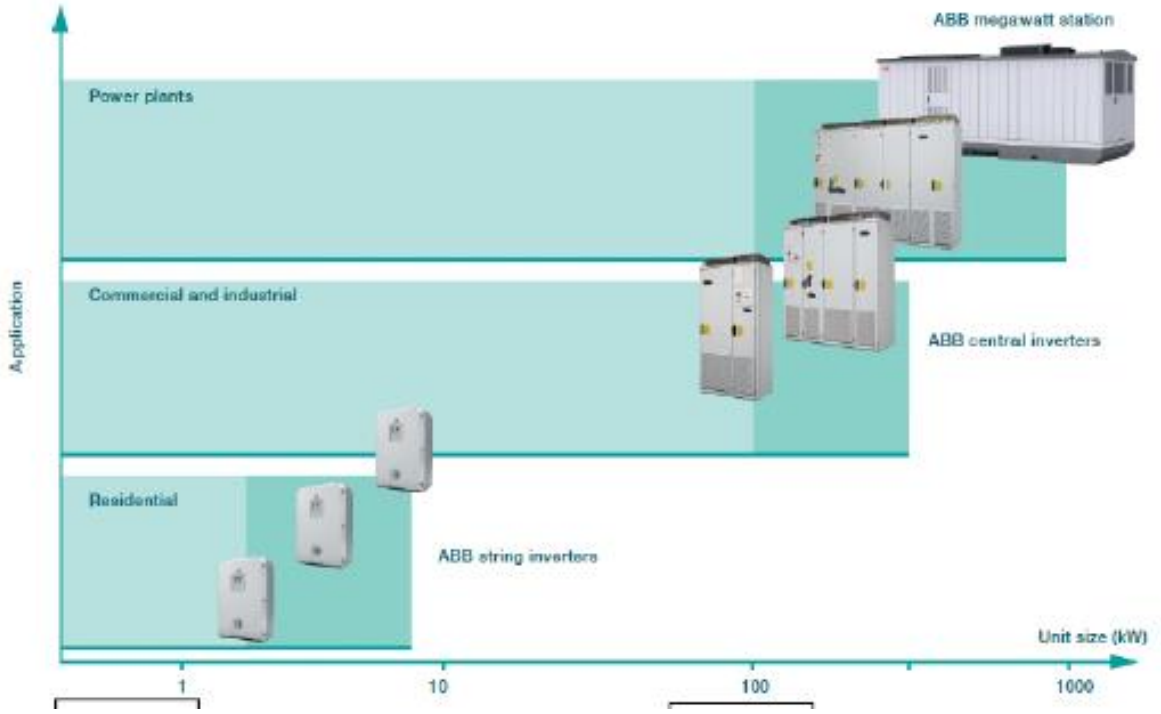


Fig2. 14: Size Inverter[1]

# CHAPTER III
# Site Survey & Make the Design Process

## 3.1 Introduction

Survey site of the interested zone and how to make the design process of these type of power plant are given in this chapter.

The study case is Bin-Walid city, four places with deferent area and location were taken to complete this study, the site survey is achieved by determining the location, calculation site temperature, solar radiation calculation, then sun path position, after that determining the appropriate PV module, as well as the panel design. Many scenarios will be taken with energy analysis of the resulting system.

The software used is PV* which is simulation program for design, simulation and economic efficiency forecast of grid connected photovoltaic systems.

## 3.2 Location Determination

The site is located in bin – walid Libya.

Type: open space

Table (3.1) shows the proposed sites for the design and study

Table3. 1: The Proposed Sites for the Design and Study

| Position | The nearest point | Latitude | Longitude |
|---|---|---|---|
| **Position 1** | Substation bin- waleed 66 KV | 31°46'5"N | 14°0'5"E |
| **Position 2** | Substation Al-sof 66 KV | 31°44'0"N | 14°2'1" E |
| **Position 3** | Substation Al-fuqhaa 66 KV | 31°45'5"N | 14° 4'8" E |
| **Position 4** | Between Substation Tininai & shamik 66 KV | 31°31'4"N | 13°58'3"E |

Figure (3.1) shows the location from satellite image taken from Google earth program.

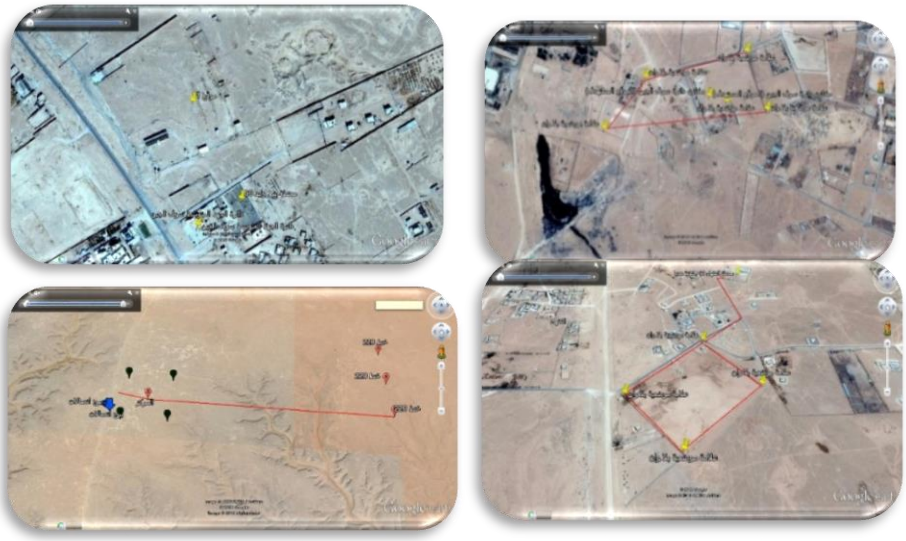

Fig3. 1: The Proposed Sites for the Design and Study

## 3.3 City Temperature Calculation

It was taken less than the highest temperature of the city from the year 1998 to 2009 as given in table (3.2) [19].

Table3. 2: The Maximum Temperature $C^0$

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 22.5 | 28.5 | 29.0 | 39.5 | 40.3 | 42.0 | 43.8 | - | 46.0 | 40.0 | 32.0 | 22.4 |
| 1999 | 21.9 | 25.0 | 31.5 | 35.5 | 42.0 | 48.0 | 43.0 | 46.0 | 42.0 | 38.5 | 30.5 | 26.5 |
| 2000 | 20.3 | 24.5 | 36.2 | 41.0 | 39.0 | 43.5 | 44.9 | 40.5 | 44.0 | 38.0 | 31.5 | 25.5 |
| 2001 | 26.5 | 31.5 | 37.5 | 34.5 | 41.0 | 41.5 | 46.5 | 43.5 | 43.5 | 39.0 | 34.2 | 26.5 |
| 2002 | 22.0 | 29.5 | 33.5 | 38.0 | 38.0 | 43.0 | 45.0 | 45.0 | 41.0 | 36.5 | 28.5 | 23.8 |
| 2003 | 27.5 | 23.0 | 29.0 | 35.5 | 37.5 | 44.5 | 46.8 | 42.5 | 43.0 | 40.2 | 38.0 | 28.0 |
| 2004 | 23.0 | 33.8 | 35.0 | 39.0 | 37.0 | 44.0 | 41.0 | 44.0 | 35.0 | 39.0 | 33.5 | 24.5 |
| 2005 | 22.5 | 29.0 | 34.2 | 38.0 | 42.5 | 40.3 | 45.0 | 42.0 | 43.0 | 36.0 | 30.0 | 24.0 |
| 2006 | 20.5 | 26.5 | 36.0 | 38.0 | 40.8 | 44.0 | 44.0 | 45.0 | 40.0 | 34.0 | 30.0 | 21.5 |
| 2007 | 28.5 | 26.5 | 29.0 | 34.0 | 39.0 | 45.7 | 40.5 | 43.5 | 39.5 | 35.5 | 28.0 | 23.5 |
| 2008 | 19.5 | 23.0 | 33.8 | 41.0 | 44.0 | 43.0 | 42.5 | 40.0 | 40.3 | 35.0 | 32.5 | 24.0 |
| 2009 | 25.0 | 28.0 | 34.5 | 36.5 | 38.0 | 42.5 | 46.0 | 42.0 | 41.5 | 37.0 | 33.0 | 30.0 |

The calculation of the average temperature for each month as given in figure (3.2)

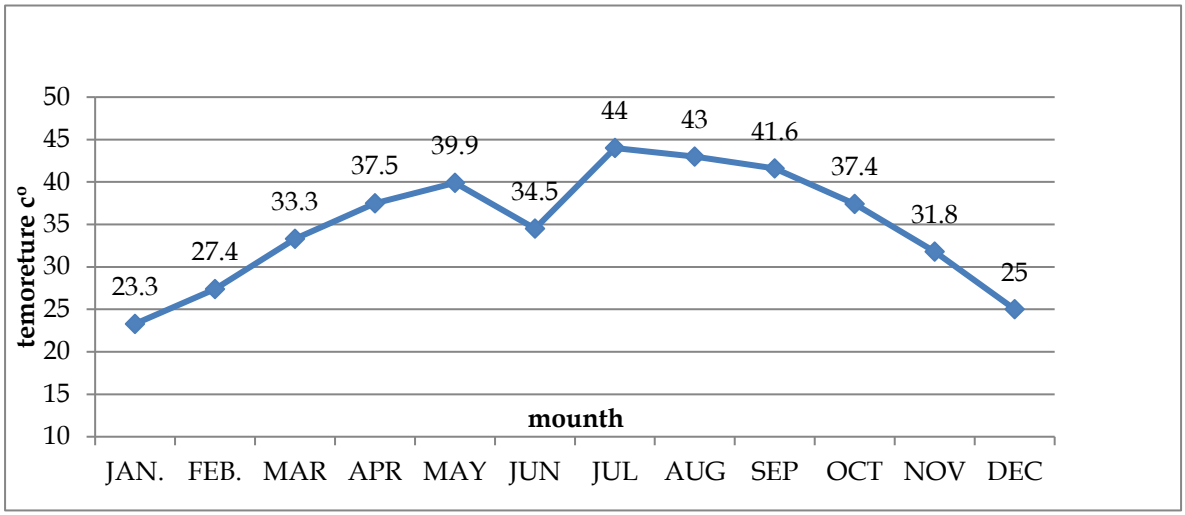


Fig3. 2: The Average Maximum Temperature

## 3.4 Solar Radiation Calculation

The solar radiation is calculated using RETSCREEN INTERNATIONAL program as shown in figure (3.3)

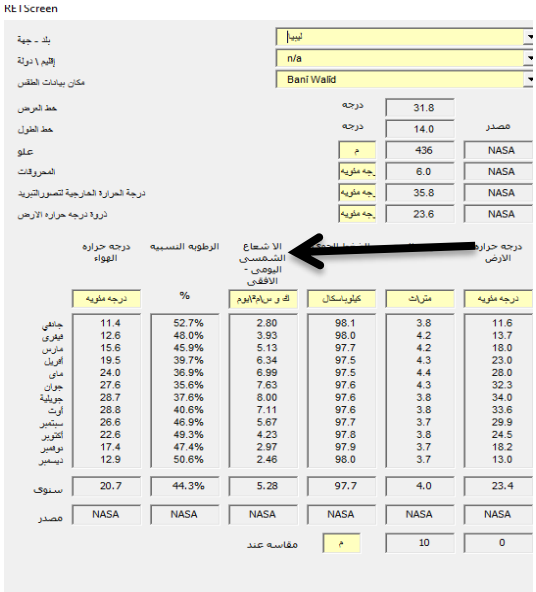


Fig3. 3: Solar Radiation Calculated Using “Ret Screen International “

After knowing solar radiation and temperature of the site are brought to the program METEOSYN as shown in figure (3.4)

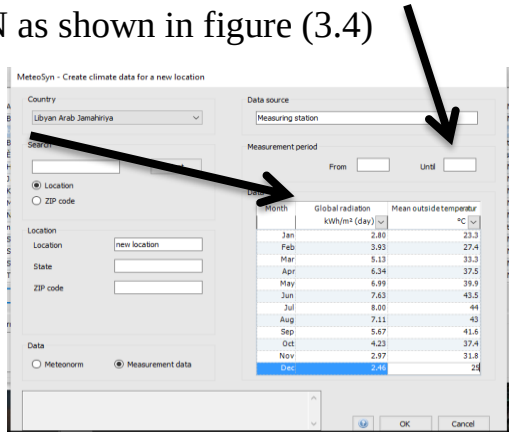


Fig3. 4: Writing Solar Radiation and Temperature for Each Month

## 3.5 Sun Path Position:

Plotting a sun chart tells how much direct sunlight you can expect over the course of a day. Sun charts are provide a way to represent the movement of the sun across the sky[20].

Using Software Sun position Calculations, the results of the selected location in BIN-WALED Libya during the year 2016 presented in the following selected tables (3.3 and 3.4).

Table3. 3: Azimuth and Elevation for Location [20]

| Azimuth ° | Elevation ° |
|---|---|
| 109.38 | 34.18 |

Table3. 4: Sun Position Calculations [20]

| Date: | 29/03/2016 \| GMT1 | |
|---|---|---|
| coordinates: | 31°46'50"N, 14° 0'5"E | |
| location: | Unnamed Road, Bani waled, Libya | |
| hour | Elevation | Azimuth |
| 06:56:02 | -0.833° | 85.31° |
| 7:00:00 | 0.01° | 85.83° |
| 8:00:00 | 12.76° | 93.75° |
| 9:00:00 | 25.39° | 102.29° |
| 10:00:00 | 37.56° | 112.55° |
| 11:00:00 | 48.69° | 126.37° |
| 12:00:00 | 57.54° | 146.69° |
| 13:00:00 | 61.78° | 175.41° |
| 14:00:00 | 59.4° | 205.8° |
| 15:00:00 | 51.62° | 228.62° |
| 16:00:00 | 40.99° | 244.01° |
| 17:00:00 | 29.05° | 255.09° |
| 18:00:00 | 16.53° | 264.02° |
| 19:00:00 | 3.8° | 274.93° |
| 19:21:52 | -0.833° | 274.93° |

## 3.6 Determine The Appropriate PV Module

It was chosen two types of PV modules for the design of the system depending on the specific specifications such as painting space, temperature, specifications, and efficiency, the work will be of a comparison between the two units to get the best out of them, Will be the experience of PV modules 1 & 2 in 3 different designs to see their best.

The site will be divided into a set of fields, each field = 3 hectares

### 3.6.1 Module1

The first module is Clearline PV 30/500, use cell type of Si monocrystalline, and the data sheet of this module is given table (2.5).

Table3. 5: Data Sheet for Clearline PV 30/500

| PV Module: Clearline PV 30/500 | |
|---|---|
| Manufacturer | Clearline |
| Available | Yes |
| Power warranty | 90%10years,80%25years |
| Standards | IEC61215,61730,TUV,MCS,BBA |
| Mismatch (Manufacturer Information) | 2% |
| **Electrical Data** | |
| Cell Type | Si monocrystalline |
| Only Transformer Inverters suitable | No |
| Number of Cells | 126 |
| Efficiency | 14.7 |
| NOCT[4] | 44.6 |
| Width | 1,173 mm |
| Height | 2,898 mm |
| Depth | 82 mm |
| Weight | 57 kg |
| **I/V Characteristics at STC** | |
| $V_{PP}$ | 63.6 V |
| $I_{PP}$ | 7.9A |
| Output | 500 W |
| Open Circuit Voltage | 79.5 V |
| Short-Circuit Current | 8.5A |

### 3.6.2 Module2

The second module is Trina solar TSM-PA14, use cell type of Si multicrystalline, and the data sheet of this module is given table 2.6

Table3. 6: Data Sheet for Trina Solar TSM-PA14

| PV Module: Trina solar TSM-PA14 | |
|---|---|
| Manufacturer | Trina solar |
| Available | Yes |
| Power warranty | 90%10years,80%25years |
| Standards | ICO9001,ISO14001, |
| **Electrical Data** | |
| Cell Type | Si multicrystalline |
| Only Transformer Inverters suitable | No |
| Number of Cells | 72 |
| Efficiency | 15.7 |
| NOCT[4] | 45$^{o}$ |
| Mismatch (Manufacturer Information) | 2% |
| Width | 992 mm |
| Height | 1956 mm |
| Depth | 46 mm |
| Weight | 27.6 kg |
| **I/V Characteristics at STC** | |
| $V_{PP}$ Voltage | 33.4 V |
| $I_{PP}$ Current | 6.62A |
| Output | 305 W |
| Open Circuit Voltage | 41.4 V |
| Short-Circuit Current | 7.17 A |

## 3.7 The Panel Design

### 3.7.1 Using Module 1

The following data shows the proposed design for each of the three hectares for the first module (vertical, horizontal and 2* horizontal) and the number of panels for each design shown in figure (3.7).

Table3. 7: Data for Design Module 1

| Types | vertical | horizontal | 2* horizontal |
|---|---|---|---|
| Number Solar Modules | 3821 | 2010 | 3330 |
| Generator Surface | 3 hectares | | |
| Orientation | Vertical | horizontal | horizontal |
| Number of vertical modules | 1 | 1 | 2 |
| Module spacing – horizontal(w1) | 0.005 m | | |
| Module spacing – Vertical(w2) | 0.005 m | | |
| Height of bottom edge (h1) | 0.3 m | | |
| Inclination of mounting surface (β1) | 0 $^{o}$ | | |
| Orientation to mounting surface($\alpha_1$) | -70.7 $^{o}$ | | |
| Title angle | 0 $^{o}$ | | |
| Mount angle ($\beta_r$ ) | 33 $^{o}$ | | |
| Azimuth angle | East 109.3 $^{o}$ | | |
| Orientation to mounting surface($\alpha_r$) | -70.7 $^{o}$ | | |
| Mounting support clearance (d1) | 4 m | | |
| Depth of row (d) | 2.430 | 0.984 m | 1.972 m |
| Row spacing | 6.430 | 4.984 m | 5.972 m |
| Cable loss | 1% | | |

Samples such as (β1, h1, etc.) presented in a above table are illustrated in figure (3.5)

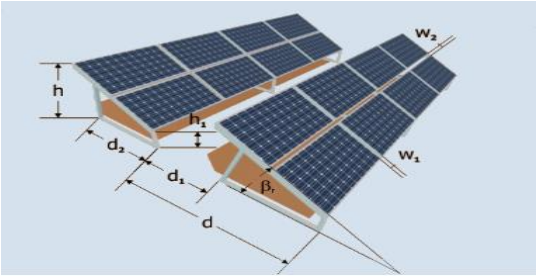


Fig3. 5: Height of Bottom Edge

The following table (3.8) shows the number and type of each inverter design for module 1

Table3. 8: Data for Inverter Module 1

| **inverter** | vertical | horizontal | 2* horizontal |
|---|---|---|---|
| Inverter 1 | 1 x CIS 1000 | 1 x CIS 1000 | 1 x CIS 1000 |
| Manufacturer | Conergy AG | Conergy AG | Conergy AG |
| Configuration | MPP 1: 61 x 11<br>MPP 2: 63 x 10<br>MPP 3: 61 x 10<br>MPP 4: free standing | MPP 1: 67 x 10<br>MPP 2: 67 x 10<br>MPP 3: 67 x 10<br>MPP 4: free-standing | MPP 1: 60 x 10<br>MPP 2: 60 x 10<br>MPP 3: 59 x 10<br>MPP 4: free-standing |
| | | | |
| Inverter 2 | 1 x CIS 1000 | | 1 x CIS 1000 |
| Manufacturer | Conergy AG | | Conergy AG |
| Configuration | MPP 1: 64 x 10<br>MPP 2: 64 x 10<br>MPP 3: 63 x 10<br>MPP 4: free-standing | | MPP 1: 70 x 11<br>MPP 2: 70 x 11<br>MPP 3: free-standing MPP 4: free-standing |

Figure (3.6, 3.7 and 3.8) shown single line diagram in PV*SOL for (vertical, horizontal and 2*horizontal) for module 1.




Fig3. 6: Single Line Diagram for Module 1 in Vertical

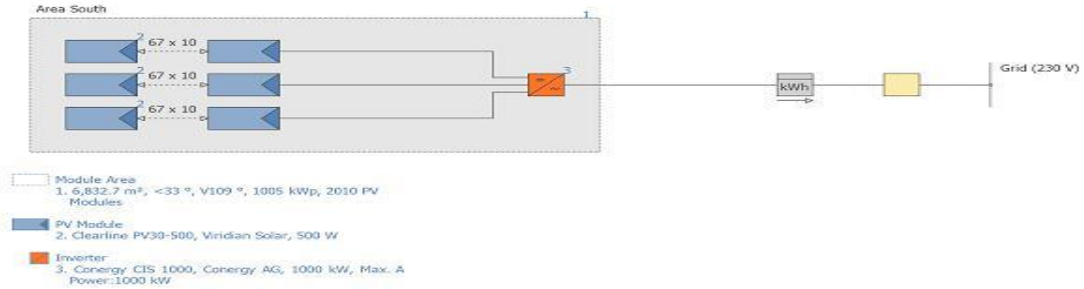


Fig3. 7: Single Line Diagram for Module 1 in Horizontal

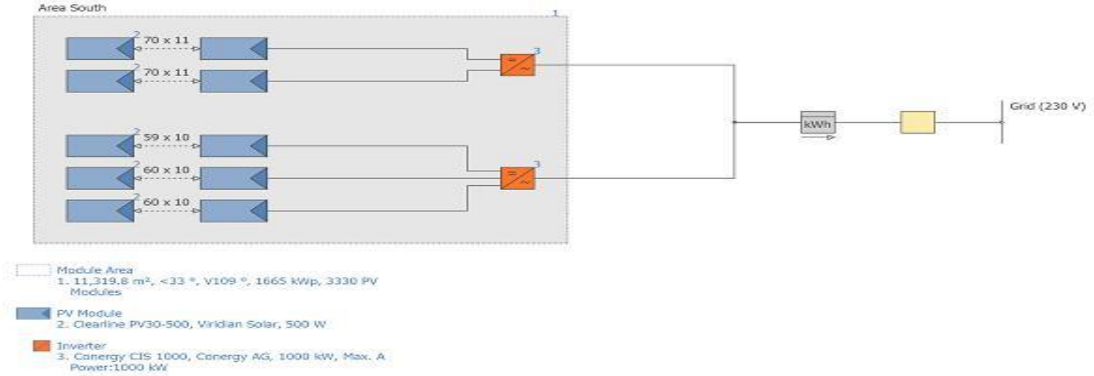


Fig3. 8: Single Line Diagram for Module 1 In (2* Horizontal)

Figure (3.9, 3.10 and 3.11) shown panel position in PV*SOL for (vertical, horizontal and 2*horizontal) for module 1.



Fig3. 9: Module 1 in Vertical



Fig3. 10: Module 1 in Horizontal

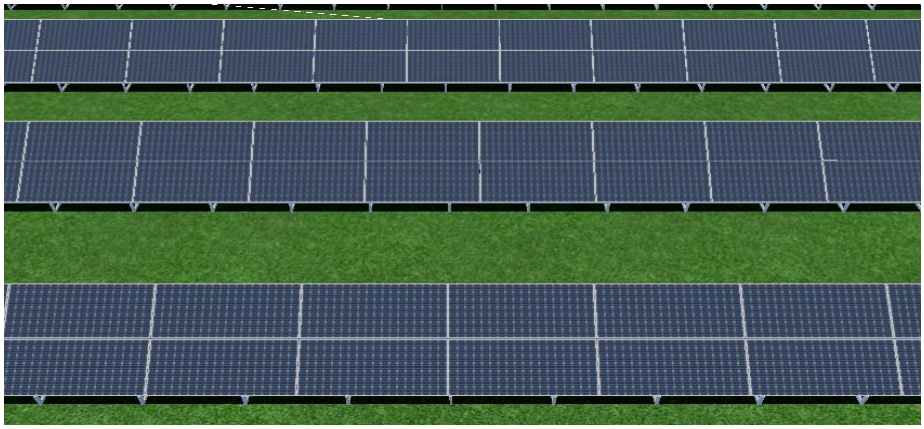

Fig3. 11: Module 1 in (2*Horizontal)

### 3.7.2 Using Module 2

The following data shows the proposed design implementation for each of the three hectares for the second module (vertical, horizontal and 2* horizontal) and the number of panels for each design shown in table (3.9).

Table3. 9: Data for Design Module 2

| Types | vertical | horizontal | 2* horizontal |
|---|---|---|---|
| Number Solar Modules | 4,494 | 3,085 | 4,966 |
| Generator Surface | 3 hectares | | |
| Orientation | Vertical | horizontal | horizontal |
| Number of vertical modules | 1 | 1 | 2 |
| Module spacing – horizontal(w1) | 0.005 m | | |
| Module spacing – Vertical(w2) | 0.005 m | | |
| Height of bottom edge (h1) | 0.3 m | | |
| Inclination of mounting surface (β1) | 0 ° | | |
| Orientation to mounting surface($\alpha_1$) | -70.7 ° | | |
| Title angle | 0 ° | | |
| Mount angle ($\beta_r$ ) | 33 ° | | |
| Azimuth angle | East 109.3 ° | | |
| Orientation to mounting surface($\alpha_r$) | -70.7 ° | | |
| Mounting support clearance (d1) | 4 m | | |
| Depth of row (d) | 1.640 | 0.832 m | 1.668m |
| Row spacing | 5.840 | 4.832 m | 5.668 m |
| Cable loss | 1% | | |

The following table (3.10) shows the number and type of each inverter design for module 2.

Table3. 10: Data for Inverter Module 2

| inverter | vertical | horizontal | 2* horizontal |
|---|---|---|---|
| Inverter 1 | 2 x CIS 1000 | 3 x IPG 300C | 1 x CIS 1000 |
| Manufacturer | Conergy AG | Conergy AG | Conergy AG |
| Configuration | MPP 1: 67 x 19<br>MPP 2: 68 x 18<br>MPP 3: free-standing<br>MPP 4: free-standing | MPP 1: 42 x 18 | MPP 1: 71 x 19<br>MPP 2: 63 x 18<br>MPP 3: free-standing<br>MPP 4: free-standing |
| | | | |
| Inverter 2 | | 1 x IPG 300C | |
| Manufacturer | | Conergy AG | |
| Configuration | | MPP 1: 43 x 19 | |

Figure (3.12, 3.13 and 3.14) shown single line diagram in PV*SOL for (vertical, horizontal and 2*horizontal) for module 2.

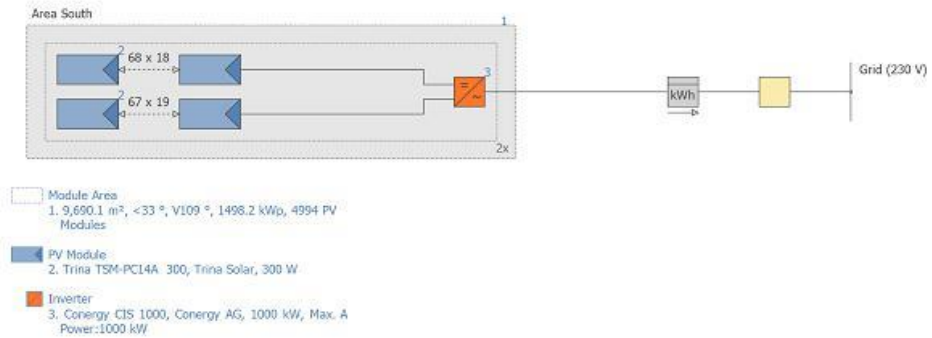


Fig3. 12: Single Line Diagram for Module 2 in Vertical

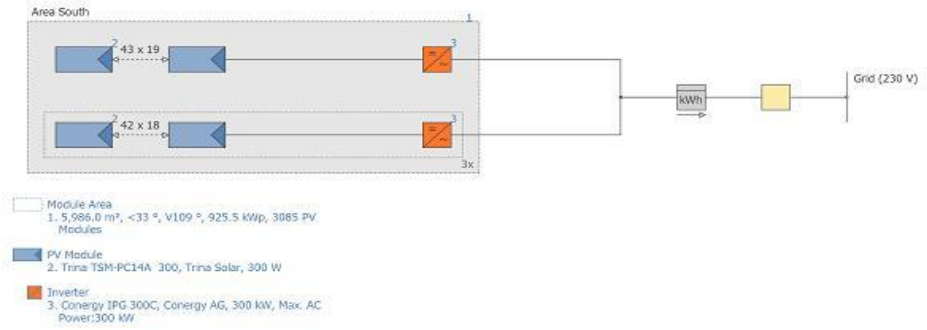


Fig3. 13: Single Line Diagram for Module 2 in Horizontal

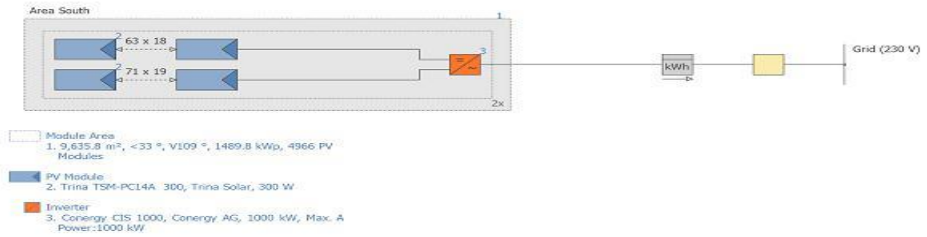


Fig3. 14: Single Line Diagram for Module 2 In (2* Horizontal)

Figure (3.15, 3.16 and 3.17) shown panel position in PV*SOL for (vertical, horizontal and 2*horizontal) for module 2.

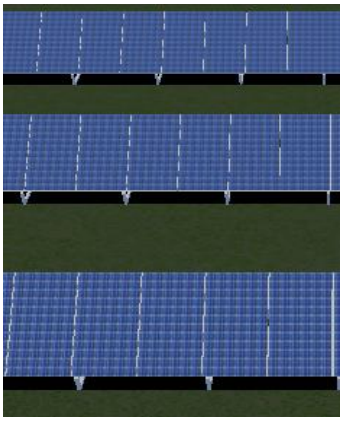

Fig3. 15: Module 2 in Vertical

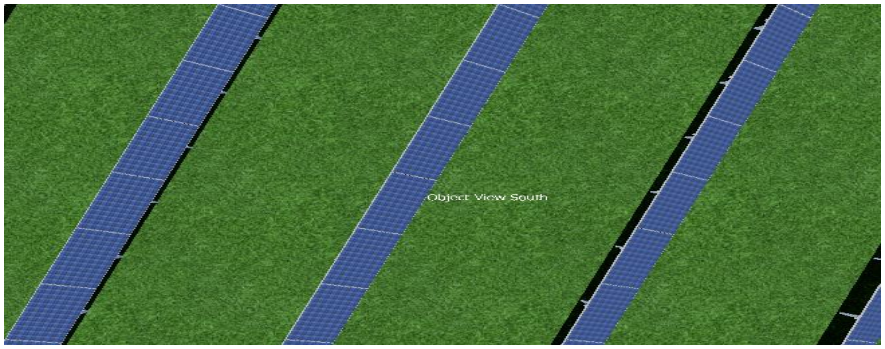


Fig3. 16: module 2 in horizontal

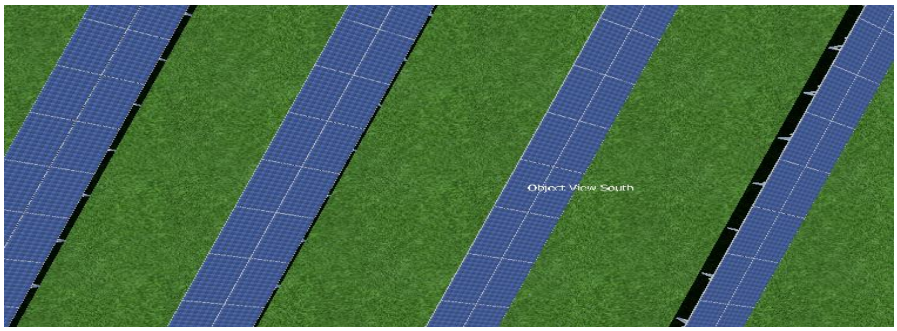


Fig3. 17: Module 2 in (2*Horizontal)

## 3.8 The Result of All Design

The following table (3.11) shows the final results of all designs

Table3. 11: the result of all design

| | Module1 (V) | Module1 (H) | Module1 (2*H) | Module2 (V) | Module1 (H) | Module2 (2* H) |
|---|---|---|---|---|---|---|
| PV Generator Output (kw) | 1,910.5 | 1,005 | 1,665 | 1,498.2 | 925.5 | 1,489.8 |
| Annual Grid Feed-in kWh | 2,762,745 | 1,448,64 | 2,412,33 | 2,059,69 | 1,284,68 | 2,047,80 |
| Performance Ratio (%) | 79 | 78.8 | 79.2 | 75.1 | 75.8 | 75.1 |
| Yield Reduction due to Shading (%/year) | 1.9 | 1.7 | 1.8 | 1.9 | 1.8 | 1.9 |
| cable loss(W) | 19,105 | 10,050 | 16,650 | 14,982 | 9,255 | 1,4898 |

From the above results we note that the first design (Module 1 in vertical) is better between them in terms of both the number of panels and the resulting capacity Subject to the proportion of shade that does not exceed 2% This shows us that there is a relationship between the module space and shade, and the distance between rows and after several experiments, we found that the best distance maintain the ratio of shade less than 2% and be logical is 4 meters and is separated by a space between the rows allow workers to conduct the station Cleaning Units of paintings and maintenance process freely.

We also note that the second type (Trina solar TSM-PA14) of paintings that can offer us the percentage remained less than a percent in a distance of almost a meter, but this is not enough for maintenance and cleaning and this shows us that the results of the (Module 1 in vertical) is the best design. Figure (3.18) shows the expected generation for each month during one year

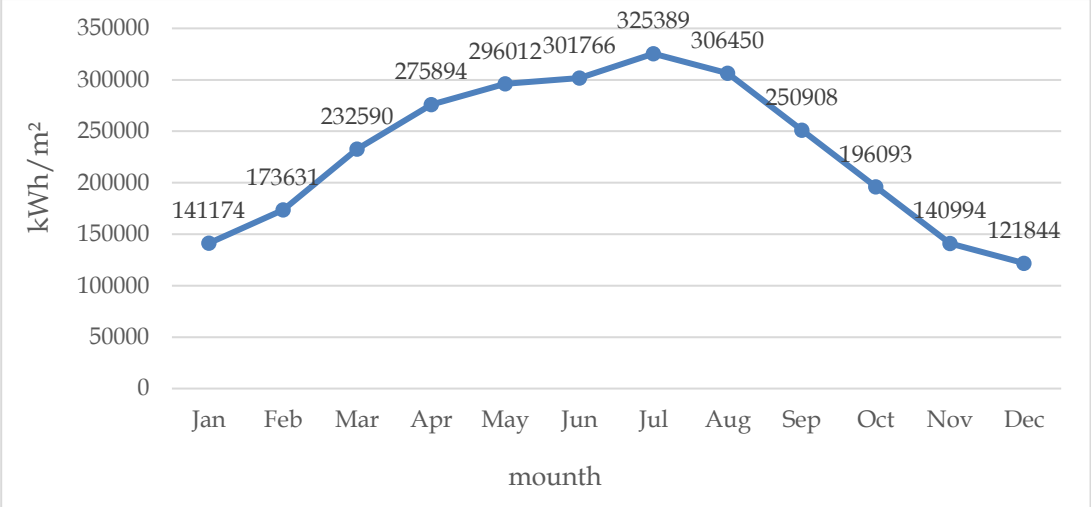


Fig3. 18: Production Forecast for Year

Figure (3.19) shows the expected generation per inverter

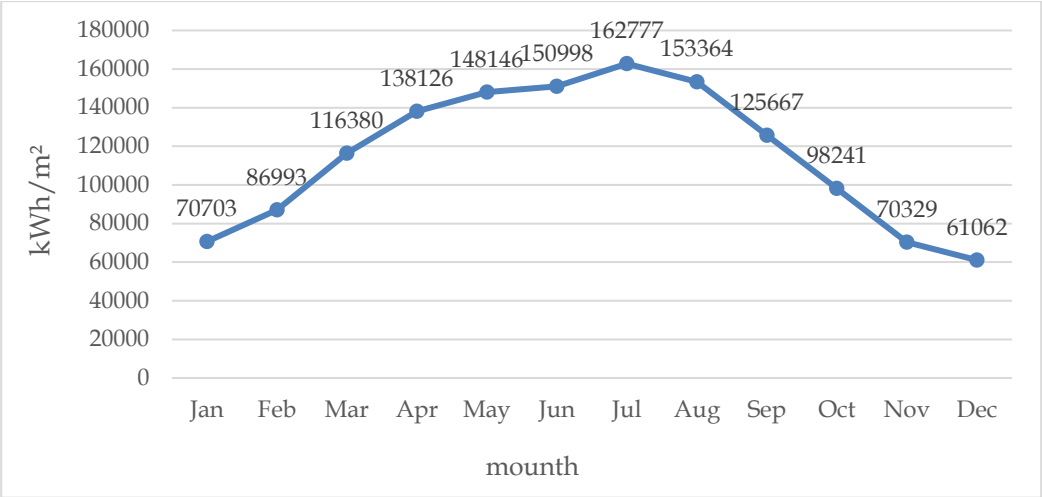


Fig3. 19: Production Forecast for Each Inverter

Figure (3.20) shows the ratio of expected performance for each month in one year

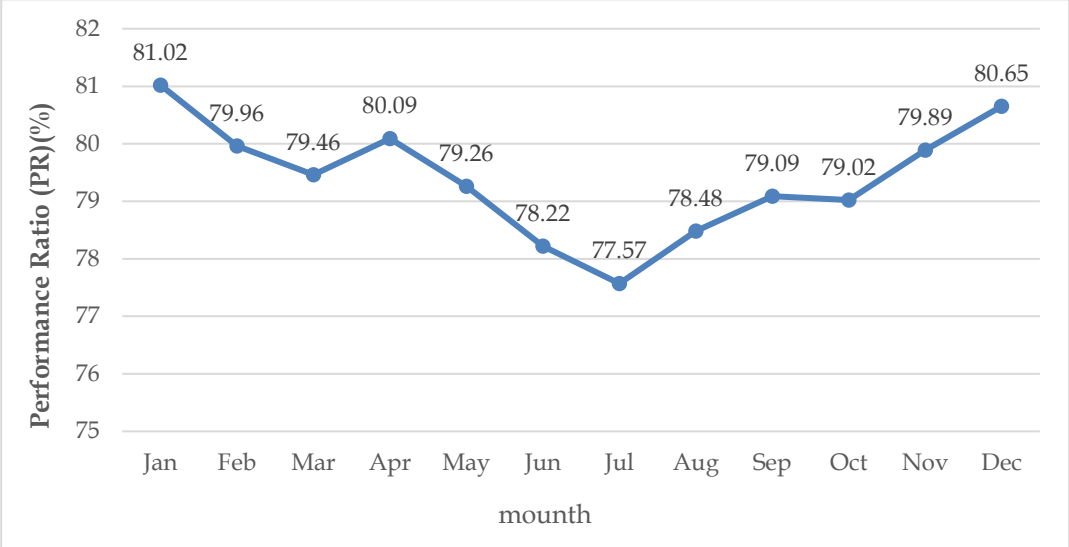


Fig3. 20: Performance Ratio (BR)

## 3.9 Losses Calculation

In this section, determining the losses for each stage in solar power plant such as irradiance losses, spectrum deviation, temperature, and many other factors affecting energy losses.

- Global Radiation – Horizontal:

Figure (3.21) shows the radiation – horizontal from the monthly the total radiation is 1,926.2 kWh/m² for a year,

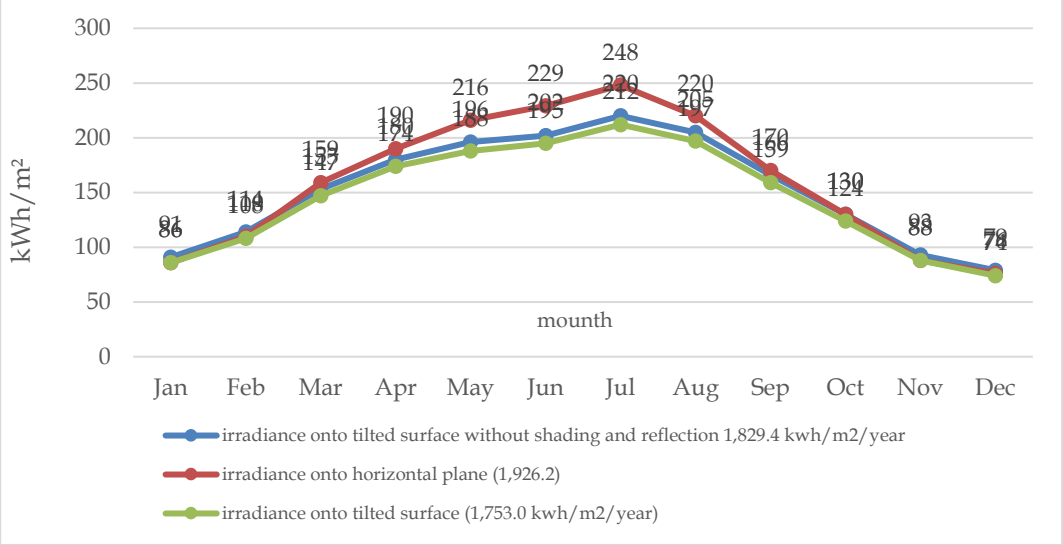


Fig3. 21: Irradiance

- Deviation From Standard Spectrum :

Figure (3.22) shows the losses from the monthly deviation of standard spectrum for a year, and the total losses is 19.26 kWh/m², which is about 1% of total energy.

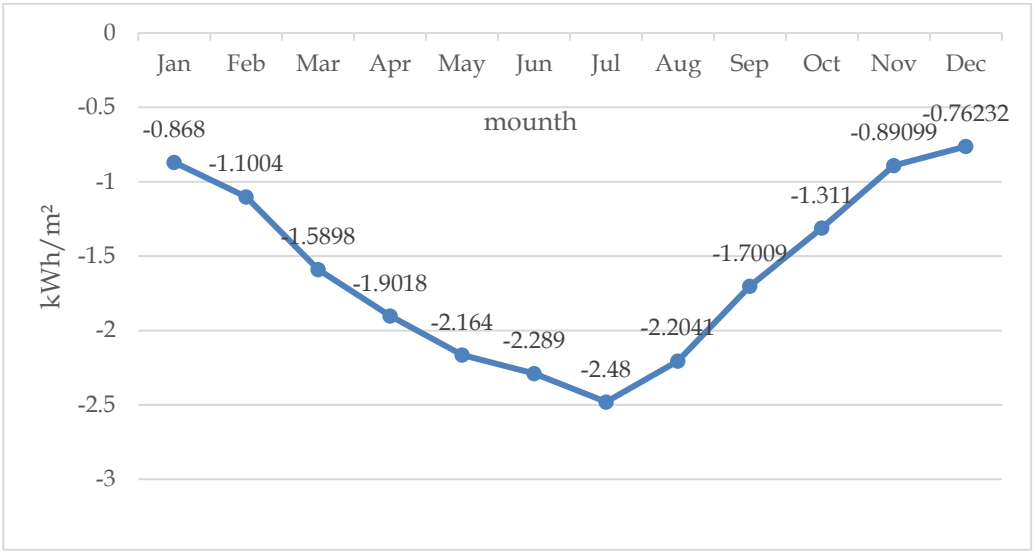


Fig3. 22: Deviation from Standard Spectrum

- Orientation And Inclination Of The Module Surface:

Figure (3.23) shows the losses from the monthly Orientation and inclination for a year, and the total losses is 77.52 kWh/m², which is about 4.07% of total energy.

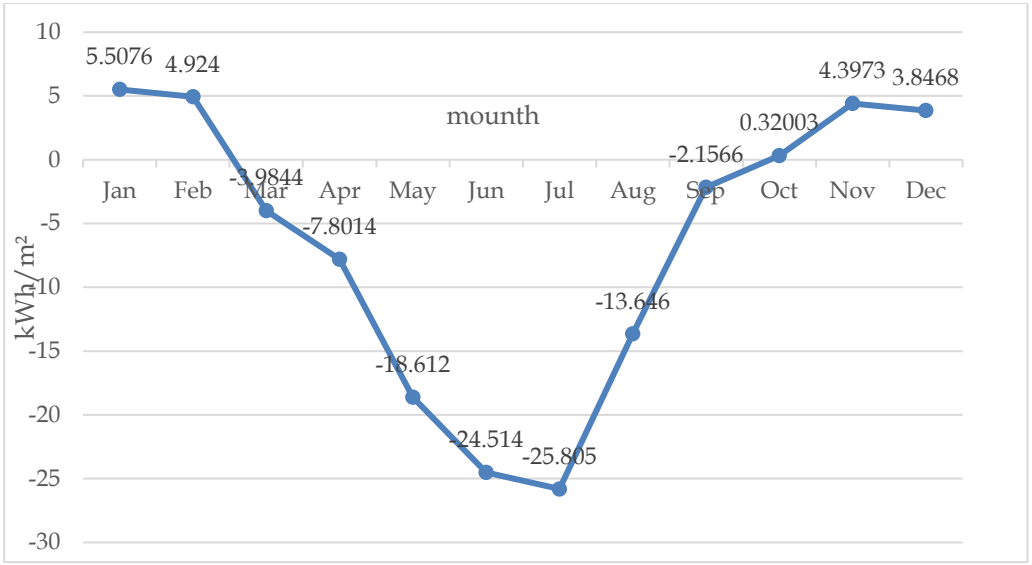


Fig3. 23: Orientation and Inclination of the Module Surface

- Reflection on the Module Interface :

Figure (3.24) shows the losses from the monthly Reflection on the Module Interface for a year, and the total losses is 76.44 kWh/m², which is about 4.18% of total energy.

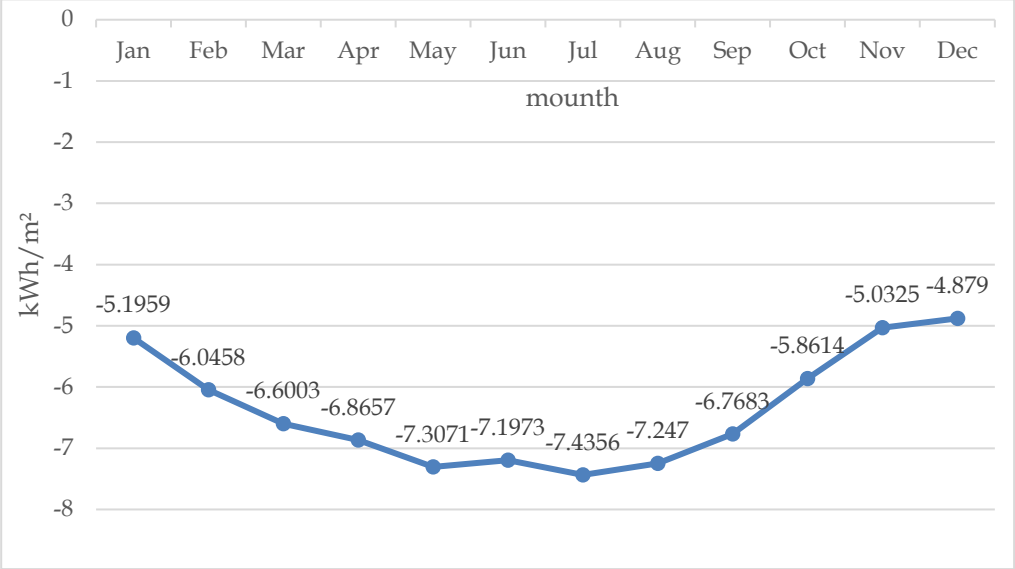


Fig3. 24: Reflection on the Module Interface

Now, before going on to calculate the rest of losses, we can find the net energy arrived to module by following

Global Radiation at the Module

= 1,926.2-(19.26+77.52+76.44) = 1,753.0 kWh/m²

Global PV Radiation=1,753.0 kWh/m²* AREA (m²) = 22,769,705.1 kWh

Global PV Radiation =1,753.0 kWh/m²* 12988.93 = 22,769,705.1 kWh

Rated Efficiency of Module (14.71%) = - 85.29 % =-19,420,113.88 kWh

Rated PV Energy=22,769,705.1kWh - 19,420,113.88 = **3,349,591.3kWh**

- Module-Specific Partial Shading

Figure (3.25) shows the losses from the monthly Shading for a year, and the total losses is 20,464.15 kWh/m², which is about 0.61 % of total energy.

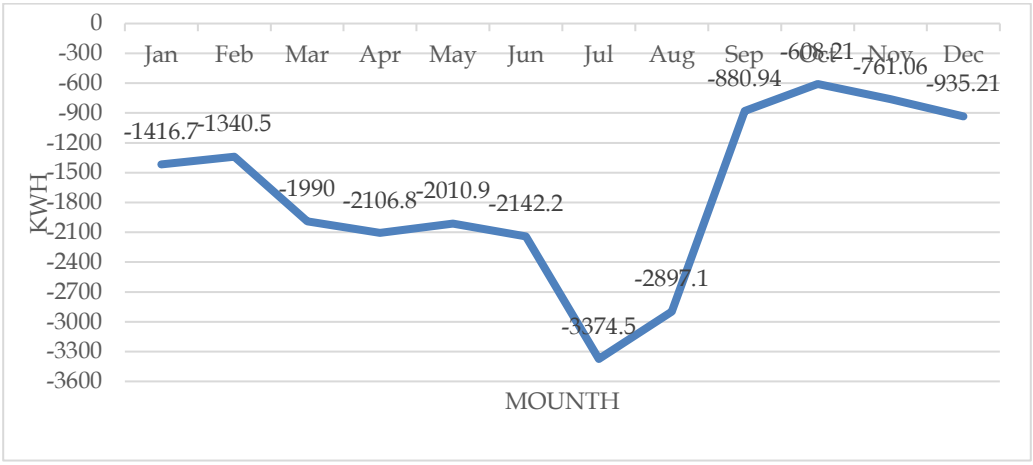


Fig3. 25: Module-Specific Partial Shading

- Partial Load= 75,463.90 kWh = 2.27 %

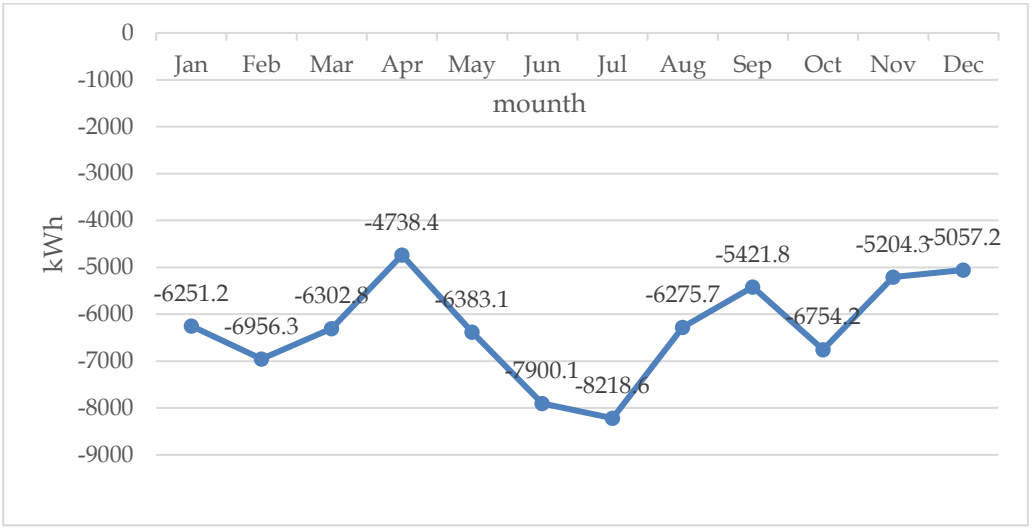


Fig3. 26: Partial Load

- Temperature :

Figure (3.27) shows outside temperature and the temperature module per month.

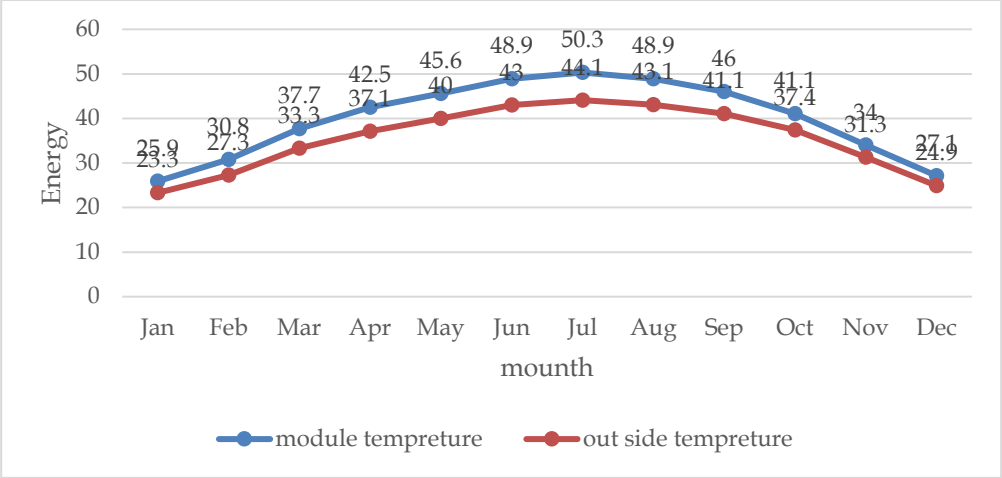


Fig3. 27: Temperature

Figure (3.28) shows the losses from the monthly temperature for a year, and the total losses is 295,567.25 kWh/m², which is about 9.08 % of total energy.

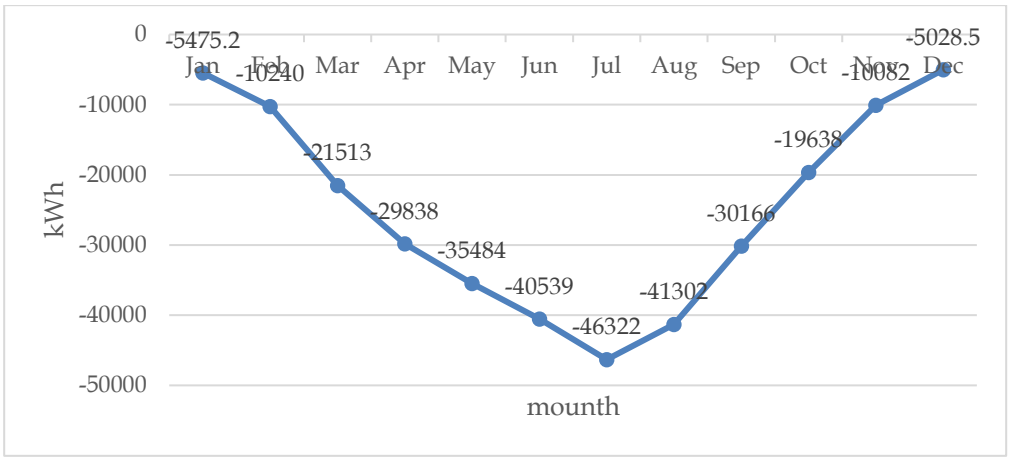


Fig3. 28: Temperature Panel Losses

- Diodes :

Figure (3.29) shows the losses from the monthly the diodes in inverter for a year, and the total losses is 545.91 kWh/m², which is about 0.02 % of total energy.

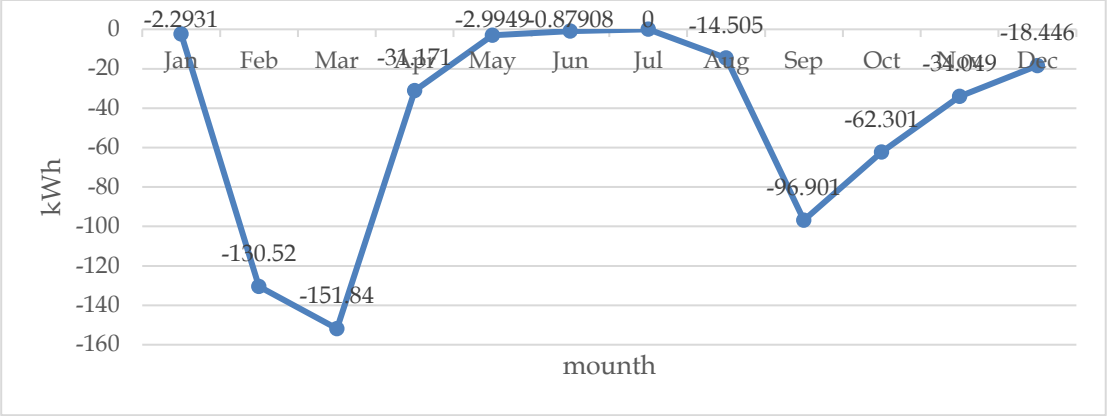


Fig3. 29: Losses in Diodes

- Mismatch (Manufacturer Information) :

Figure (3.30) shows the losses from the monthly Mismatch (Manufacturer Information) for a year, and the total losses is 59,151.00 kWh/m², which is about 2.00 % of total energy.

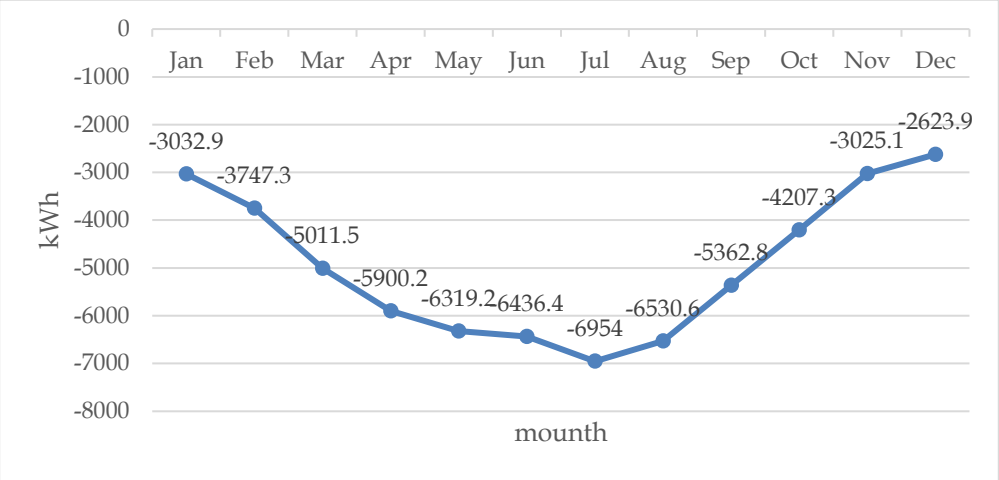


Fig3. 30: Mismatch (Manufacturer Information)

- Mismatch (Configuration/Shading):

Figure (3.31) shows the losses from the monthly Mismatch (Configuration/Shading) for a year, and the total losses is -2,310.05 kWh/m², which is about -0.08 % of total energy.

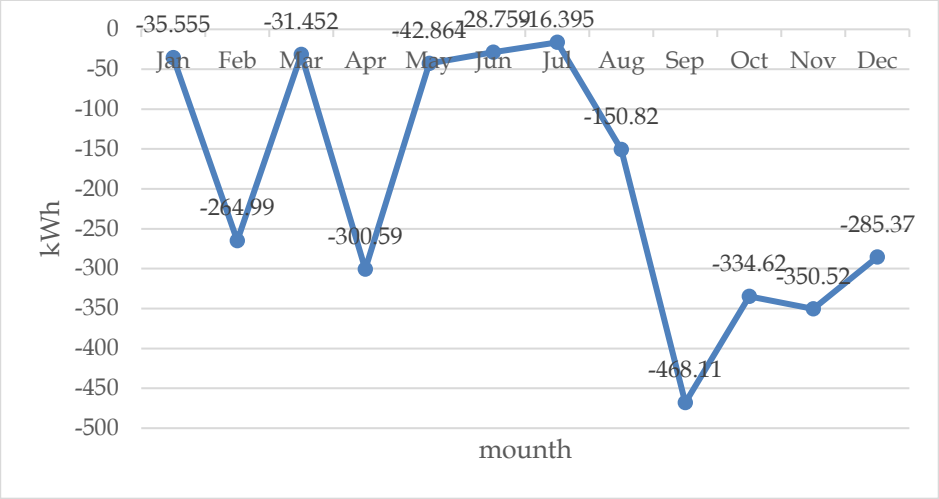


fig3. 31: Mismatch (Configuration/Shading)

Now, before going on to calculate the rest of losses, we can find the net energy arrived to the module by following.

PV Energy (DC) without inverter regulation = 3,349,591.3kWh-(20,464.15+75,463.90+295,567.25+545.91+59,151.00+59,151.00) kWh =**2,896,089.0 kWh**

- Regulation on account of the MPP Voltage Range :

Figure (3.32) shows the losses from the monthly the Regulation on account of the MPP Voltage Range for a year, and the total losses is 10,456.45kWh/m², which is about 0.36 % of total energy.

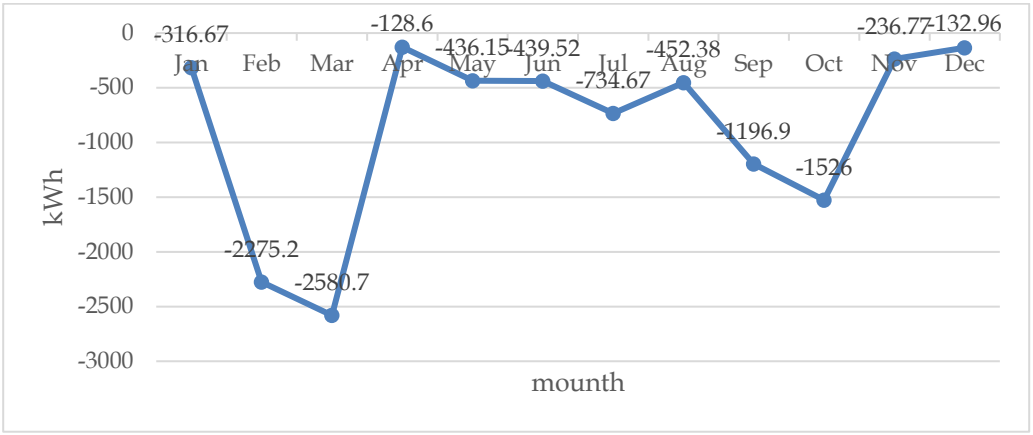


Fig3. 32: Regulation on Account of the MPP Voltage Range

- MPP Matching:

Figure (2.35) shows the losses from the monthly MPP matching (Maximum Power Point) for a year, and the total losses is 2,885.65 kWh/m², which is about 0.10 % of total energy.

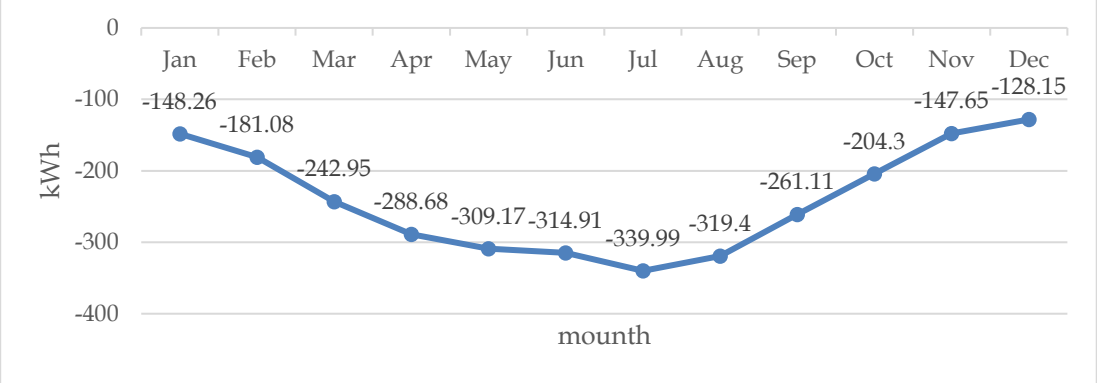


Fig3. 33: MPP Matching

Now, we calculate the Energy at the Inverter Input=PV energy (DC) 2,898,302.3kWh–(10,456.45 +2,885.65) =**2,882,746.9 kWh**

Figure (3.34) shows the losses from the monthly the Energy at the Inverter Input for a year, and the total losses is 2,885.65 kWh/m², which is about 0.10 % of total energy.

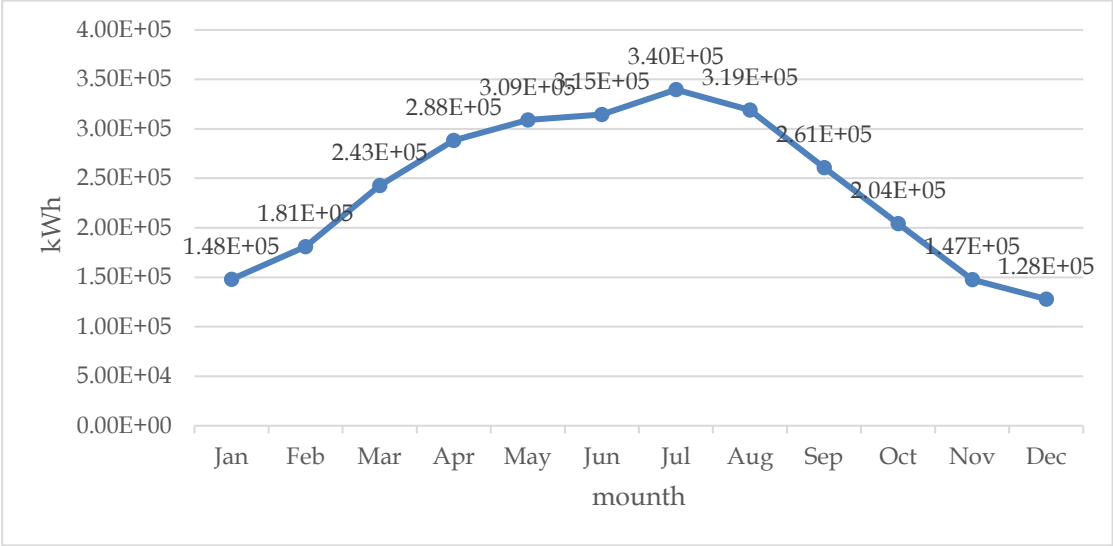


Fig3. 34: Energy at the Inverter Input

- Input Voltage Deviates From Rated Voltage:

Figure (3.35) shows the losses from the monthly the Input voltage deviates from rated voltage for a year, and the total losses is 7,549.23 kWh/m², which is about 0.26 % of total energy.

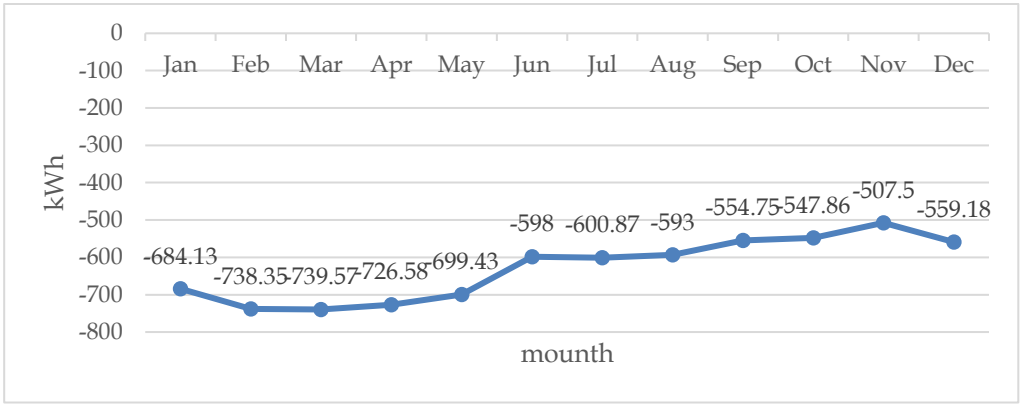


Fig3. 35: Input Voltage Deviates From Rated Voltage

- DC/AC Conversion :

Figure (3.36) shows the losses from the monthly the Conversion form DC to AC for a year, and the total losses is 75,817.05 kWh/m², which is about 0.26% of total energy.

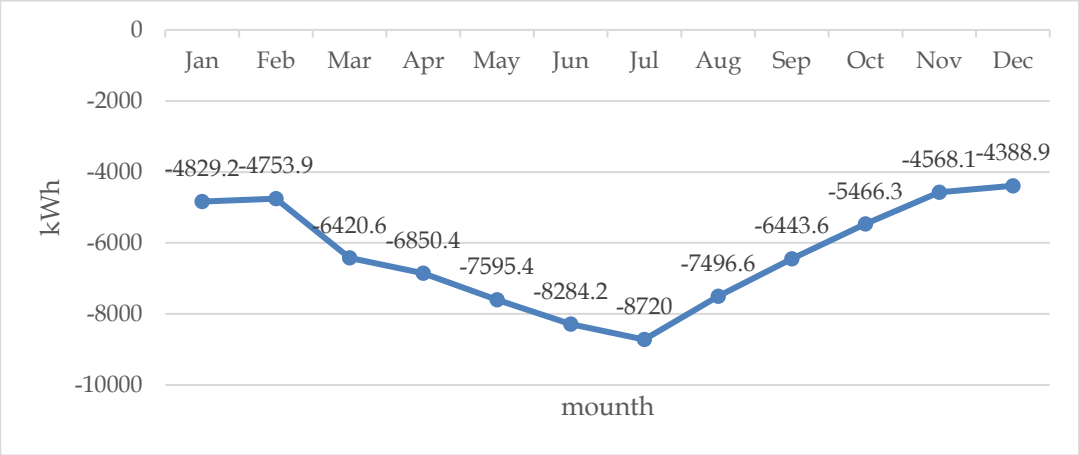


Fig3. 36: DC/AC Conversion

- Own Consumption (Standby or Night):

Figure (3.37) shows the losses from the monthly the Own Consumption for a year, and the total losses is 3,864.96 kWh/m², which is about 0.14 % of total energy.

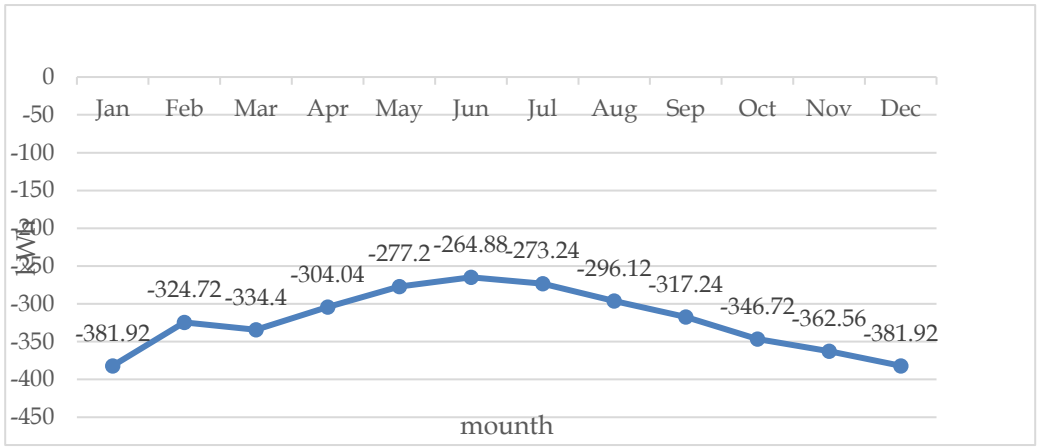


Fig3. 37: Own Consumption

- Regulation of Radiation Peaks

Figure (3.38) shows the losses from the monthly Regulation of Radiation Peaks for a year, and the total losses is 8,732.74 kWh/m², which is about 0.31 % of total energy.

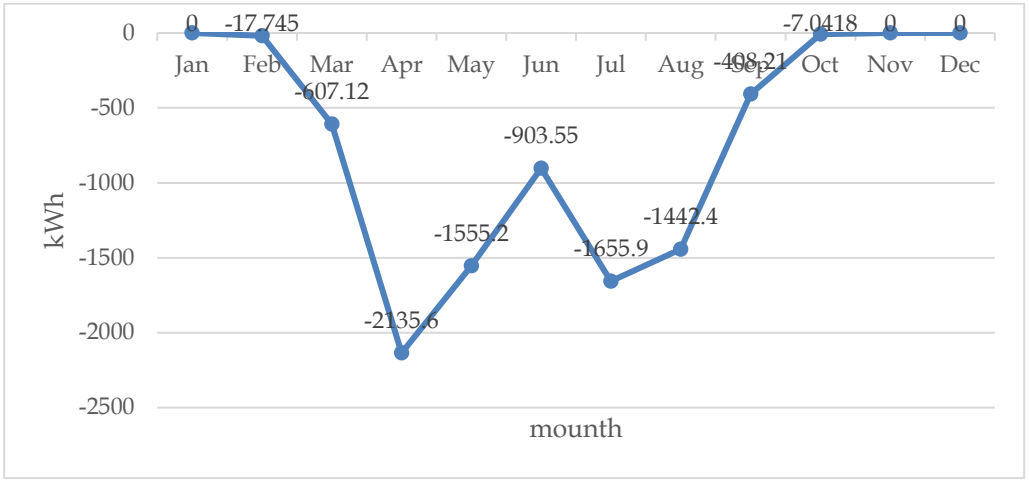


Fig3. 38: Regulation of Radiation Peaks

- Cable :

Figure (3.39) shows the losses from the monthly cable for a year, which is about 1% of total energy.

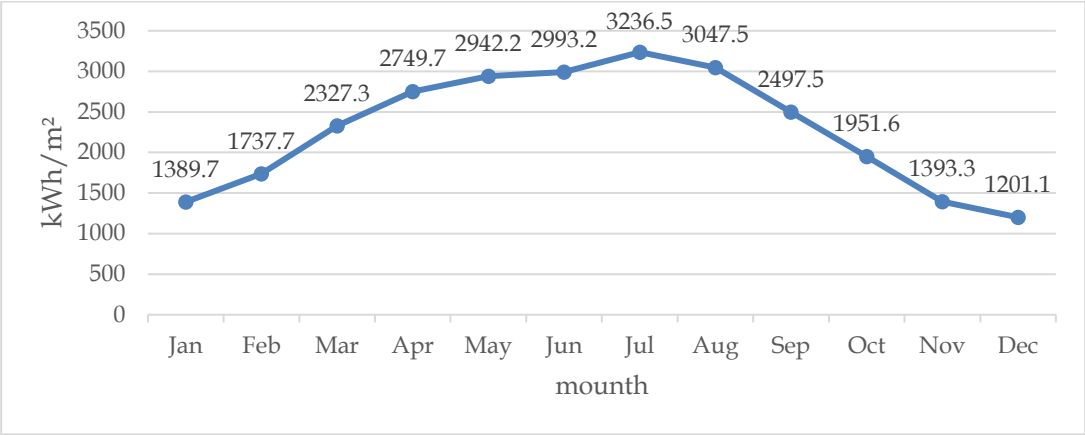


Fig3. 39: Total Cable Losses

**Annual Grid Feed-In Incl. Degradation of Module = 2,762,744.8 Kwh**

## 3.10 Total Energy Production For Each Site[21]

$V_{dc}=V_{PP}*N_{se}$ (3.1)

$I_{dc}=I_{pp}*N_{par}$ (3.2)

PV Generator Output = $V_{dc} * I_{dc}$ (3.3)

$V_{dc}$=DC voltage for position.

$I_{dc}$=DC current for position.

$V_{PP}$=voltage for one module.

$I_{pp}$=current for one module.

$N_{se}$=number of row in series

$N_{par}$=number of modules

As an example the PV generator output in ALSOF substation:

$V_{dc}$=63.6 V

$I_{dc}$=7.9 A

$N_{se=}$106

$N_{par}$=119

Vdc=63.6*106=6.75 KV (3.4)

Idc=7.9*119=0.9401 KA (3.5)

Output power=6.75*0.9401=6.36 MW (3.6)

Table (3.12) shown Annual Grid Feed-in incl. Degradation of Module in (kWh), PV Generator Output in (MW), and DC voltage in KV for each site.

Table3. 12: Production Account the Total Area Of Sites

| Position | The total area (hectares) | Annual Grid Feed-in incl. Degradation of Module(kwh) | PV Generator Output (MW) | $V_{dc}$ (KV) |
|---|---|---|---|---|
| **bin- waleed** | 34.5 | 3.13226E7 | 21.96 | 23.2944 |
| **Al-sof** | 10 | 9.079E6 | 6.36 | 6.75 |
| **Al-fuqhaa** | 7.5 | 6.80925E6 | 4.775 | 5.064 |
| **alantena** | 200 | 1.8158E8 | 127.33 | 135.04 |

# CHAPTER IV

# Load Flow & Short Circuit

## 4.1 Introduction

After a design of PV power plants in Bni-Walid were an accomplished , the PV power plant now is ready to connect to the grid , but before the connecting these section , a number of studies should be done . Therefore: the power system under study is simulated to investigate the impact of PV generation on PCC, load flow analysis and short circuit level. While the next chapter investigates the effect of harmonic.

## 4.2 Network Description

The network under-study is a real data of a Bin-Walid electrical network loop given from GECOL for the year of 2015 as shown in (APPENDIX A).

The network is consists of one substation of 220 KV of a main feeder and 13 substation of 66 KV distribution on all area of Bin-Walid city. The lines is about 446 KM and the max load is about 66.5 MW.

Tables (4.1, 4.2, 4.3, 4.4, and 4.5) shows the analysis result of network under study

Table4. 1: Loading Rate for Each Transformer 66KV

| No. | Substation name | Year2015 load each transformer | | | Loading |
|---|---|---|---|---|---|
| | | NO-TR | MW | MVAR | % |
| 1 | Bani waleed 220 | 3 | 22.526 | 11.967 | 40.48 |
| 2 | Bani waleed 1 | 3 | 0.667 | 0.328 | 3.71 |
| 3 | Shamik 66 | 1 | 0.5 | 0.248 | 11.16 |
| 4 | Tininai66 | 2 | 1.5 | 0.753 | 8.36 |
| 5 | Al-sof | 2 | 11.043 | 6.192 | 63.30 |
| 6 | Biot-alshabab | 1 | 4.507 | 2.318 | 25.34 |
| 7 | Bani waleed 2 | 2 | 8.526 | 4.640 | 48.53 |
| 8 | Al-fuqhaa | 1 | 3.001 | 4.566 | 33.84 |
| 9 | Sof aljeen | 2 | 1.350 | 0.677 | 15.10 |
| 10 | Al-sdada | 2 | 0.50 | 0.245 | 5.57 |
| 11 | Grza mjrora | 1 | 0.4 | 0.198 | 8.93 |
| 11 | Al-mrdoom | 2 | 1.9 | 0.965 | 21.31 |
| 12 | Al-shmalia | 2 | 2.502 | 1.255 | 14 |
| 13 | Wshtata | 1 | 0.6 | 0.3 | 13.42 |
| | | 1 | 1 | 0.496 | 11.16 |

Table4. 2: Data of the Cable Network Used in Bin-Walid 220 KV System

| Line From - To | Cable size mm² ( Bear) | No. of Circuits | Length KM | R Ω/KM | X Ω/KM | C UF/KM | Max current (A) | Loading MW | Loading MVAR |
|---|---|---|---|---|---|---|---|---|---|
| Bw1- Shm | 326.5 | 1 | 46 | 0.122 | 0.37 | 0.0097 | 480 | 1.810 | 0.731 |
| Shm- Tni | 326.5 | 1 | 14 | 0.122 | 0.37 | 0.0097 | 480 | 1.310 | 0.483 |
| Bw1- Tni | 326.5 | 1 | 60 | 0.122 | 0.37 | 0.0097 | 480 | 1.697 | 0.104 |
| Bw1- Sof | 326.5 | 2 | 6 | 0.122 | 0.37 | 0.0097 | 480 | 30.74 | 14.80 |
| Sof-Bw2 | 326.5 | 2 | 12 | 0.122 | 0.37 | 0.0097 | 480 | 14.44 | 7.499 |
| Bw2-fog | 326.5 | 1 | 26.5 | 0.122 | 0.37 | 0.0097 | 480 | 6.668 | 1.921 |
| Fog-jen | 326.5 | 1 | 28.1 | 0.122 | 0.37 | 0.0097 | 480 | 3.668 | 0.356 |
| Bw2-jen | 326.5 | 1 | 35.1 | 0.122 | 0.37 | 0.0097 | 480 | 4.254 | 0.959 |
| jen-sd | 326.5 | 2 | 40 | 0.122 | 0.37 | 0.0097 | 480 | 0.700 | 0.072 |
| Sd-gm | 326.5 | 1 | 70 | 0.122 | 0.37 | 0.0097 | 480 | 0.400 | 0.198 |
| Bw2-sha | 326.5 | 1 | 10 | 0.122 | 0.37 | 0.0097 | 480 | 5.014 | 2.419 |
| Bw2-wsh | 326.5 | 1 | 40 | 0.122 | 0.37 | 0.0097 | 480 | 1.6 | 0.796 |

Table4. 3: Bus Bar Data and the Percentage of Load for Bin-Walid 66KV

| No | Bus bar Name | Voltage (KV) | Voltage (%) |
|---|---|---|---|
| 1 | Bw220 | 220 | 100 |
| 2 | Bw1 | 64..381 | 97.55 |
| 3 | Tni | 64.023 | 97 |
| 4 | Sof | 63.502 | 96.22 |
| 5 | Bw 2 | 62.578 | 94.82 |
| 6 | Fogha | 62.408 | 94.56 |
| 7 | aljen | 92.121 | 94.12 |
| 8 | Sd | 62.14 | 94.15 |
| 9 | Grm | 62.175 | 94.2 |
| 10 | Mrd | 61.901 | 93.79 |
| 11 | Wash | 62.319 | 94.42 |
| 12 | Sha | 62.334 | 94.45 |
| 13 | Shm | 64.104 | 97.13 |

Table4. 4: Bus Bar Data and the Percentage of Load for Bin-Walid 11KV

| No. | Bus bar Name | Voltage (KV) | Voltage (%) |
|---|---|---|---|
| 1 | BW1 | 10.71 | 97.36 |
| 2 | Sham | 10.635 | 96.68 |
| 3 | Tni | 10.596 | 96.32 |
| 4 | Sof | 10.217 | 92.88 |
| 5 | b-sh | 10.434 | 94.86 |
| 6 | Bw 2 | 10.148 | 92.25 |
| 7 | Fogha | 10.244 | 93.13 |
| 8 | aljen | 10.284 | 93.49 |
| 9 | Sd | 10.331 | 93.92 |
| 10 | Grm | 10.332 | 93.83 |
| 11 | Mrd | 10.218 | 92.89 |
| 12 | Wash | 10.336 | 93.96 |
| 13 | Shm | 10.31 | 93.72 |

Table4. 5: Loads During the Year 2015

| No | Substation name | Load of year 2015 | |
|---|---|---|---|
| | | MW | Power factor |
| 1 | BW1 | 2.0 | 0.9 |
| 2 | Sham | 0.5 | 0.9 |
| 3 | Tni | 3.0 | 0.9 |
| 4 | Sof | 22 | 0.9 |
| 5 | b-sh | 4.5 | 0.9 |
| 6 | Bw 2 | 17 | 0.9 |
| 7 | Fogha | 3.0 | 0.9 |
| 8 | aljen | 2.7 | 0.9 |
| 9 | Sd | 1.0 | 0.9 |
| 10 | Grm | 0.4 | 0.9 |
| 11 | Mrd | 3.8 | 0.9 |
| 12 | Wash | 1.6 | 0.9 |
| 13 | Shm | 5.0 | 0.9 |
| **Total MW Required** | | **66.5** | **0.9** |

In the table (4.3 and 4.4) the result shown that: there are some busses voltage are under limit.

## 4.3 Studies Cases

In this case study ,the simulation is divided into a different scenarios , and each scenario contains load flow and short circuit cases studies the description of these scenario is a following the description of these scenario as following :

### 4.3.1 Scenario 1:Normal Network

In this scenario the simulation investigate the base network without any penetration of PV system, the result load flow shown in table (4.6), and the short circuit shown in table (4.7).

Table4. 6: Result Load Flow for Network Bin-Walid 220kv in 2015

| From Area/Zone | To Area/Zone | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load | Gen. Cost | Qc Shunt | Ql Shunt | Q Comp | Iron Losses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MW | MVar | MW | MVar | MW | MVar | MW | MVar | Curr. Units | MVar | MVar | MVar | MW |
| Area 1 | | 1.074 | 3.679 | 0 | 0 | 67.574 | 35.886 | 66.5 | 32.207 | 0 | 0 | 0 | 0 | 0 |
| Zone 1 | | 1.074 | 3.679 | 0 | 0 | 67.574 | 35.886 | 66.5 | 32.207 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | | | | | | |
| kV | | MW | MVar | MW | MVar | | | | | | | | | |
| 66 | | 0.767 | -3.54 | 0.152 | 3.35 | | | | | | | | | |
| 220 | | 0 | 0 | 0.155 | 3.869 | | | | | | | | | |

Table4. 7: Short Circuit Current Value in Network Bin-Walid 66 KV At 2015

| n | Fault location | Vn(KV) | Ik''(RST) ( KA) | AIK'' (RST) $^{o}$ | TYPE FAULT |
|---|---|---|---|---|---|
| 1 | BW220 | 220 | 9.037 | -83.56 | 3 phase fault |
| 2 | BW 1 | 66 | 11.518 | -86.67 | 3 phase fault |
| 3 | Tni | 66 | 2.751 | -75.23 | 3 phase fault |
| 4 | Sof | 66 | 8.772 | -83.05 | 3 phase fault |
| 5 | BW 2 | 66 | 5.961 | -79.32 | 3 phase fault |
| 6 | Fogha | 66 | 4.4 | -77.36 | 3 phase fault |
| 7 | aljen | 66 | 3.017 | -75.58 | 3 phase fault |
| 8 | Sd | 66 | 1.934 | -74.18 | 3 phase fault |
| 9 | Grm | 66 | 0.586 | 72.08 | 3 phase fault |
| 10 | Mrd | 66 | 2.224 | -74.56 | 3 phase fault |
| 11 | Wash | 66 | 1.852 | -74.08 | 3 phase fault |
| 12 | Shm | 66 | 3.824 | -76.62 | 3 phase fault |
| 13 | Sham | 66 | 2.871 | -75.39 | 3 phase fault |

From table (4.7) the result show that the short circuit is within limit

### 4.3.2 Scenario 2:PV Power Plant Connected To 66KV Substation

In this scenario all PV generation (1, 2, 3, 4) are connected to 66 KV substation

Table (4.9 &4.10) shown the result of load flow for (N&N-1), and table (4.11) shown the result of short circuit

Table4. 8: Bus Bar Data and the Percentage of Load For Bin-Walid 66kv For The Scenario 2

| No. | Bus bar Name | Voltage Kv | Voltage rate % |
|---|---|---|---|
| 1 | Bw220 | 220 | 100 |
| 2 | Bw1 | 66.201 | 100.3 |
| 3 | Tni | 72.227 | 109.43 |
| 4 | Sof | 66.151 | 100.23 |
| 5 | Bw 2 | 66.331 | 100.50 |
| 6 | Fogha | 66.590 | 100.89 |
| 7 | aljen | 66.185 | 100.28 |
| 8 | Sd | 66.224 | 100.34 |
| 9 | Grm | 66.281 | 100.43 |
| 10 | Mrd | 65.988 | 99.98 |
| 11 | Wash | 66.099 | 100.15 |
| 12 | Sha | 66.105 | 100.16 |
| 13 | Shm | 70.825 | 107.31 |

Table4. 9: Result for (N) When Connect PV (1, 2, 3, 4) To Network Bin-Walid 66 KV

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Network | | 7.951 | 32.602 | -89.513 | 41.69 | 163.964 | 23.118 | 156.013 | -9.483 |
| Area 1 | | 7.951 | 32.602 | 0 | 0 | 163.964 | 23.118 | 156.013 | -9.483 |
| Zone 1 | | 7.951 | 32.602 | 0 | 0 | 163.964 | 23.118 | 156.013 | -9.483 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 66 | | 7.093 | 15.497 | 0.36 | 4.656 | | | | |
| 135.04 | | 0 | 0 | 0.24 | 6.005 | | | | |
| 220 | | 0 | 0 | 0.258 | 6.444 | | | | |
| | | | | | | | | | |
| Overloads | | | | | | | | | |
| Elements | % | Type | | | | | | | |
| L1751 | 177.4 | Line | | | | | | | |

Table4. 10: Result For (N-1) When Connect PV (1, 2, 3, 4) To Network Bin-Walid 66 KV

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Network | | 31.852 | 105.443 | -65.612 | 70.984 | 163.964 | 66.666 | 132.112 | -38.777 |
| Area 1 | | 31.852 | 105.443 | 0 | 0 | 163.964 | 66.666 | 132.112 | -38.777 |
| Zone 1 | | 31.852 | 105.443 | 0 | 0 | 163.964 | 66.666 | 132.112 | -38.777 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 66 | | 30.872 | 87.546 | 0.485 | 5.538 | | | | |
| 135.04 | | 0 | 0 | 0.248 | 6.184 | | | | |
| 220 | | 0 | 0 | 0.247 | 6.175 | | | | |
| | | | | | | | | | |
| Overloads | | | | | | | | | |
| Elements | % | Type | | | | | | | |
| L1756 | 234.82 | Line | | | | | | | |
| L1077404148 | 233.88 | Line | | | | | | | |
| TR2-10774040 | 63.33 | 2W Transf | | | | | | | |
| TR2-10774040 | 63.33 | 2W Transf | | | | | | | |
| TR2-352 | 51.14 | 2W Transf | | | | | | | |
| TR2-10774044 | 51.14 | 2W Transf | | | | | | | |
| TR2-349 | 51.14 | 2W Transf | | | | | | | |

Table4. 11: Short Circuit Current Value66 KV in Network Bin-Walid When Connect PV (1, 2, 3, 4) To Busses Bin-Walid 66 KV

| N | Fault location | Vn (KV) | Ik''(RST) ( KA) | AIK'' (RST) $^{o}$ | TYPE FAULT |
|---|---|---|---|---|---|
| 1 | Bw220 | 220 | 12.27 | -81.86 | 3 phase fault |
| 2 | Bw1 | 66 | 13.98 | -86.28 | 3 phase fault |
| 3 | Tni | 66 | 9.304 | -79.82 | 3 phase fault |
| 4 | Sof | 66 | 13.06 | -81.29 | 3 phase fault |
| 5 | Bw 2 | 66 | 8.843 | -78.89 | 3 phase fault |
| 6 | Fogha | 66 | 6.090 | -77.02 | 3 phase fault |
| 7 | aljen | 66 | 3.676 | -74.79 | 3 phase fault |
| 8 | Sd | 66 | 2.184 | -73.53 | 3 phase fault |
| 9 | Grm | 66 | 0.902 | -72.45 | 3 phase fault |
| 10 | Mrd | 66 | 2.562 | -73.85 | 3 phase fault |
| 11 | Wash | 66 | 2.065 | -73.37 | 3 phase fault |
| 12 | Sha | 66 | 4.862 | -75.65 | 3 phase fault |
| 13 | Shm | 66 | 5.564 | -75.66 | 3 phase fault |
| 14 | Ant | 66 | 13.67 | -83.69 | phase fault |

In table (4.9 and 4.10) the result show that there is a loading on line (TENENAI-BANI WALID) is about 177% and the voltages at TENNAI and SHMIK is high where are 109.41% and 107.3 respectively.

In the table (4.11) the result shown that the PV power plant connection doesn't affect the short circuit level.

### 4.3.3 Scenario 3:Connect PV (1,2,4) Power Station To The Network Bin-Walid 66 KV & Connect PV3 To Bus Bar Bin-Walid 220 KV

In this scenario PV generation (1, 2, and 4) are connected to 66 KV substation and PV generation 3 is connected to 220 KV substation.

Table (4.12) the voltage in busses for network Bin-Walid, table (4.13 &4.14) shown the result of load flow for (N&N-1), and table (4.15) shown the result of short circuit.

Table4. 12: Bus Bar Data and the Percentage of Load for Bin-Walid 66kv For the Scenario 3

| No | Bus bar Name | Voltage (KV) | Voltage (%) |
|---|---|---|---|
| 1 | Bw220 | 220 | 100 |
| 2 | Bw1 | 64.537 | 97.78 |
| 3 | Tni | 64.180 | 97.24 |
| 4 | Sof | 64.624 | 97.92 |
| 5 | Bw 2 | 65.322 | 98.97 |
| 6 | Fogha | 65.457 | 99.18 |
| 7 | aljen | 65.077 | 98.60 |
| 8 | Sd | 65.109 | 98.65 |
| 9 | Grm | 65.159 | 98.73 |
| 10 | Mrd | 64.870 | 98.29 |
| 11 | Wash | 65.136 | 98.69 |
| 12 | Sha | 64.261 | 97.36 |
| 13 | Shm | 65.112 | 98.65 |

Table4. 13: Result for (N) From Scenario 3

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Network | | 1.816 | -7.4 | -92.978 | 23.848 | 161.294 | 0.959 | 159.478 | 8.359 |
| Area 1 | | 1.816 | -7.4 | 0 | 0 | 161.294 | 0.959 | 159.478 | 8.359 |
| Zone 1 | | 1.816 | -7.4 | 0 | 0 | 161.294 | 0.959 | 159.478 | 8.359 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 66 | | 0.154 | -5.781 | 0.308 | 4.274 | | | | |
| 220 | | 1.086 | -12.592 | 0.268 | 6.7 | | | | |

Table4. 14: Result for (N-1) From Scenario 3

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Network | | 1.829 | -7.358 | -92.965 | 23.876 | 161.294 | 0.973 | 159.465 | 8.331 |
| Area 1 | | 1.829 | -7.358 | 0 | 0 | 161.294 | 0.973 | 159.465 | 8.331 |
| Zone 1 | | 1.829 | -7.358 | 0 | 0 | 161.294 | 0.973 | 159.465 | 8.331 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 66 | | 0.166 | -5.742 | 0.308 | 4.275 | | | | |
| 220 | | 1.086 | -12.592 | 0.268 | 6.701 | | | | |

Table4. 15: Short Circuit Current Value 66kv in Network Bin-Walid from Scenario 3

| n | Fault location | Vn (KV) | Ik''(RST) ( KA) | AIK'' (RST) $^{o}$ | Type fault |
|---|---|---|---|---|---|
| 1 | Bw220 | 220 | 12.27 | -81.86 | 3 phase fault |
| 2 | Bw1 | 66 | 13.98 | -86.28 | 3 phase fault |
| 3 | Tni | 66 | 2.869 | -74.66 | 3 phase fault |
| 4 | Sof | 66 | 11.19 | -83.25 | 3 phase fault |
| 5 | Bw 2 | 66 | 8.108 | -80.47 | 3 phase fault |
| 6 | Fogha | 66 | 5.755 | -78.22 | 3 phase fault |
| 7 | aljen | 66 | 3.550 | -75.61 | 3 phase fault |
| 8 | Sd | 66 | 2.139 | -74.06 | 3 phase fault |
| 9 | Grm | 66 | 0.894 | -72.68 | 3 phase fault |
| 10 | Mrd | 66 | 2.501 | -74.45 | 3 phase fault |
| 11 | Wash | 66 | 2.024 | -73.87 | 3 phase fault |
| 12 | Sha | 66 | 4.636 | -76.70 | 3 phase fault |
| 13 | Shm | 66 | 2.999 | -74.79 | 3 phase fault |
| 14 | Ant | 220 | 10.18 | -79.56 | 3 phase fault |
| 15 | Pv1 | 32.294 | 10.95 | -80.45 | 3 phase fault |
| 16 | Pv2 | 6.750 | 19.68 | -88.00 | 3 phase fault |
| 17 | Pv3 | 135.04 | 12.89 | -84.67 | 3 phase fault |
| 18 | Pv4 | 5.064 | 18.654 | -84.88 | 3 phase fault |

From the results above its clear that all bus voltages and line loading of the network under study within their limit. And it can be noted that about 90 MW is distributed to the remaining 220 KV stations in the meddle Region, this means that the PVs with this connection can change the load flow distribution of Bin-Walid network.

### 4.3.4 Scenario 4: Connecting PVS (1,2,3,4) To 220 KV Meddle Region

In this scenario all PV generation (1, 2, 3, and 4) are connected to 220 KV substation.

Table (4.16, 4.17, and 4.18) shown the result for the network region 220 KV.

Table4. 16: Substation Name 220 KV in Meddle Region

| No. | Substation Name | Code | Voltage (KV) | P (MW) | Q (MVAR) |
|---|---|---|---|---|---|
| 1 | GRBUL2 | GR2 | 220 | 74 | 35.8 |
| 2 | HOMS SOUTH | HS | 220 | 3 | 1 |
| 3 | HOMS POWER | HP | 220 | 45 | 16 |
| 4 | HOMS SWITCH | HSW | 220 | 65 | 24 |
| 5 | KAAM | KA | 220 | 28 | 13 |
| 6 | ZLETN | ZL | 220 | 93 | 43.5 |
| 7 | TMVSOUTH | TS | 220 | 96 | 34 |
| 8 | CMNTZ | CM | 220 | 5 | 2.4 |
| 9 | BNWALD | BW | 220 | 67.6 | 35.9 |
| 10 | GMMRA1 | GM1 | 400 | 5.6 | 2.8 |
| 11 | SDADA | SD | 220 | 1 | 0.5 |
| 12 | ZAMZAM | ZM | 220 | 12 | 3.1 |
| 13 | MSRST | MS | 220 | 230 | 111.4 |
| 14 | MSRTE | ME | 220 | 147 | 68 |
| 15 | SIRST | SR | 220 | 94 | 37 |

Table4. 17: Unit in Power Station

| No. | Substation Name | NO. of unit | $V_{rating}$ KV | P(MW) for rach unit | $S_{rating}$ MVA |
|---|---|---|---|---|---|
| 1 | HOMS POWER | 4-HMP-ST | 10.5 | 127 | 158.75 |
| | | 4-HMP-GT | 15.75 | 168 | 210 |
| | | 1-SM | 15.8 | 178.5 | 210 |
| 3 | ZLETN | 220 | 15.8 | 178.5 | 210 |
| 3 | MSRTS | 6-MST-ST | 20 | 269.6 | 337 |
| | | 2-PS | | | |
| 4 | MSRTE | 1-GT | 11 | 29.75 | 35 |

Table4. 18: Conductor in Meddle Region

| N | Conductor name | Size $mm^2$ | voltage (KV) | max current (A) | R Ω/KM | X Ω/KM | C UF/KM |
|---|---|---|---|---|---|---|---|
| 1 | 400O.H.L | 413.5 | 400 | 800 | 0.0279 | 0.311 | 0.116 |
| 2 | AL ALLOY BUNDLE | 413.5 | 220 | 800 | 0.0397 | 0.3108 | 0.1165 |
| 3 | SUPER CONDUCTOR SINGLE | 365 | 220 | 800 | 0.0898 | 0.4275 | 0.00867 |
| 4 | RUSSIAN BUNDLE | 413.5 | 220 | 800 | 0.04 | 0.3011 | 0.01180 |
| 5 | RADWING | 413.5 | 220 | 800 | 0.0407 | 0.3031 | 0.1180 |

Table (4.19 &4.20) shown the result of load flow for (N&N-1), table (4.21) shown the result of voltage in busses, and table (4.22) shows the result short circuit.

Table4. 19: Summary for Electrical Power Network of 220kv to Meddle Region for the Year 2015(N)

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Zone 3 | | 24.263 | -772.911 | -783.164 | -141.915 | 1764 | 149.951 | 956.573 | 425.722 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 220 | | 131.371 | -1569.865 | 16.92 | 443.272 | | | | |
| 400 | | 7.161 | -1089.316 | 8.899 | 298.894 | | | | |
| | | | | | | | | | |
| From | To | | | P Tie | Q Tie | P Tie Sch | | | |
| Area/Zone | Area/Zone | | | MW | MVar | MW | | | |
| Zone 2 | Zone 3 | | | -479.608 | -239.201 | | | | |
| Zone 3 | Zone 4 | | | 564.023 | -143.61 | | | | |
| Zone 3 | zone 5 | | | -260.467 | 46.324 | | | | |

Table4. 20: Summary for Electrical Power Network of 220 KV to the Meddle Region for (N-1)

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Zone 3 | | 24.538 | -770.992 | -782.889 | -141.249 | 1764 | 151.138 | 956.573 | 425.722 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 220 | | 131.601 | -1568.143 | 16.922 | 443.319 | | | | |
| 400 | | 7.163 | -1089.156 | 8.894 | 298.78 | | | | |
| | | | | | | | | | |
| From | To | | | P Tie | Q Tie | P Tie Sch | | | |
| Area/Zone | Area/Zone | | | MW | MVar | MW | | | |
| Zone 2 | Zone 3 | | | -479.616 | -238.526 | | | | |
| Zone 3 | Zone 4 | | | 564.03 | -143.545 | | | | |
| Zone 3 | zone 5 | | | -260.758 | 46.269 | | | | |
| | | | | | | | | | |
| Overloads | | | | | | | | | |
| Nodes (lower | % | | | | | | | | |
| Elements | % | Type | | | | | | | |
| HMP-HMSW220 | 72.29 | Line | | | | | | | |
| HMP-HMSW220 | 72.29 | Line | | | | | | | |

Table4. 21: Bus Bar Data and the Percentage of Load for 220 KV to the Meddle Region

| No. | Bus bar Name | Voltage (KV) | Voltage (%) |
|---|---|---|---|
| 1 | GRBUL2 | 214.5 | 97.5 |
| 2 | HOMS SOUTH | 219 | 99.6 |
| 3 | HOMS POWER | 219.1 | 99.6 |
| 4 | HOMS SWITCH | 217.3 | 98.8 |
| 5 | KAAM | 217.3 | 98.8 |
| 6 | ZLETN | 217.5 | 98.9 |
| 7 | TMVSOUTH | 218.4 | 99.3 |
| 8 | CMNTZ | 219 | 99.6 |
| 9 | BNWALD | 224.6 | 102.1 |
| 10 | GMMRA1 | 407 | 102 |
| 11 | SDADA | 225.7 | 102.6 |
| 12 | ZAMZAM | 225.5 | 102.5 |
| 13 | MSRST | 218.2 | 99.2 |
| 14 | MSRTE | 218 | 99.1 |
| 15 | SIRST | 225.9 | 102.7 |

Table4. 22: Short Circuit in Network of 220 KV to the Meddle Region for the Year 2015

| n | Fault location | Vn (KV) | Ik"(RST) ( KA) | AIK" (RST) $^{O}$ | TYPE FAULT |
|---|---|---|---|---|---|
| **1** | HOMSW2 -B1 | 220 | 29.421 | -84.74 | 3phase fault |
| **2** | HOMSW2 -B2 | 220 | 26.757 | -83.93 | 3phase fault |
| **3** | MSRST2-B1 | 220 | 21.452 | -85.01 | 3phase fault |
| **4** | MSRST2-B2 | 220 | 21.452 | -85.01 | 3phase fault |
| **5** | MSRTA2-B1 | 220 | 21.265 | -85.02 | 3phase fault |
| **6** | MSRTA2-B2 | 220 | 21.265 | -85.02 | 3phase fault |
| **7** | GRBUL2 -B1 | 220 | 27.696 | -83.64 | 3phase fault |
| **8** | GRBUL2 -B2 | 220 | 27.696 | -83.64 | 3phase fault |

| | | | | | |
|---|---|---|---|---|---|
| **9** | MSRTE2-B1 | 220 | 20.172 | -84.23 | 3phase fault |
| **10** | MSRTE2-B2 | 220 | 20.172 | -84.23 | 3phase fault |
| **11** | BNWLD2-B1 | 220 | 8.637 | -83.27 | 3phase fault |
| **12** | BNWLD2-B2 | 220 | 8.637 | -83.27 | 3phase fault |
| **13** | KALEJ2-B2 | 220 | 10.241 | -84.33 | 3phase fault |
| **14** | ZAMZM2-B2 | 220 | 11.941 | -83.58 | 3phase fault |
| **15** | KALEJ2-B1 | 220 | 10.241 | -84.33 | 3phase fault |
| **16** | ZAMZM2-B1 | 220 | 11.941 | -83.58 | 3phase fault |
| **17** | SIRST2-B1 | 220 | 8.749 | -83.98 | 3phase fault |
| **18** | SIRST2-B2 | 220 | 8.749 | -83.98 | 3phase fault |
| **19** | CMNTZ2-B1 | 220 | 12.265 | -83.40 | 3phase fault |
| **20** | HOMSP2 -B1 | 220 | 29.358 | -84.76 | 3phase fault |
| **21** | HOMSP2-3 | 220 | 29.358 | -84.76 | 3phase fault |
| **22** | HOMSP2 -B2 | 220 | 27.166 | -84.00 | 3phase fault |
| **23** | SDASA2-B1 | 220 | 9.317 | -83.31 | 3phase fault |
| **24** | SDASA2-B2 | 220 | 9.317 | -83.31 | 3phase fault |
| **25** | HOMSP2 -B4 | 220 | 27.166 | -83.99 | 3phase fault |
| **26** | WKAAM2-B1 | 220 | 15.172 | -81.21 | 3phase fault |
| **27** | WKAAM2-B2 | 220 | 14.812 | -81.11 | 3phase fault |
| **28** | ZLETN2 -B1 | 220 | 17.774 | -82.09 | 3phase fault |
| **29** | HOMSWT B-1 | 220 | 23.677 | -82.51 | 3phase fault |
| **30** | HOMSWT B-2 | 220 | 23.677 | -82.51 | 3phase fault |
| **31** | ZLETN2 -B2 | 220 | 17.774 | -82.09 | 3phase fault |
| **32** | HOMSW2 -B3 | 220 | 29.421 | -84.73 | 3phase fault |
| **33** | HOMSW2 -B4 | 220 | 26.757 | -83.94 | 3phase fault |
| **34** | TMNSW2-B1 | 220 | 22.119 | -84.47 | 3phase fault |
| **35** | TMNSW2-B2 | 220 | 22.119 | -84.47 | 3phase fault |
| **36** | GMMR14-B1 | 400 | 3.143 | -84.63 | 3phase fault |
| **37** | HOMS4-B1 | 400 | 10.271 | -86.11 | 3phase fault |
| **38** | KALEJ4-B2 | 400 | 5.800 | -84.80 | 3phase fault |

### 4.3.5 Scenario 5:Reduce 163 MW From Koms Power Station And Add 163 MW PV

Table (4.23) shown the result of voltage in busses, table (4.24&4.25) shown the result load flow when reduce 163 MW from koms power station and add 163 MW PV, and table (4.26) shows the result short circuit.

Table4. 23: Bus Bar Data and the Percentage of Load for 220 KV to the Meddle Region

| No. | Bus bar Name | Voltage (KV) | Voltage (%) |
|---|---|---|---|
| 1 | GRBUL2 | 214.5 | 97.5 |
| 2 | HOMS SOUTH | 219 | 99.6 |
| 3 | HOMS POWER | 219.1 | 99.6 |
| 4 | HOMS SWITCH | 217.3 | 98.8 |
| 5 | KAAM | 217.3 | 98.8 |
| 6 | ZLETN | 217.5 | 98.9 |
| 7 | TMVSOUTH | 218.4 | 99.3 |
| 8 | CMNTZ | 219 | 99.6 |
| 9 | BNWALD | 224.6 | 102.1 |
| 10 | GMMRA1 | 407 | 102 |
| 11 | SDADA | 225.7 | 102.6 |
| 12 | ZAMZAM | 225.5 | 102.5 |
| 13 | MSRST | 218.2 | 99.2 |
| 14 | MSRTE | 218 | 99.1 |
| 15 | SIRST | 225.9 | 102.7 |

Table4. 24: Summary When Reduce 163 MW from Koms Power Station and Add 163 Mw PV (N)

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Zone 3 | | 19.99 | -818.55 | -624.437 | -181.788 | 1601 | 143.906 | 956.573 | 425.722 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 220 | | 129.803 | -1578.763 | 17.033 | 446.123 | | | | |
| 400 | | 6.616 | -1095.015 | 8.803 | 296.662 | | | | |
| | | | | | | | | | |
| From | To | | | P Tie | Q Tie | P Tie Sch | | | |
| Area/Zone | Area/Zone | | | MW | MVar | MW | | | |
| ZONE 1 | Zone 3 | | | 162.238 | -34.434 | | | | |
| Zone 2 | Zone 3 | | | -479.608 | -237.826 | | | | |
| Zone 3 | Zone 4 | | | 564.881 | -136.499 | | | | |
| Zone 3 | zone 5 | | | -257.813 | 46.027 | | | | |

Table4. 25: Summary When Reduce 163 MW from Koms Power Station and Add 163 Mw PV (N-1)

| From | To | P Loss | Q Loss | P Imp | Q Imp | P Gen | Q Gen | P Load | Q Load |
|---|---|---|---|---|---|---|---|---|---|
| Area/Zone | Area/Zone | MW | MVar | MW | MVar | MW | MVar | MW | MVar |
| Zone 3 | | 20.149 | -817.468 | -624.278 | -181.365 | 1601 | 144.536 | 956.573 | 425.722 |
| | | | | | | | | | |
| Un | | P Loss Li | Q Loss L | P Loss T | Q Loss | | | | |
| kV | | MW | MVar | MW | MVar | | | | |
| 220 | | 129.937 | -1577.791 | 17.034 | 446.147 | | | | |
| 400 | | 6.617 | -1094.944 | 8.799 | 296.583 | | | | |
| | | | | | | | | | |
| From | To | | | P Tie | Q Tie | P Tie Sch | | | |
| Area/Zone | Area/Zone | | | MW | MVar | MW | | | |
| Zone 2 | Zone 3 | | | -479.613 | -237.449 | | | | |
| Zone 3 | Zone 4 | | | 564.885 | -136.464 | | | | |
| Zone 3 | zone 5 | | | -257.982 | 46.006 | | | | |
| | | | | | | | | | |
| Overloads | | | | | | | | | |
| Nodes (lower | % | | | | | | | | |
| Elements | % | Type | | | | | | | |
| HMP-HMSW220 | 54.87 | Line | | | | | | | |
| HMP-HMSW220 | 54.87 | Line | | | | | | | |

Table4. 26: Short Circuit When Reduce 163 MW from Koms Power Station and Add 163 Mw PV

| N | Fault location | Vn (KV) | Ik"(RST) ( KA) | AIK" (RST) o | TYPE FAULT |
|---|---|---|---|---|---|
| **1** | HOMSW2 -B1 | 220 | 27.898 | -84.54 | 3phase fault |
| **2** | HOMSW2 -B2 | 220 | 26.798 | -83.98 | 3phase fault |
| **3** | MSRST2-B1 | 220 | 21.542 | -85.01 | 3phase fault |
| **4** | MSRST2-B2 | 220 | 21.542 | -85.01 | 3phase fault |
| **5** | MSRTA2-B1 | 220 | 21.354 | -85.03 | 3phase fault |
| **6** | MSRTA2-B2 | 220 | 21.354 | -85.03 | 3phase fault |
| **7** | GRBUL2 -B1 | 220 | 27.448 | -83.64 | 3phase fault |
| **8** | GRBUL2 -B2 | 220 | 27.448 | -83.64 | 3phase fault |
| **9** | MSRTE2-B1 | 220 | 20.261 | -84.24 | 3phase fault |
| **10** | MSRTE2-B2 | 220 | 20.261 | -84.24 | 3phase fault |
| **11** | BNWLD2-B1 | 220 | 10.652 | -84.09 | 3phase fault |
| **12** | BNWLD2-B2 | 220 | 10.652 | -84.09 | 3phase fault |
| **13** | KALEJ2-B2 | 220 | 10.346 | -84.34 | 3phase fault |
| **14** | ZAMZM2-B2 | 220 | 12.297 | -83.64 | 3phase fault |
| **15** | KALEJ2-B1 | 220 | 10.346 | -84.34 | 3phase fault |
| **16** | ZAMZM2-B1 | 220 | 12.297 | -83.64 | 3phase fault |
| **17** | SIRST2-B1 | 220 | 8.819 | -83.99 | 3phase fault |
| **18** | SIRST2-B2 | 220 | 8.819 | -83.99 | 3phase fault |
| **19** | CMNTZ2-B1 | 220 | 12.119 | -83.37 | 3phase fault |
| **20** | HOMSP2 -B1 | 220 | 27.294 | -84.49 | 3phase fault |
| **21** | HOMSP2-3 | 220 | 27.295 | -84.49 | 3phase fault |
| **22** | HOMSP2 -B2 | 220 | 27.153 | -84.04 | 3phase fault |
| **23** | SDASA2-B1 | 220 | 9.718 | -83.41 | 3phase fault |
| **24** | SDASA2-B2 | 220 | 9.718 | -83.41 | 3phase fault |
| **25** | HOMSP2 -B4 | 220 | 27.152 | -84.04 | 3phase fault |
| **26** | WKAAM2-B1 | 220 | 14.970 | -81.22 | 3phase fault |
| **27** | WKAAM2-B2 | 220 | 14.799 | -81.12 | 3phase fault |

| | | | | | |
|---|---|---|---|---|---|
| **28** | ZLETN2 -B1 | 220 | 17.709 | -82.10 | 3phase fault |
| **29** | HOMSWT B-1 | 220 | 23.275 | -82.51 | 3phase fault |
| **30** | HOMSWT B-2 | 220 | 23.275 | -82.51 | 3phase fault |
| **31** | ZLETN2 -B2 | 220 | 17.709 | -82.10 | 3phase fault |
| **32** | HOMSW2 -B3 | 220 | 27.898 | -84.54 | 3phase fault |
| **33** | HOMSW2 -B4 | 220 | 26.798 | -83.98 | 3phase fault |
| **34** | TMNSW2-B1 | 220 | 22.232 | -84.49 | 3phase fault |
| **35** | TMNSW2-B2 | 220 | 22.232 | -84.49 | 3phase fault |
| **36** | GMMR14-B1 | 400 | 3.215 | -84.69 | 3phase fault |
| **37** | HOMS4-B1 | 400 | 10.240 | -86.06 | 3phase fault |
| **38** | KALEJ4-B2 | 400 | 5.842 | -84.82 | 3phase fault |

From the results illustrated above an improvement in the bus voltages, lines loading as well as the losses in the network of meddle region.

Here either the short circuit level is within limit according to IEC60909 standard whishes applied for GECOL.

# CHAPTER V

# Harmonics Analysis

## 5.1 Definitions

Harmonics are sinusoidal voltage or currents having frequencies that are multiples of the frequency at which the supply system is designed to operate (50 or 60 Hz).[21]

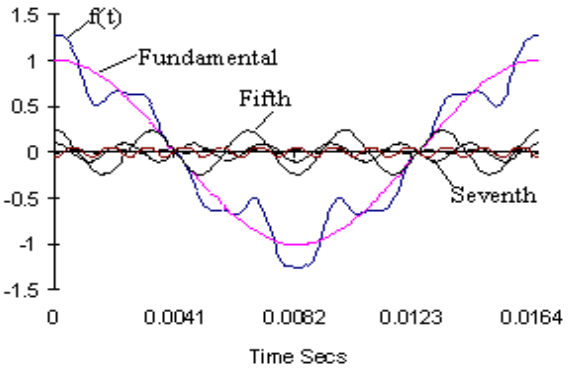


Fig5. 1: Example of Voltage/Current Waveform With Harmonics[21]

The harmonic spectrum of a wave shape represents the value RMS of every harmonic as percentage of the value RMS of the fundamental[21].

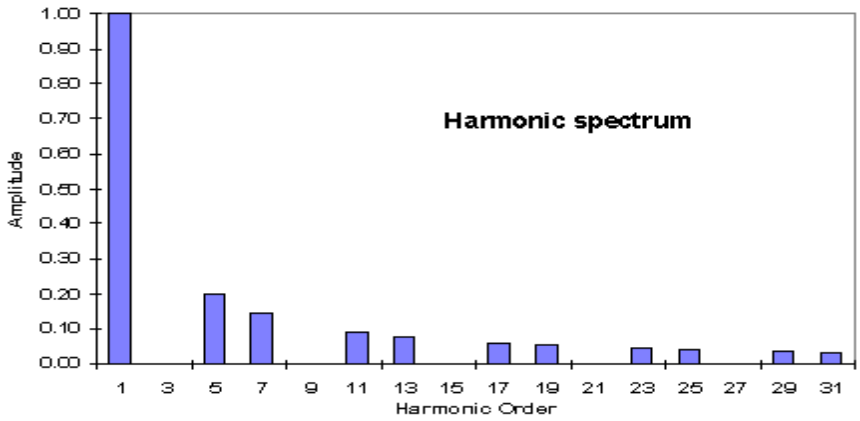


Fig5. 2: Example of Voltage/Current Harmonic Spectrum

## 5.2 Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) is a widely used notion in defining the level of harmonic content in alternating signals. This value is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. This THD value is used for low, medium, and

high voltage systems. Usually the current distortion is defined as THDi and the voltage distortion as THDv.[22]

### 5.2.1 Total Harmonic Distortion of Voltage (THDv)

Total Harmonic Distortion of Voltage (THDv) indicates the total magnitude of the voltage distortion. This value is defined as the ratio (in %) of the harmonic voltage to the fundamental (non-harmonic) voltage. Typically, the geometrical sum of all voltage harmonics is calculated in relation to the fundamental frequency voltage up to the 50th harmonic order[22]

$$\mathrm{THD_v} = \frac{\sqrt{\mathrm{V2}^2+\mathrm{V3}^2+V4^2+V5^2+\cdots}}{V1} \times 100 \qquad (5.1)$$

Where Vn is the RMS voltage of the nth harmonic and n = 1 is the fundamental frequency.

### 5.2.2 Total Harmonic Distortion of Current (THDi)

Total Harmonic Distortion of Current (THDi) indicates the total harmonic current distortion of the wave form. This value is defined as the ratio (in %) of the harmonic current to the fundamental (non-harmonic) current measured at a load point at the particular moment when the measurement is taken. Typically, the geometrical sum of all current harmonics is calculated in relation to the fundamental frequency current up to the 50th harmonic order[22]:

$$\mathrm{THD_i} = \frac{\sqrt{\mathrm{I2}^2+\mathrm{I3}^2+\mathrm{I4}^2+\mathrm{I5}^2+\cdots}}{\mathrm{I1}} \times 100 \qquad (5.2)$$

Where In is the RMS current of the nth harmonic and n = 1 is the fundamental frequency.

Usually the distorting loads inject current affected by harmonic content and this generate a voltage distortion in the electrical network and point of common coupling of other loads.

## 5.3 Point of Common Coupling (or Point of Common Connection)

The PCC is a point in the electrical system where multiple customers or multiple electrical loads may be connected[23, 24].

## 5.4 Standard G5/4

Engineering Recommendation G5/4 for UK and Hong Kong sets the planning levels for harmonic voltage distortion to be used in the process for the connection of non-linear equipment. These planning levels are set with respect to harmonic voltage distortion compatibility levels. For systems less than 35kV these are set by International Standards. For systems above 35kV by the compatibility levels appropriate to the UK. A process for establishing individual customer emission limits based on these planning levels is described. The planning levels of harmonic voltage distortion should not normally be exceeded when considering the connection of non-linear loads and generating plant to Transmission Systems under the Grid Codes, or to Distribution Networks under the Distribution Codes[24, 25].

The THD limit for the voltage system at PCC is present in the table (5.1)

Table5. 1: THD Planning Levels [24]

| System Voltage at the PCC | THD Limit |
|---|---|
| 400V | 5% |
| 6.6, 11 and 20kV | 4% |
| 22kV to 400kV | 3% |

While table (5.2) gives the Maximum allowable harmonic current for aggregate loads / equipment rated >16A per phase at 400V.

Table5. 2::Maximum Allowable Harmonic Current For Aggregate Loads / Equipment Rated >16a Per Phase At 400v [24]

| Harmonic order (h) | Emission current (Ih) | Harmonic order (h) | Emission current (Ih) | Harmonic order (h) | Emission current (Ih) |
|---|---|---|---|---|---|
| **2** | 28.9 | **19** | 9.1 | **36** | 0.4 |
| **3** | 48.1 | **20** | 1.4 | **37** | 2.1 |
| **4** | 9 | **21** | 0.7 | **38** | 0.8 |
| **5** | 28.9 | **22** | 1.3 | **39** | 0.4 |
| **6** | 3 | **23** | 7.5 | **40** | 0.7 |
| **7** | 41.2 | **24** | 0.6 | **41** | 1.8 |
| **8** | 7.2 | **25** | 4 | **42** | 0.3 |
| **9** | 9.6 | **26** | 1.1 | **43** | 1.6 |
| **10** | 5.8 | **27** | 0.5 | **44** | 0.7 |
| **11** | 39.4 | **28** | 1 | **45** | 0.3 |
| **12** | 1.2 | **29** | 3.1 | **46** | 0.6 |
| **13** | 27.8 | **30** | 0.5 | **47** | 1.4 |
| **14** | 2.1 | **31** | 2.8 | **48** | 0.3 |
| **15** | 1.4 | **32** | 0.9 | **49** | 1.3 |
| **16** | 1.8 | **33** | 0.4 | **50** | 0.6 |
| **17** | 13.6 | **34** | 0.8 | | |
| **18** | 0.8 | **35** | 2.3 | | |

Table (5.3) gives Maximum allowable harmonic current per customer at HV in amps RMS per phase.

Table5. 3: Maximum Allowable Harmonic Current per Customer At HV In Amps RMS Per Phase

| Harmonic order (h) | PCC on 6.6 - 20kV | PCC on 22kV | Harmonic order (h) | PCC on 6.6 - 20kV | PCC on 22kV |
|---|---|---|---|---|---|
| **2** | 4.9 | 3.3 | **27** | 0.1 | 0.1 |
| **3** | 6.6 | 4.4 | **28** | 0.2 | 0.2 |
| **4** | 1.6 | 1.3 | **29** | 0.8 | 0.8 |
| **5** | 3.9 | 2.6 | **30** | 0.1 | 0.1 |
| **6** | 0.6 | 0.6 | **31** | 0.7 | 0.7 |
| **7** | 7.4 | 5 | **32** | 0.2 | 0.2 |
| **8** | 0.9 | 0.9 | **33** | 0.1 | 0.1 |
| **9** | 1.8 | 1.5 | **34** | 0.2 | 0.2 |
| **10** | 1.4 | 1.4 | **35** | 0.6 | 0.6 |
| **11** | 6.3 | 4.7 | **36** | 0.1 | 0.1 |
| **12** | 0.2 | 0.2 | **37** | 0.5 | 0.5 |
| **13** | 5.3 | 4 | **38** | 0.2 | 0.2 |
| **14** | 0.5 | 0.5 | **39** | 0.1 | 0.1 |
| **15** | 0.3 | 0.3 | **40** | 0.2 | 0.2 |
| **16** | 0.4 | 0.4 | **41** | 0.4 | 0.4 |
| **17** | 3.3 | 2 | **42** | 0.1 | 0.1 |
| **18** | 0.2 | 0.3 | **43** | 0.4 | 0.4 |
| **19** | 2.2 | 1.8 | **44** | 0.2 | 0.2 |
| **20** | 0.3 | 0.3 | **45** | 0.1 | 0.1 |
| **21** | 0.1 | 0.1 | **46** | 0.2 | 0.2 |
| **22** | 0.3 | 0.3 | **47** | 0.3 | 0.3 |
| **23** | 1.8 | 1.1 | **48** | 0.1 | 0.1 |
| **24** | 0.1 | 0.1 | **49** | 0.3 | 0.3 |
| **25** | 1 | 1 | **50** | 0.1 | 0.1 |
| **26** | 0.3 | 0.3 | | | |

## 5.5 Harmonic Analysis

The purpose of processing the harmonics is to get on the wave of the current and voltage is clear and fine accompaniment to any interference which is produced by the equipment means for process of l within the network and which include power plants

### 5.5.1 Scenario 1 : With PVS Connected To 66KV

❖ **Without Filter**

In this scenario know the extent of the presence of harmonics and what they were when the permitted level or not.

Table (5.4) shown the result THDv in the scenario 1 without filter

Table5. 4: Results Of THDv in the 1st Scenario Without Filter

| N | Sub-station name | $V_n$ kV | THDv % | High order harmonic Order | High order harmonic Distortion% |
|---|---|---|---|---|---|
| **1** | bin- waleed | 66 | 14.62 | 17 | 13.2 |
| **2** | Al-sof | 66 | 15.35 | 17 | 14.2 |
| **3** | Al-fuqhaa | 66 | 13.30 | 17 | 11.5 |
| **4** | Alantena | 66 | 47.56 | 17 | 46 |
| **5** | Pv 1 | 23.2944 | 13.90 | 17 | 12.5 |
| **6** | Pv2 | 6.75 | 14.37 | 17 | 13.5 |
| **7** | Pv3 | 5.064 | 12.44 | 17 | 10.25 |
| **8** | Pv4 | 135.04 | 44.93 | 17 | 42.2 |

In the following figures the harmonic spectrum for each bus-bar that mentioned above.

- Bin- Walid 66Kv-1st Scenario Without Filter

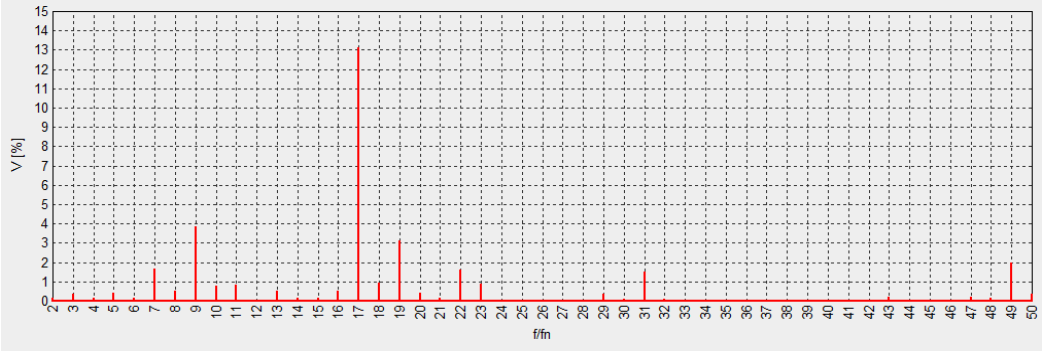


Fig5. 3: Harmonic Voltage Distortion at Bin- Walid 66kv-1st Scenario without Filter

- Al-Sof 66Kv-1st Scenario Without Filter

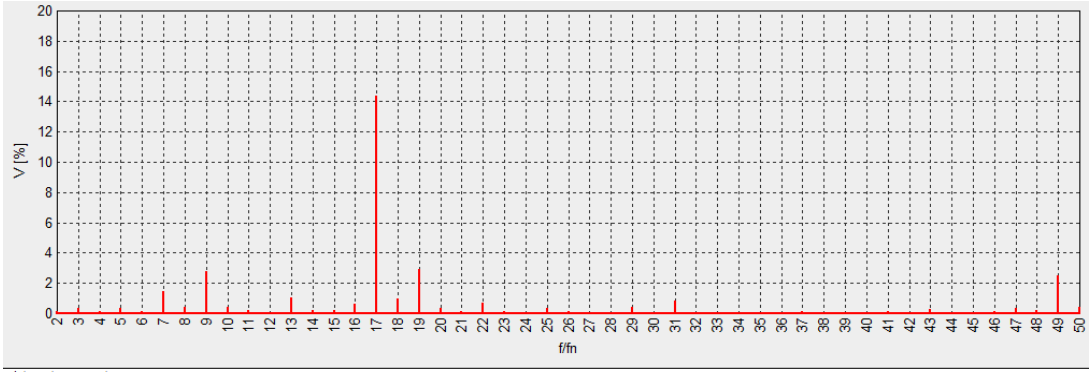


Fig5. 4: Harmonic Voltage Distortion at Al-Sof 66kv-1st Scenario Without Filter

- Al-Fuqhaa 66Kv-1st Scenario Without Filter

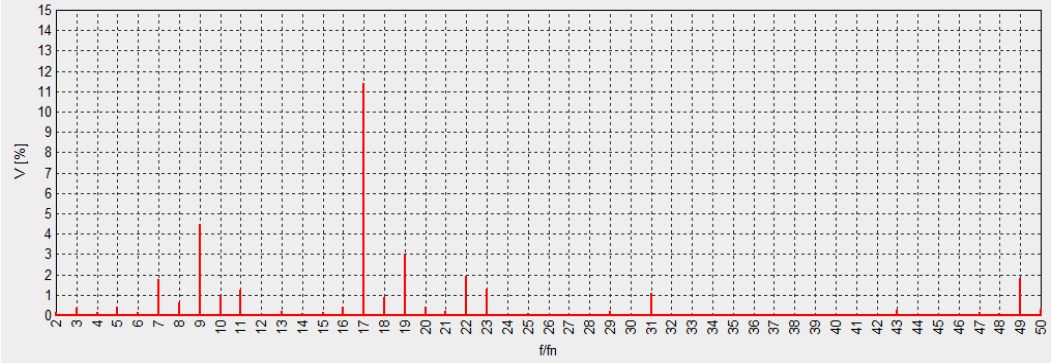


Fig5. 5: Harmonic Voltage Distortion at Al-Fuqhaa 66kv-1st Scenario Without Filter

- Alantena 66Kv-1st Scenario Without Filter

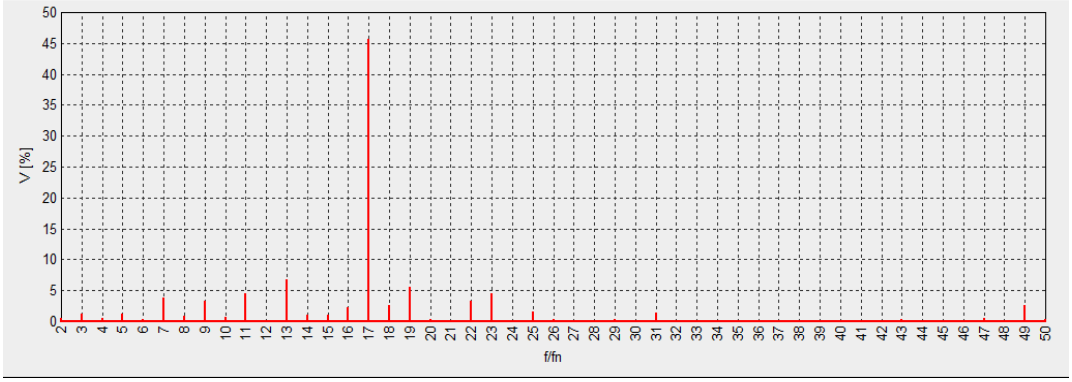


Fig5. 6: Harmonic Voltage Distortion at Alantena 66kv-1st Scenario without Filter

- PV1- 23.2944Kv-1st Scenario Without Filter

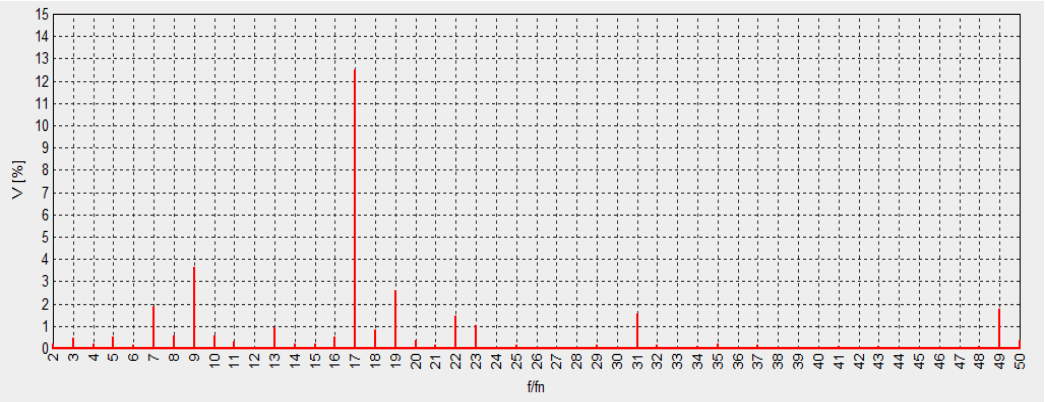


Fig5. 7: Harmonic Voltage Distortion at Pv1- 23.2944kv -1st Scenario without Filter

- PV2- 6.75 KV-1st Scenario Without Filter

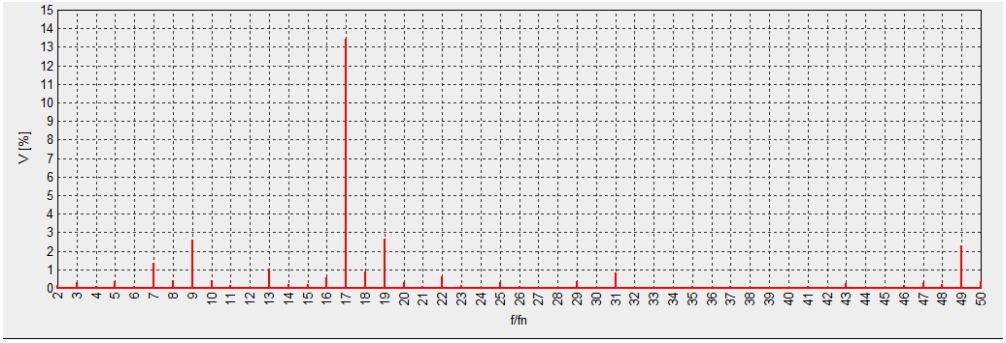


Fig5. 8: Harmonic Voltage Distortion at Pv2- 6.75 KV -1st Scenario without Filter

- PV3- 5.064 KV -1st Scenario Without Filter

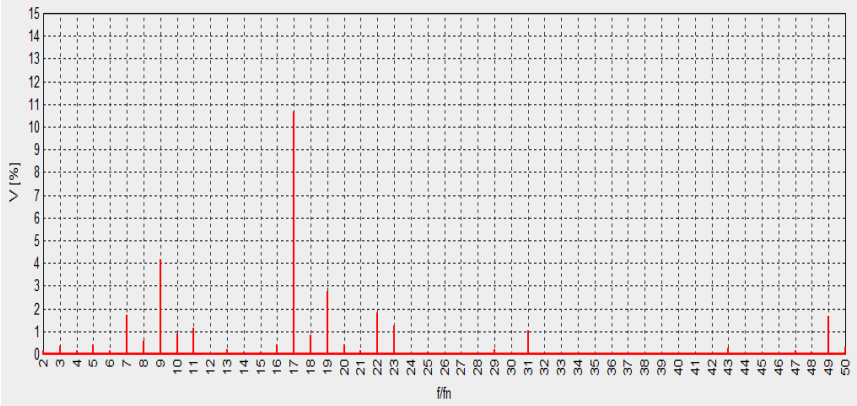


Fig5. 9: Harmonic Voltage Distortion at Pv3- 5.064 KV -1st Scenario Without Filter

- PV4- 135.04 KV -1st Scenario Without Filter

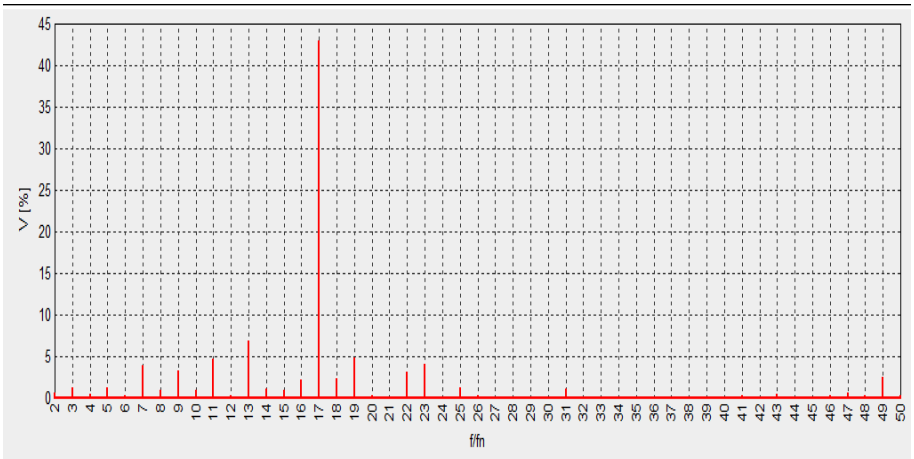


Fig5. 10: harmonic voltage distortion at pv4- 135.04 kV -1st scenario without filter

### ❖ With Filter

In this case the impact of using filter on harmonic will be study

If the parameters $Q_r$, $f_0$, G, and $D_F$ are entered, the program will calculate the parameters $R_v$, L, C, Cs, and Rd, and vice versa. The formulas are:

Calculation from $Q_r$, $f_0$, G, DF to $R_v$, L, C, Cs, Rd. [26]

$$n = \frac{f0}{fn} \quad (4.3)$$

$$Ch = \frac{n^2 - 1}{n^2} \cdot \frac{1}{2 \cdot \pi \cdot fn \cdot Ur^2} \cdot Qr \quad (4.4)$$

$$L = \frac{1}{(2 \cdot \pi \cdot fn)^2 \cdot Ch} \quad (4.5)$$

$$Rv = \frac{2 \cdot \pi \cdot f0 \cdot L}{G} \quad (4.6)$$

$V_r$ is a rated voltage in kV.

$F_o$ is a Resonance and stop frequency of filter in Hz.

G is a Q factor of filter in pu.

Rv is a Resistance of low frequency filter in Ohm.

L is an Inductance of low frequency filter in mH.

Fn is a nominal system frequency in Hz.

Qr is a Reactive power of positive sequence of filter in kvar. The power is given as positive, although the power is capacitive.

Table (5.5) shown the result THDv in the scenario 1 when add filter

Table5. 5: Results of THDv in the 1st Scenario After Filter

| N | Sub-station | $V_n$ | THDv | High order harmonic | |
|---|---|---|---|---|---|
| | name | kV | % | Order | Distortion% |
| 1 | bin- waleed | 66 | 6.36 | 9 | 5.2 |
| 2 | Al-sof | 66 | 5.22 | 9 | 3.7 |
| 3 | Al-fuqhaa | 66 | 7.49 | 9 | 5.95 |
| 4 | Alantena | 66 | 24.85 | 13 | 18.7 |
| 5 | Pv 1 | 23.2944 | 5.83 | 9 | 4.7 |
| 6 | Pv2 | 6.75 | 4.94 | 9 | 3.5 |
| 7 | Pv3 | 5.064 | 9.34 | 9 | 7.4 |
| 8 | Pv4 | 135.04 | 24.82 | 13 | 18 |

In the following figures the harmonic spectrum for each bus-bar that mentioned above.

- Bin- Walid 66Kv-1st Scenario With Filter

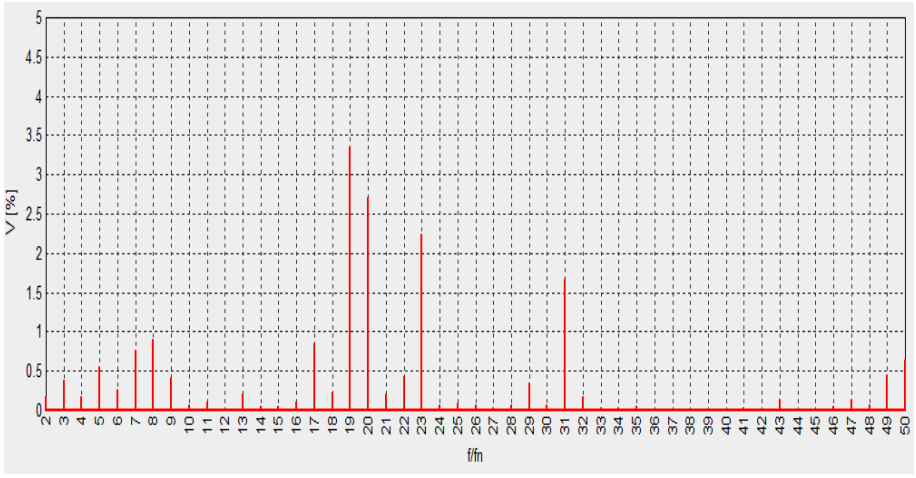


Fig5. 11: Harmonic Voltage Distortion At Bin- Walid 66kV-1st Scenario With Filter

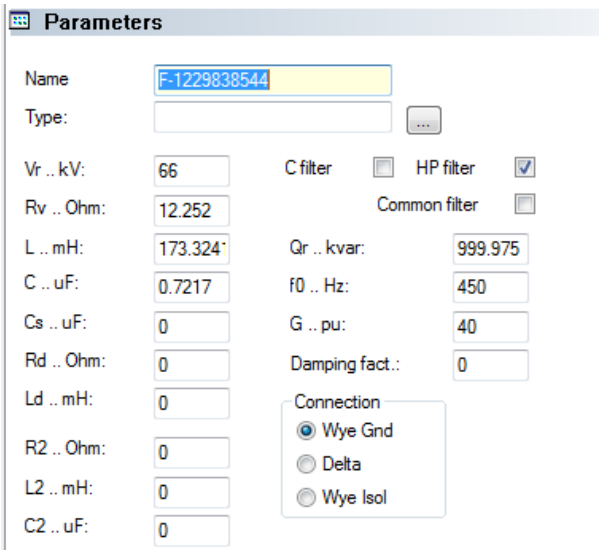


Fig5. 12: Data of Filter on Bus Bar Bin- Walid 66 KV -1st Scenario With Filter

- Al-Sof 66Kv-1st Scenario With Filter

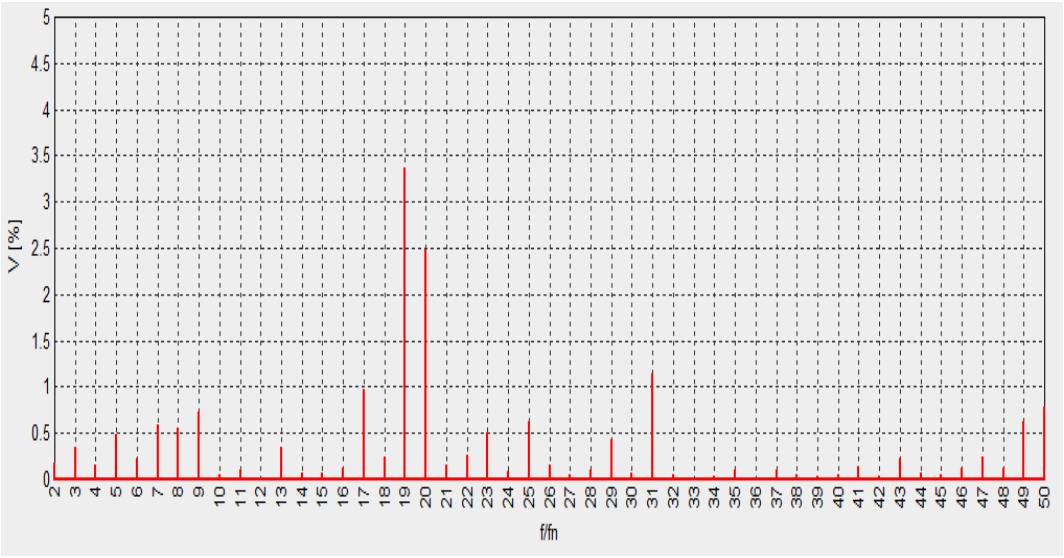


Fig5. 13: Harmonic Voltage Distortion at Al-Sof 66kv-1st Scenario with Filter

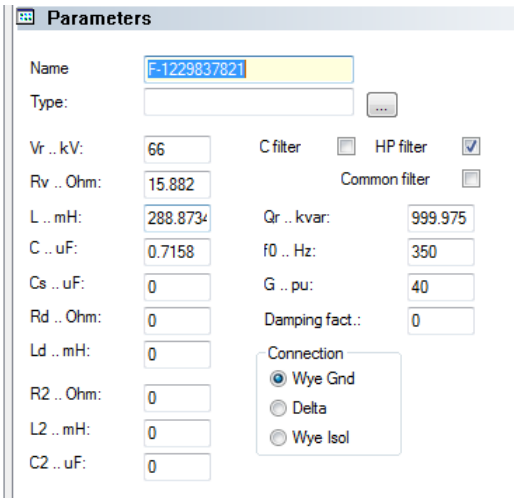


Fig5. 14: Data of Filter on Bus Bar Alsof 66 KV -1st Scenario With Filter

- Al-Fuqhaa 66Kv-1st Scenario With Filter

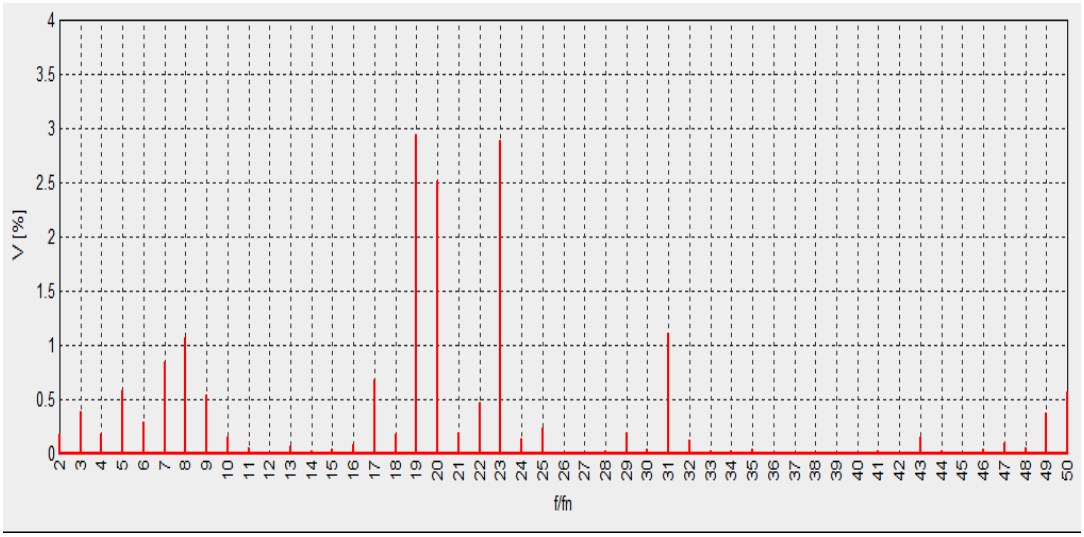


Fig5. 15: Harmonic Voltage Distortion at Al-Fuqhaa 66kv-1st Scenario with Filter

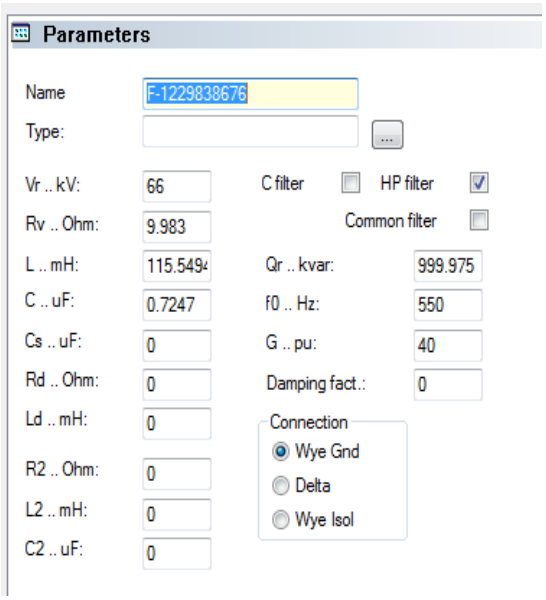


Fig5. 16: Data of Filter on Bus Bar Al-Fuqhaa 66 KV-1st Scenario with Filter

- Alantena 66Kv-1st Scenario With Filter

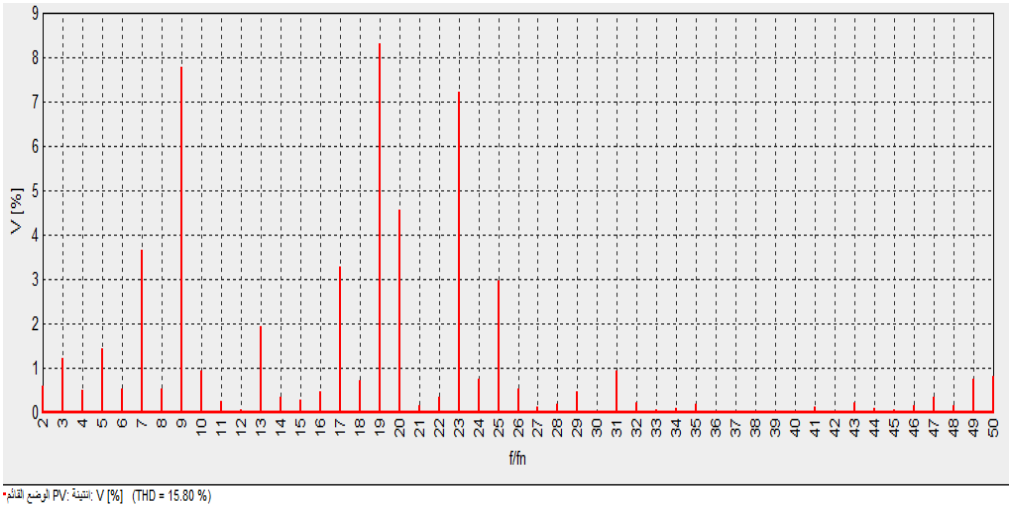


Fig5. 17: Harmonic Voltage Distortion at Alantena 66kv-1st Scenario with Filter

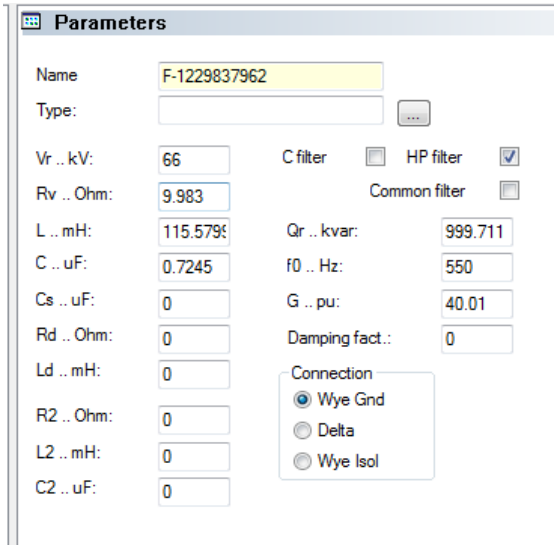


Fig5. 18: Data of Filter on Bus Bar Alantena 66 KV -1st Scenario with Filter

- PV1- 23.2944Kv-1st Scenario With Filter

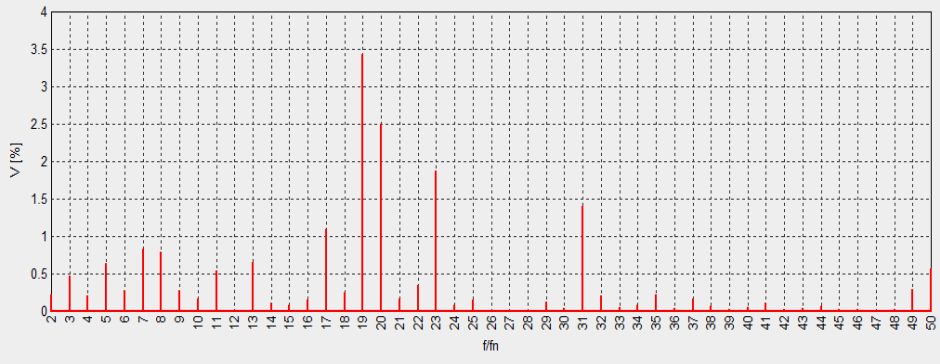


Fig5. 19: Harmonic Voltage Distortion at PV1- 23.2944KV -1st Scenario with Filter

- PV2- 6.75 KV-1st Scenario With Filter

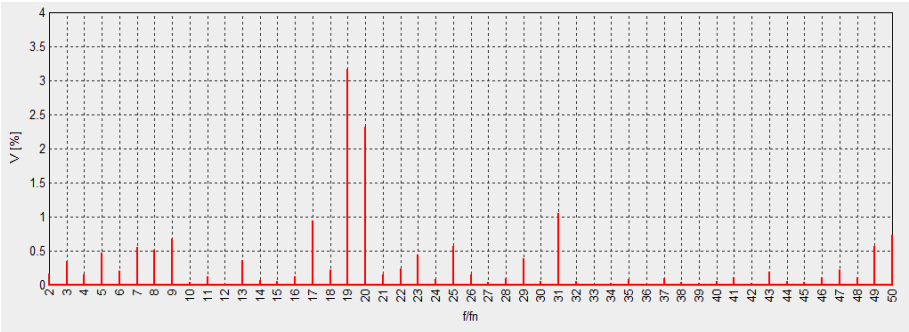


Fig5. 20: Harmonic Voltage Distortion at Pv2- 6.75 KV -1st Scenario with Filter

- Pv3- 5.064 KV -1st Scenario With Filter

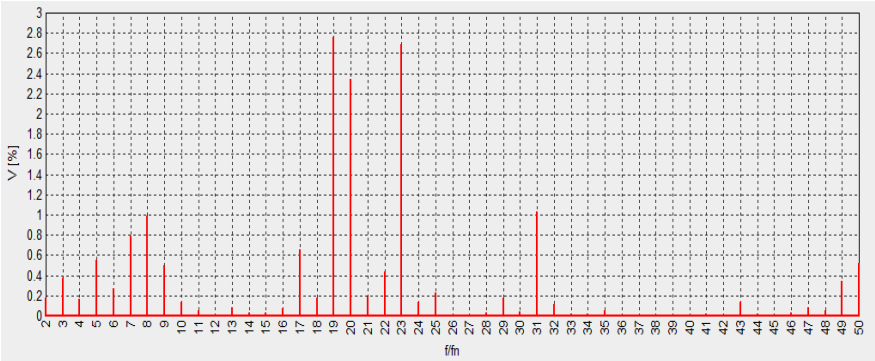


Fig5. 21: Harmonic Voltage Distortion at Pv3- 5.064 KV -1st Scenario with Filter

- PV4- 135.04 KV -1st Scenario With Filter

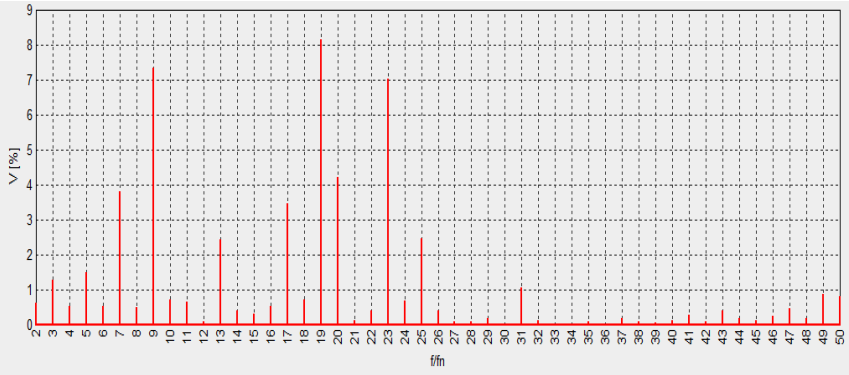


Fig5. 22: Harmonic Voltage Distortion at Pv4- 135.04 KV -1st Scenario with Filter

### 5.5.2 Scenario 2:PVS(1,2,4) Connected To 66 KV And PV3 Connected To 220 KV

❖ **Without Filter**

In this scenario know the extent of the presence of harmonics and what they were when the permitted level or not.

Table (5.6) shown the result THDv in the scenario 2 without filter

Table5. 6: Results Of THDv In The Second Scenario 2 Without Filter

| N | Sub-station name | $V_n$ kV | THDv % | High order harmonic | |
|---|---|---|---|---|---|
| | | | | Order | Distortion% |
| **1** | bin- waleed | 66 | 2.49 | 9 | 1.86 |
| **2** | Al-sof | 66 | 1.95 | 9 | 1.3 |
| **3** | Al-fuqhaa | 66 | 2.72 | 9 | 2.15 |
| **4** | alantena | 220 | 2.17 | 13 | 1.37 |
| **5** | Pv 1 | 23.2944 | 2.67 | 9 | 1.75 |
| **6** | Pv2 | 6.75 | 2.83 | 13 | 0 |
| **7** | Pv3 | 5.064 | 2.80 | 9 | 2 |
| **8** | Pv4 | 135.04 | 2.64 | 13 | 1.79 |

In the following figures the harmonic spectrum for each bus-bar that mentioned above.

- Bin- Waleed 66Kv- Scenario 2 Without Filter

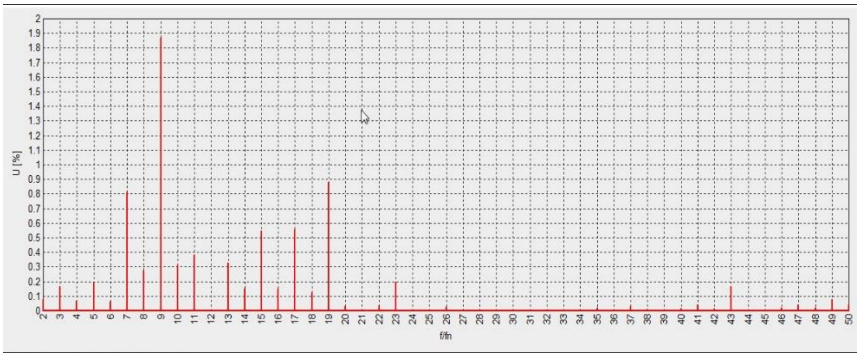


Fig5. 23: Harmonic Voltage Distortion at Bin- Walid 66kv- Scenario 2 without Filter

- Al-Sof 66Kv- Scenario 2 Without Filter

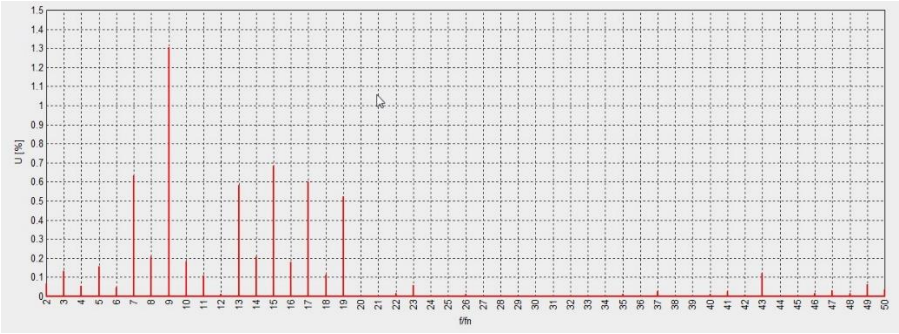


Fig5. 24: Harmonic Voltage Distortion at Al-Sof 66kv- Scenario 2 without Filter

- Al-Fuqhaa 66Kv- Scenario 2 Without Filter

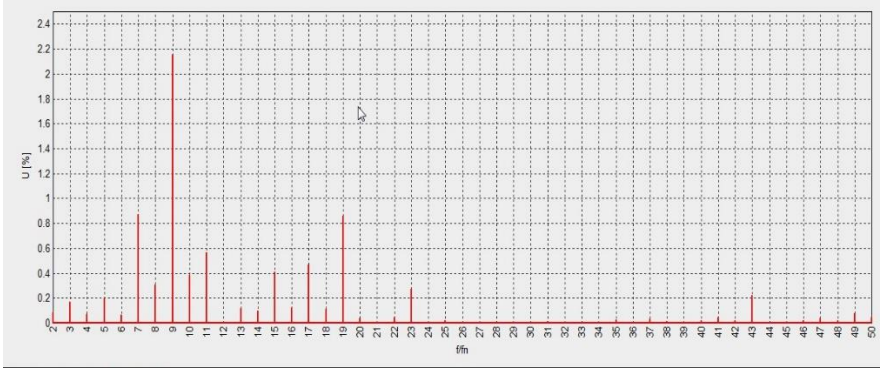


Fig5. 25: Harmonic Voltage Distortion at Al-Fuqhaa 66kv- Scenario 2 without Filter

- Alantena 66Kv- Scenario 2 Without Filter

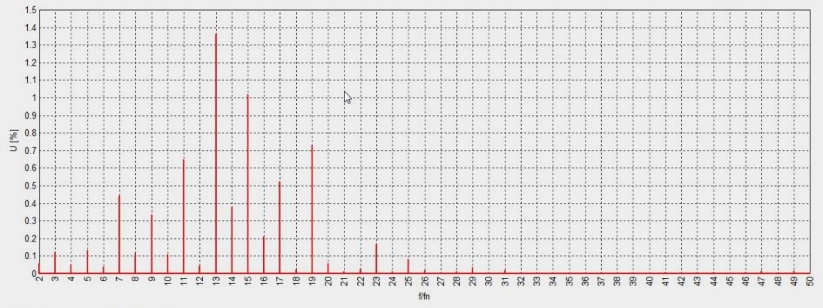


Fig5. 26: Harmonic Voltage Distortion at Alantena 66kv- Scenario 2 without Filter

- PV1- 23.2944Kv- Scenario 2 Without Filter

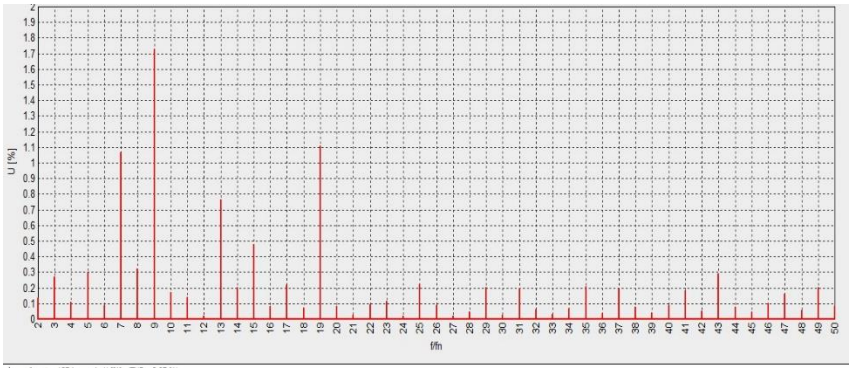


Fig5. 27: Harmonic Voltage Distortion at Pv1- 23.2944kv- Scenario 2 without Filter

- PV2- 6.75 KV- Scenario 2 Without Filter

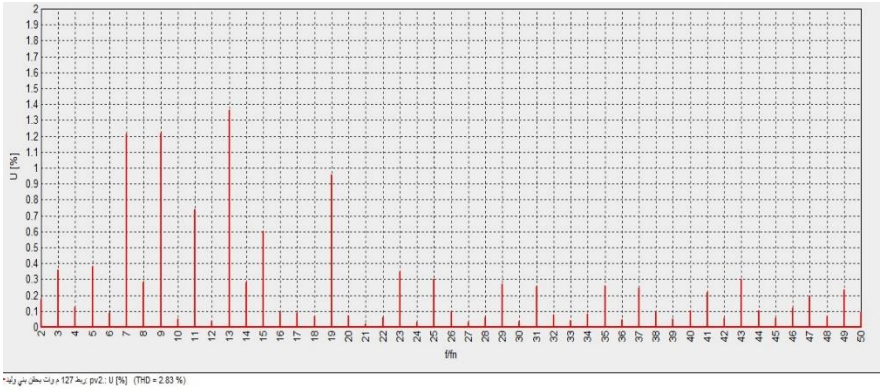


Fig5. 28: Harmonic Voltage Distortion at Pv2- 6.75 KV- Scenario 2 without Filter

- PV3- 5.064 KV – Scenario 2 Without Filter

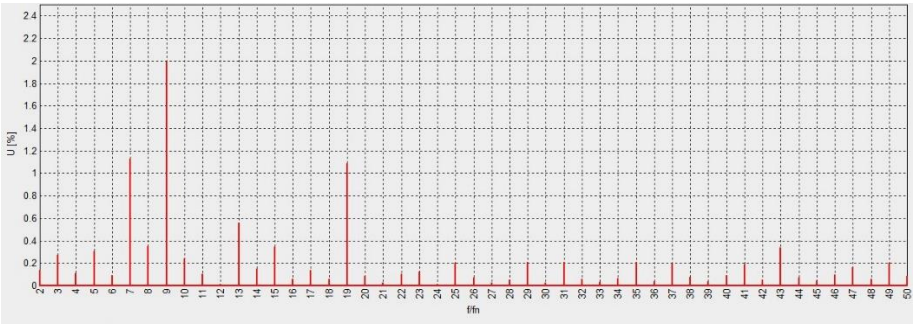

Fig5. 29: Harmonic Voltage Distortion at Pv3- 5.064 KV – Scenario 2 without Filter

- PV4- 135.04 KV – Scenario 2 Without Filter

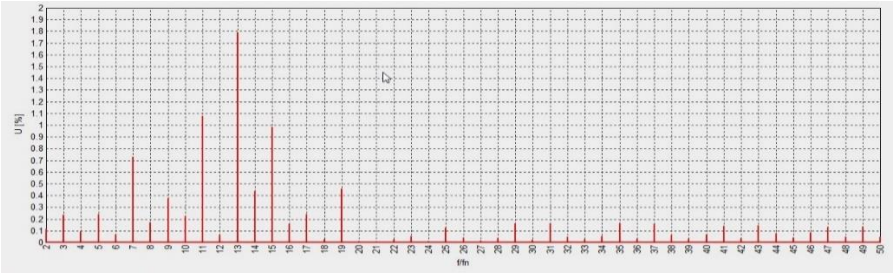

Fig5. 30: Harmonic Voltage Distortion at Pv4- 135.04 KV – Scenario 2 without Filter.

### ❖ With Filter

Table5. 7: Results of THDv in the Scenario 2 With Filter

| N | Sub-station name | $V_n$ kV | THDv % | High order harmonic | |
|---|---|---|---|---|---|
| | | | | Order | Distortion% |
| **1** | bin- waleed | 66 | 0.47 | 13 | 0.46 |
| **2** | Al-sof | 66 | 0.99 | 19 | 0.46 |
| **3** | Al-fuqhaa | 66 | 1.05 | 0.45 | 0.41 |
| **4** | alantena | 220 | 1.50 | 19 | 0.90 |
| **5** | Pv 1 | 23.2944 | 1.14 | 13 | 0.42 |
| **6** | Pv2 | 6.75 | 2.02 | 19 | 0.95 |
| **7** | Pv3 | 5.064 | 1.12 | 13 | 0.42 |
| **8** | Pv4 | 135.04 | 1.20 | 19 | 1.92 |

In the following figures the harmonic spectrum for each bus-bar that mentioned above.

- Bin- Waleed 66Kv- Scenario 2 With Filter

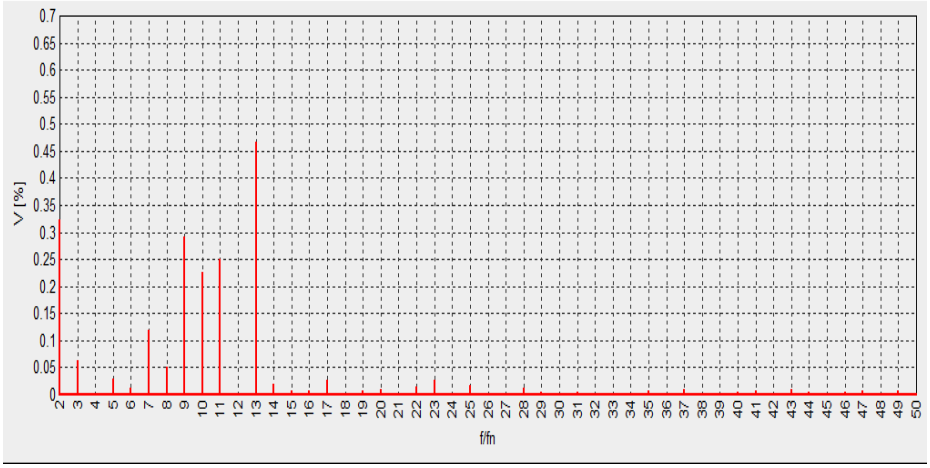


Fig5. 31: Harmonic Voltage Distortion at Bin- Walid 66kv- Scenario 2 with Filter

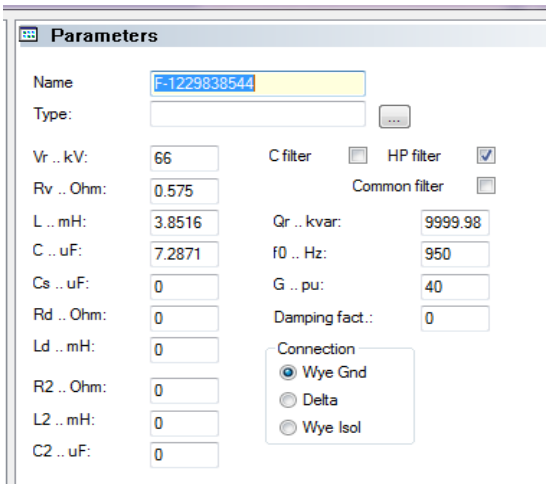


Fig5. 32: Data of Filter on Bus Bar Bin- Walid 66 KV

- Al-Sof 66Kv- Scenario 2 With Filter

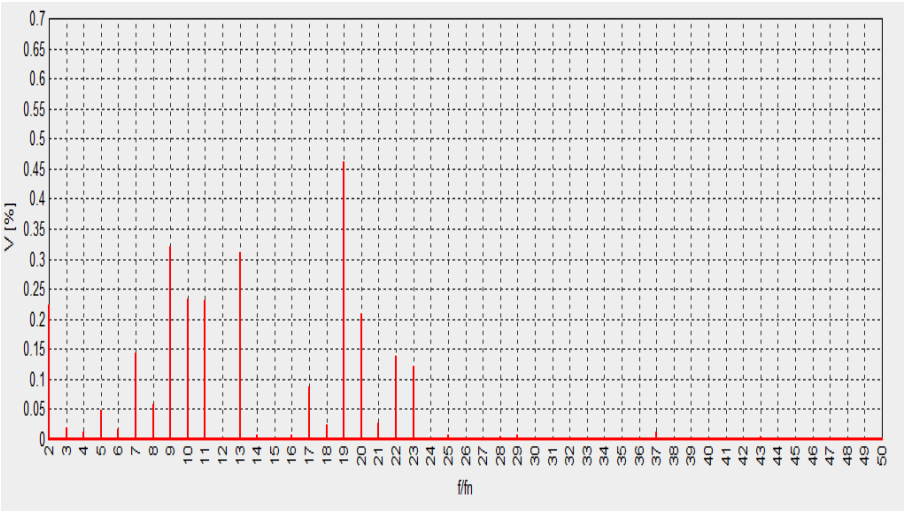


Fig5. 33: Harmonic Voltage Distortion at Al-Sof 66kv- Scenario 2 with Filter

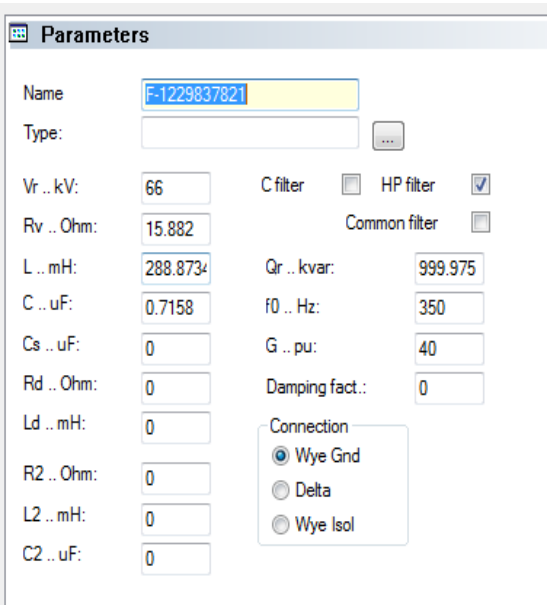


Fig5. 34: Data of Filter on Bus Bar Alsof 66 KV

- Al-Fuqhaa 66Kv- Scenario 2 With Filter

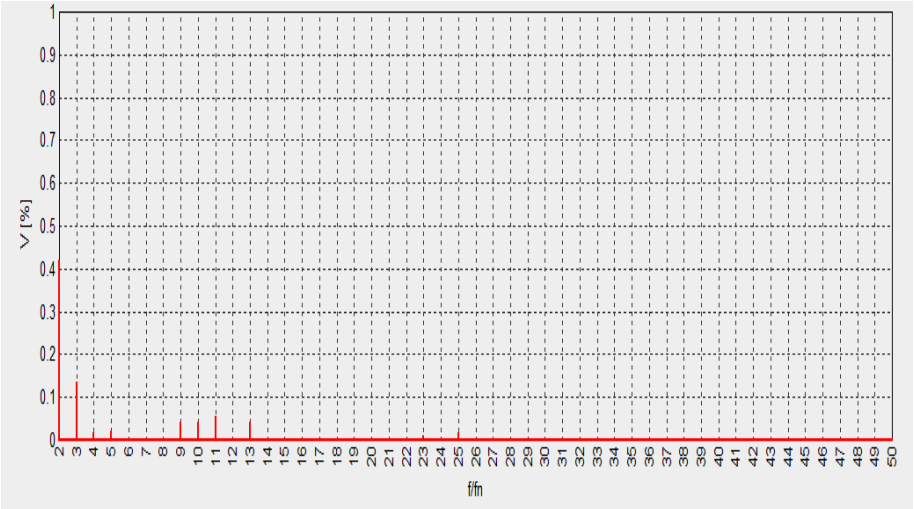


Fig5. 35: Harmonic Voltage Distortion at Al-Fuqhaa 66kv- Scenario 2 with Filter

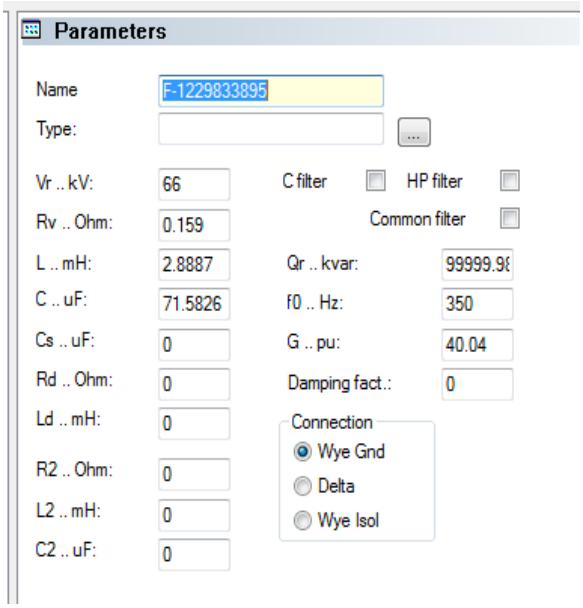


Fig5. 36: Data of Filter on Bus Bar Alfogha 66 KV

- Alantena 66Kv- Scenario 2 With Filter

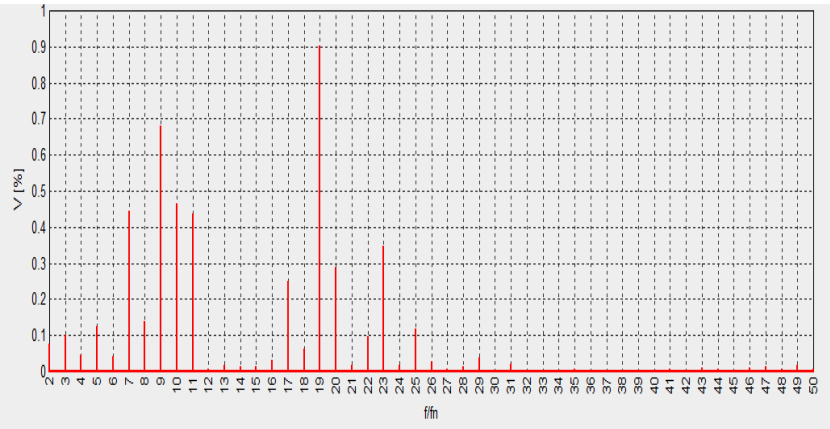


Fig5. 37: Harmonic Voltage Distortion at Alantena 66kv- Scenario 2 with Filter

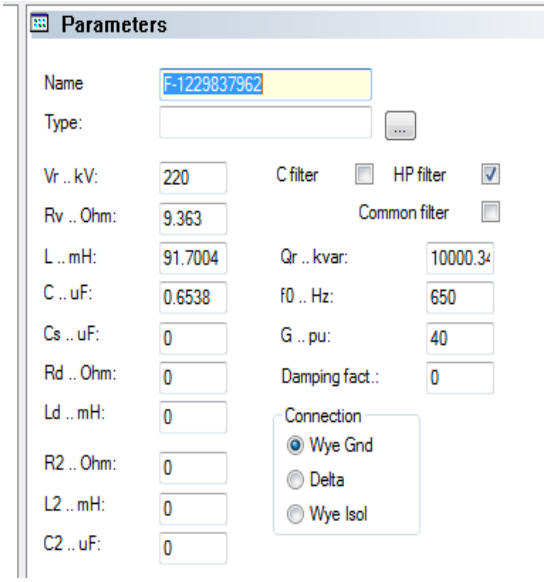


Fig5. 38: Data of Filter on Bus Bar Alantena 66 KV

- PV1- 23.2944Kv- Scenario 2 With Filter

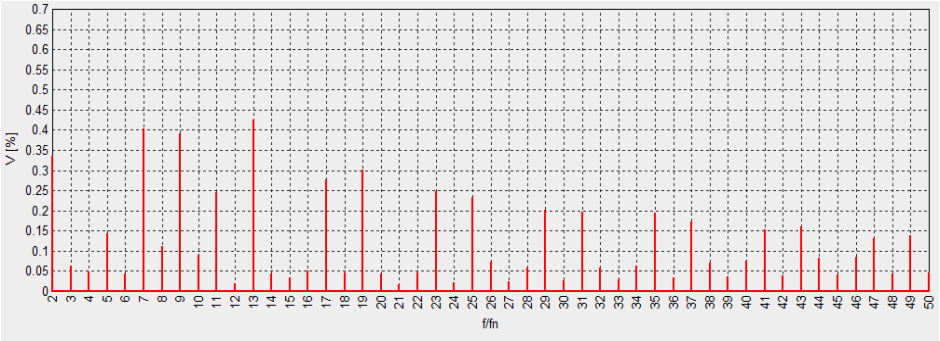


Fig5. 39: Harmonic Voltage Distortion at Pv1 66kv- Scenario 2 with Filter

- PV2- 6.75 KV- Scenario 2 With Filter

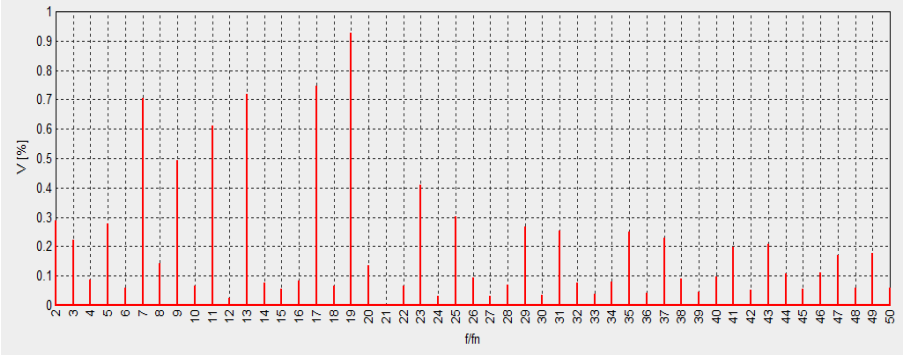


Fig5. 40: Harmonic Voltage Distortion at Pv2 66kv- Scenario 2 with Filter

- PV3- 5.064 KV – Scenario 2 With Filter

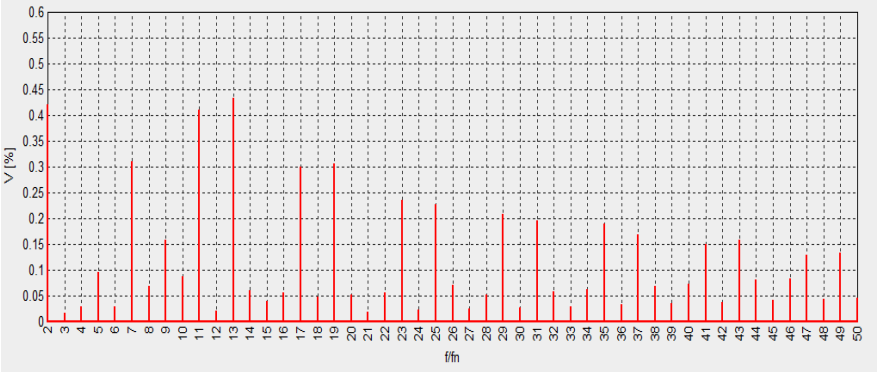


Fig5. 41: Harmonic Voltage Distortion at Pv3 66kv- Scenario 2 with Filter

- PV4- 135.04 KV – Scenario 2 With Filter

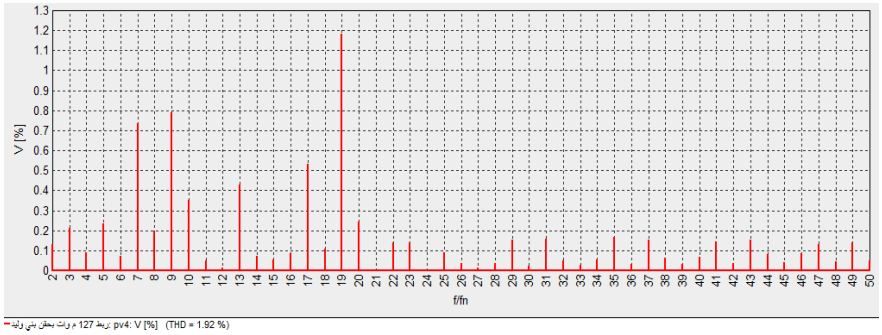


Fig5. 42: Harmonic Voltage Distortion at Pv4- 135.04 KV – Scenario 2 with Filter

### 4.2.1 Comparison Between The Two Scenarios In Term Of THDv Values

Figure (4.41) shown Comparison between the two scenarios in term of THDv values

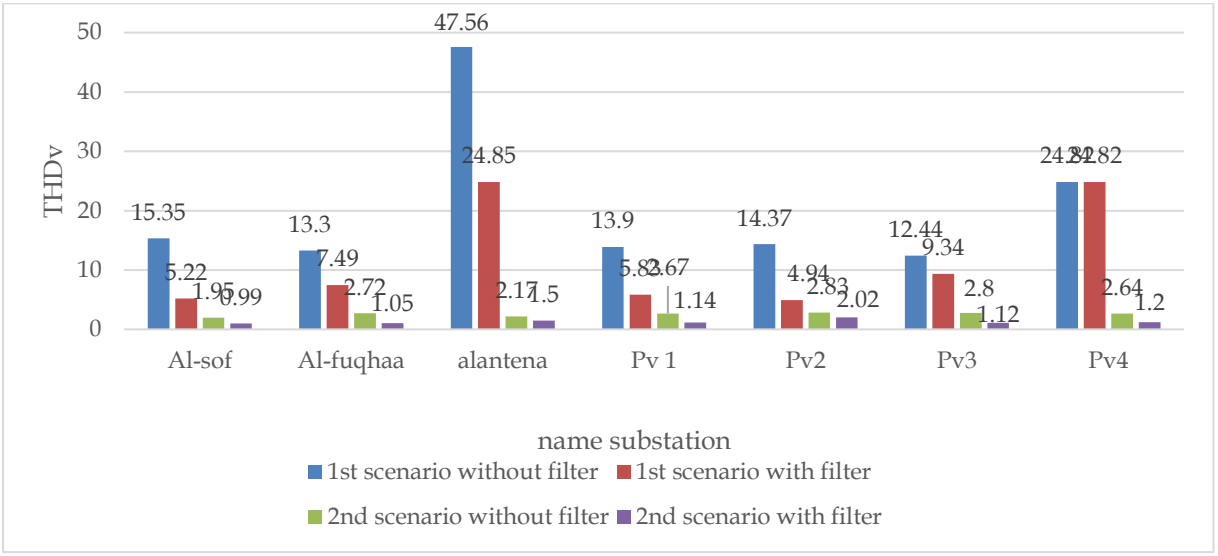


Fig5. 43: Comparison between the Two Scenarios in Term of THDv Values

From the previous table, it is clear that the second scenario is the best in terms of harmonics analysis, because the THD for all substations are under limits especially in case of adding a filter. While in the other scenario the THD is out of limit even when adding a filter.

# CHAPTER VI

# Economic & Environmental Study

## 6.1 Introduction

In this chapter the economic and environmental impact, which produce an establishment of solar stations, where concerned.

## 6.2 Input Data

Table (6.1, 6.2, 6.3 and 6.4) shown Core prices, which will build upon the economic study, such as light fuel and gas, heavy equipment prices and the price of the currency differential price.

Table6. 1: Economic Feasibility Study for the Installation of Solar Power Plant Study (PV)

| Input study | the quantity | Unit |
|---|---|---|
| The cost of the solar cell system | 1.39 | EUR / Watt |
| Construction and installation period | 1 | Year |
| Operating and maintenance expenses | 0.1 | % |
| Euro Exchange Rate | 1.6 | Ld |
| dollars Exchange Rate | 1.3 | Ld |
| The shelf life of the plant | 20 | Year |
| Cost for cable | 220 | $/500ft |
| Convolution ft to KM | 0.0003048 | KM |

Table6. 2: Local And Global Fuel Prices (LD / m3) For the Year 2015

| fuel type | the local | Universal |
|---|---|---|
| Heavy | 36 | 510.2 |
| Light | 150 | 485.8 |
| Gas | 0.008405 | 0.32947 |

Table6. 3: The Cost of Transformers (Invertor)

| Size inverter | Price (EUR / kW) |
|---|---|
| Less than 100 KW | 140 |
| More than 100 KW | 100 |

Table6. 4: Other Ratios of Fuel

| Input study | Light fuel | Fuel mixture |
|---|---|---|
| Consumer Aid Ratio for the year 2014 | 0.34% | 1.68% |
| The proportion of technical losses in the energy transport network | 2.0% | 2.0% |

## 6.3 Energy & Fuel Consumption

Table (6.5) shown the amount of energy produced, fuel consumed and the rate of fuel consumption by fuel type in 2014.

Table6. 5: The Amount of Energy Produced, Fuel Consumed and the Rate of Fuel Consumption by Fuel Type in 2014

| Case | 2014 | | | |
|---|---|---|---|---|
| | **Heavy** | **Light** | **Gas** | **Without fuel** |
| Quantities of spent fuel at the output terminals (m 3) | 939,150 | 2,936,155 | 5,283,712,638 | - |
| The amount of energy produced (megawatt hour) | 3,152,362 | 9,383,709 | 17,873,493 | 3,514,473 |
| Energy produced by fuel type (%) | 9% | 28% | 53% | 10% |
| Fuel consumption rate (m3 / MW-hour) | 0.298 | 0.313 | 295.617 | - |

## 6.4 Analysis & Dictation

In this section encomia and environment analysis, will be studied from table (3.12) in chapter 3 the overall energy produced from PV plant are 163 MW. Table (6.6) summarized the analysis.

Table6. 6: A Table Showing Analytical Data for Medium Voltage Stations and Linked to the Proposed Solar PV Stations As Well As the Savings Expected in the Fuel Bill for Fuel, Transportation and Carbon Emissions of Co2

| Sub station name | free area (hec) | power for PV (MW) | Total expected energy production Of the PV plant | Total expected energy production Light fuel | Construction cost PV plant | Of economy expected Bill Light fuel / y | | economy Of in carbon dioxide emission |
|---|---|---|---|---|---|---|---|---|
| | | | (MWH/Y) | (MWH/Y) | (LD) | local (LD) | Universal (L D) | $tCO_2$ |
| Bani waled | 34.5 | 21.96 | 3.13226E4 | 3.205E4 | 48.839E6 | 1.5047E6 | 4.8733E6 | 27.941E3 |
| Al-sof | 10 | 6.36 | 9.079E3 | 9.292E3 | 14.144E6 | 0.4362E6 | 1.4128E6 | 8.100E3 |
| fuqhaa | 7.5 | 4.775 | 6.80925E3 | 6.969E3 | 10.61E6 | 0.3271E6 | 1.0181E6 | 6.075E3 |
| Alantenh | 200 | 127.33 | 1.8158E5 | 1.858E5 | 2.831E8 | 8.7233E6 | 28.251E6 | 0.161E6 |
| Summation | **252** | **163.12** | **2.2879E5** | **2.338E5** | **3.5669E8** | **10.991E6** | **35.555E6** | **20.311E4** |

Now, the estimated cost of PV plant:

- **Total expected energy production Light fuel (MWH/YEAR)** = Total expected energy production Of the PV plant for one year (MWH/YEAR) * (1+ the percentage change in the consumer aid)*(1+ the proportion of technical losses in the energy transport network).

  For example (Bin-Walid substation):

  **Total expected energy production Light fuel (MWH/YEAR)** = 3.13226E4*(1+0.0034)*(1+0.02) = **3.205E4**
- **Construction cost PV plant (Libyan Dinar)** = power for PV (MW) *1000000* the cost of the solar cell system (EUR / Watt) ***** Euro Exchange Rate **(**Ld**).**

  For example (Bin-Walid substation):

**Construction cost PV plant (Libyan Dinar) =** 21.96 * 1000000 * 1.39 * 1.6 = **48.839E6**

- **Economy Of expected Bill Light fuel (Libyan Dinar / year ) =** Total expected energy production Light fuel (MWH/YEAR)***** Fuel consumption rate at year 2014 (m3 / MW-hour) ***** Local and global fuel prices (LD / m3)

  **Economy Of expected Bill Light fuel (Libyan Dinar / year) =**3.205E4*0.313*150=1.5047E6
- **The rate of carbon emissions in the field of electricity generation per year (tCO2/MWh) = 0.8718.**
- **Of economy in carbon dioxide emissions (tCO2) =** Total expected energy production Light fuel (MWH/YEAR) * the rate of carbon emissions in the field of electricity generation per year (tCO2/MWh).

  **Of economy in carbon dioxide emissions (tCO2) =** 3.205E4*0.8718 =**27.941E3**

- **The price of one ton of carbon emissions =** 15 (USD / tC dollars)
- **The total value of carbon emissions =** economy of in carbon dioxide emission (tCO2) ***** the price of one ton of carbon emissions (USD / tC dollars) ***** dollars Exchange Rate (Ld) = 15*20.311E4= **304.665 E4 (LD / year)**
- **The rate of investment, operation and maintenance / default value of 20 years =** 228.79 LD/YR*20=45758 LD/20YR
- **Over the total values in the annual fuel bill for local =** 10.991E6 LD

**Over the total values in the annual fuel bill for Universal =** 35.555E6 LD

- **Net Of economy realized from the project =** (Over the total values in the annual fuel bill+ the total value of carbon emissions) - The rate of investment, operation and maintenance default value of 20 years= (38.55E6) Ld for Universal = (13.99E6) Ld for local.

## Conclusion

This thesis presents the studying of the effects of penetration (PV system) penetration on distribution system operation and performance, based on load flow analysis, short circuit, harmonic and economic.

A local distribution network in bin-walid loop is considered as a case study for analysis.

The studies shows that the PV system penetration is the good solution for enhancing system performance where the following benefits are accomplished:

- Bani-Walid area is an optimum place for production of solar energy, because of it open land, adaptive, temperature, and solar irradiation and other factors that give a best design.
- detailed photovoltaic power plant design has been proposed in Bani-Walid
- one hectare in Bani-Walid can produce approximately 0.6 MW
- From the results study the module type and panel position have an effect on the overall efficiency of solar power plant.
- Reducing system losses after adding PV to about 20%.
- Improve voltage system almost 66KV substations to about 4.5%.
- The best point of common coupling (PCC) for PV generation (1, 2, and 4) is on 66 KV while for PV3 is on 220 KV.
- The present PV system can generate distortion on voltage or current waveform, and the THD was over limit.

- Filter is necessary to remove the wave distortion, when using PV system in Bani-Walid network loop.

## Recommendations

Through this study many research ideas can be conducted , such as:

1. To carry out studies for other regions within Libya and taken it this study model for it.
2. Focus on remote areas of obstetrics and remote centers in the creation of renewable energy plants.
3. The exploitation of natural resources in Libya to meet the demand for electric power.
4. Studies about using PV systems and wind generation system to solve the energy needs at far away and condensed population areas.
5. Studying the idea of isolating grids using DG's since Libya is a semi- desert areas and population densities are concentrated at aggregated manner.

## References


1. Abb, www.abb.com. 2016.
2. Moyer, t., *measurement & analysis of harmonics & flicker*, e. Test, editor.
3. "ren21. *Renewables global status report 2012*. . 2012 [cited retrieved 11 april 2016.
4. Saab, t. And m. Youssef, *towards energy autonomous house in beirut*, in *proceedings of 2016 2nd international conference on architecture, structure and civil engineering*. 2016, beirut arab university, faculty of architectural engineering: london (uk).
5. Ren21, *renewables 2014 global status report*. 2014. P. 13, 17, 21, 25.
6. Investment, g.t.i.s.e., *analysis of trends and issues in the financing of renewable energy and energy efficiency in oecd and developing countries* 2007. P. 3.
7. 21, r., *renewables 2013 global status report*. 2013.
8. Ag, p., *fraunhofer lnstiture for solar energy system ise*. 11 march 2016.
9. G.jjorgensen, a.w.c.a., *service lifetime prediction for encapsulated photovoltaic cells/minimodules*, g. Center for performance engineering and reliability national renewable energy laboratory, editor. 2010.
10. *https://www.google.com.ly/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwj_yOX20YvNAhVFGsAKHVvkC7YQFgguMAE&url=http%3A%2F%2Fcityofmissionviejo.org%2Fassets%2F0%2F72%2F100%2F106%2F43eedfbe-0176-4cd0-9abc-e3abe538848b.pdf&usg=AFQjCNH6VUCYt26ihfXHeTa4MUgHFmd72w&sig2=ToYBXWVGnVLuuB8ZWgCsEQ&bvm=bv.123664746,d.ZGg2012.*
11. Williams, c. *How to design a solar pv system 101 : the basic terms*. April 17th ,2012.
12. A.s. elhodeiby , h.m.b.m., and m.a. farahat, *performance analysis of 3.6 kw rooftop grid connected photovoltaic system in egypt*, i.c.o.e.s.a. Technologies, editor. 2011: cairo, egypt.
13. Ward bower, p.m.o.t.s., sandia national laboratories, photovoltaic systems research & development, albuquerque, *international guideline for the Certification of photovoltaic system Components and grid-connected systems*. February 2002.
14. Company, a.p., *challenges for distribution feeder voltage regulation with increasing amounts of pv*. April 19, 2012.
15. Kaur, g., *effects of distributed generation (dg) interconnections on protection of distribution feeders*, p.e.s.g. meeting, editor. 2006.
16. Mrsolar.com. *Inverters*. 2016.
17. Scoops, m. *Solar mango india newsletter*. 2012.
18. Santhanam, n. *Solar efficiency, suncyclopedia*. October 26th, 2014.
19. Libyan national meteorological center, c.c.c., *tempreture in bin-waleed*. 1998-2010.
20. Http://www.sunearthtools.com/dp/tools/pos_sun.php. 2016.
21. Saadat, *power system analysis* mcgraw-hill, 1999.
22. Schaffner, *six tough topics about harmonic distortion and power quality indices in electric power systems*, s. Group, editor. 2014.
23. Company, a., *tech notes*. 2015.

24. Abu dhabi distribution company, a.a.d.c., abu dhabi supply company for remote areas (rasco), *limits for harmonics in the electricity supply system*, r.a.s.b.f.t.w.a.e.s.o.t.e.o.a. Dhabi, editor. 30th november 2005.
25. *Regulation and supervision bureau for the water and electricity sector of the emirate of abu dhabi*.
26. Neplan, 5.5.2, editor. 1988-2013.

# APPENDICES

**APPENDIX A**: the existing 66 KV network of the city of Bin-Waid in 2015

**APPENDIX B** load flow & short circuit when connect (1, 2, 3, 4) PV power plant in buss 66 KV in network Bin-Waid in 2015

**APPENDIXC**: load flow & short circuit when connect (1,2,3) PV power plant in buss 66 KV and connect pv4 on bus bar Bin-Waid 220 KV in network Bin-Waid in 2015

**APPENDIX B** load flow & short circuit when connect (1, 2, 3, 4) PV power plant in buss 66 KV in network Bin-Waid in 2015

**APPENDIX D**: the existing 220 KV network of the meddle region in Libya 2015

**APPENDIXE**: load flow & short circuit when connect (1, 2, 3, 4) PV power plant in 220 KV network of the meddle region in Libya 2015

**APPENDIXF**: Total Harmonic Distortion (THD) when connect (1,2,3)PV power plant in buss 66 kv and connect pv4 on bus bar Bin-Waid 220 kv in network Bin-Waid in 2015

**APPENDIXG**: load flow & short circuit when connect (1, 2, 3, 4) PV power plant in buss 220 kv in bus bar Bin-Waid 220KV in network middle region of Libya