بسم الله الرحمن الرحيم

Joint Master Electrical Engineering Program Birzeit and Palestine Polytechnic Universities

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Thesis Title: Optimal Sizing and Allocation of DG Techniques for Enhancing Active Distribution Network in Palestine.

Name : Ali Abdulkareem Alzeer
186400

Supervisor: Dr. Nassim Iqteit

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Ethics statement

This thesis entitled “Optimal Sizing and Allocation of DG Techniques for Enhancing Active Distribution Network in Palestine” has been written and structured under the highest levels of ethical standards and academic guidelines line. The data has been collected from the relevant authorities with appropriate approvals. The main ethical objective for this research is to generate knowledge and insights other to be part of the contribution to enhance the electrical DN and further integrate artificial intelligence in this sector.

All references and cited data that have been collected to support and develop this thesis are written in the bibliography and all other contents are empty of unauthorized material and its attainment of independent intellectual, and I am hereby responsible for my statement if it is not true or out of the regulatory policies.

St.name : Ali Alzeer Registration Number : 186400

Date 8 /3/ 2023

Signature :

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The undersigned hereby certify that they have read, examined, and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University:

[Optimal Sizing and Allocation of DG Techniques for Enhancing Active Distribution Network in Palestine.]

[Ali Alzeer]

In partial fulfillment of the requirements for the degree of Master Electrical Engineering.

Graduate Advisory Committee:

Prof./Dr.

____

(Dr. Nassim Iqteit), University (Palestine Polytechnic University)

Signature:__________________ Date:_____________

Prof. Dr. ___________________

(Dr. Maher Maghalseh), University (Palestine Polytechnic University).

Signature:_____________ Date:______________

Prof./Dr. ______________

(Dr. Hakam shehadeh), University (Birzeit University).

Signature: _____________ Date:______________

Thesis Approved by:

Name: _____________

Dean of Graduate Studies & Scientific Research Palestine Polytechnic University

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Abstract

Recent studies show a huge demand for Renewable Energy Sources (RES) in the electrical sector as a form of Distribution Generators (DG), generating green energy with less carbon emissions is integrated into distribution networks DN for its advantages and availability during the year. This rise in demand has created new challenges in terms of maintaining the efficiency and performance of the Distribution Network (DN) while meeting the load of a real case study electrical grid. This research will look into two major areas. The first is to select the preferred bus location in the electrical grid based on the minimum loss reduction sensitivity factor, LRSF. Second, to utilize an optimization algorithm inspired by the patterns of firefly insects to determine the optimal size of PV DG in the case study. While check to reduce total power system losses without violating the practical system constraints of the transmission line for IEEE standards that have been used to set up the distribution network in Palestine, and to determine the required area of the design of the PV DG of the PV plant to be built in Hebron city in the country of Palestine.

Keywords: Distribution Generators; Firefly Algorithm; Loss Reduction; Optimal DG Placement.

الملخص

تظهر الدراسات الحديثة وجود طلب كبير على مصادر الطاقة المتجددة في قطاع الكهرباء كشكل من أشكال مولدات التوزيع الطرفية ، حيث يتم دمج مولدات الطاقة الخضراء بأقل انبعاثات كربونية في شبكات التوزيع لمزاياها وتوفرها خلال العام. أدى هذا الارتفاع في الطلب إلى خلق تحديات جديدة فيما يتعلق بالحفاظ على كفاءة شبكة التوزيع وأدائها مع الحفاظ على جودة عالية من الطاقة الكهربائية لتغطية الحاجة من الطاقة للاحمال . يرتكز هذا البحث على مجالين رئيسيين. أولاً ، اختيار افضل خط توزيع كهربائي داخل الشبكة الكهربائية بناءً على حساسية معامل خفض الفاقد LRSF ، ثانيا توظيف خوارزمية التحسين الفاير فلاي المستوحاه من طبيعة حشرات اليراع المضيئة للحصول على افضل حجم ممكن لمحطة الطاقة الكهروضوئية المراد تطبيقها وبنائها على دراسة حالة واقعية. بحيث سيتم مراعاة تقليل الفاقد الكهربائي في النظام دون انتهاك القيود الفنية للنظام لخط النقل لمعايير IEEE التي تم استخدامها لإنشاء شبكات الكهرباء في فلسطين.بالاضافة لتحديد المساحة المطلوبة لتصميم المحطة الكهروضوئية في دراسة الحالة التم اختيارها في مدينة الخليل في فلسطين .

الجمل الدالة: مولدات التوزيع, خوارزمية حشرات اليراع, تقليل الفاقد الكهربائي, الاختيار الامثل لشبكات التوزيع .

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Table of Abbreviation

Abbreviation	Definition
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
APSO	Adaptive Particle Swarm Optimization
AVC	Automatic Voltage Control
AVR	Automatic Voltage Regulator
BA	Bat Algorithm
BFA	Bacterial Foraging Algorithm
BFS	Breadth-First Search
BIBC	Bus Injection to Branch Current
BIBV	Bus Injection to Branch Voltage
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Selenide
CSA	Cuckoo Search Algorithm
DC	Direct Current
DE	Differential Evolution
DER	Distributed Energy Resources
DG	Distribution Generator
DISCO	Distribution Company (Disco)
DN	Distribution Network
DNO	Distribution Network Operator
EG	Embedded Generation
FA	Firefly Algorithm
GA	Genetic Algorithm
HEPCO	Hebron Electric Power Company
IEC	Israel Electric Corporation
IRSPSO	Inertia Reinitialized Social Structure Particle Swarm optimization
JDECO	Jerusalem District Electric Company
KV	Kilovolt
KW	Kilowatt
LP	Linear Programming
LRSF	Loss Reduction Sensitivity Factor
MPC	Main Playing Center Hebron
MPPT	Maximum Power Point Tracker
MVA	Megavolt Ampere
MVAR	Megavolt Ampere
MW	Megawatt
NEDCO	Northern Electricity Distribution Company
NR	Newton Raphson

OPF	Optimal Power Flow
P	Real Power
PEC	Palestinian Electricity Company
PF	Power Factor
PSO	Particle Swarm Optimization
PT	Palestine Territory
PU	Per Unit
PV	Photovoltaic
PVDG	Photovoltaic Distribution Generator
Q	Reactive Power
RES	Renewable Energy Sources
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SELCO	Southern Electric Company
SPV	Solar Photovoltaic Systems
T&D	Transmission and Distribution
TFSC	Thin Film Solar Cell
VCS	Voltage Control Switch
WB	West Bank

Preface

Planning for the integration of Distributed Energy Resources (DERs) into the power system has become a primary concern for researchers wishing to maintain system reliability and stability. As a promising solution to the increasing load demand and related real power losses in the distribution system, DGs have been connected as a primary duty to fill this gap. However, the complex and non-linear nature of the power system is challenging. In recent years, powerful tools have been deployed to solve these challenges in the distribution system, modeled on the behavior of natural creatures, animals, and the human brain system, known as Artificial Intelligence (AI).

This thesis presents an AI-based technique based on the behavior of firefly ants utilized to optimize the sizing and location of DG systems in a real-world case study in the city of Hebron in the Palestinian Territories electrical grid.

Ultimately, this thesis has the potential to contribute to the efficiency of the power system and make it more reliable with the support of clean, renewable energy sources. The use of AI techniques can improve the stability and reliability of the system.

Chapter 1. Introduction

1.1. Background

Electricity is the most adaptable energy source available, accessible to over 5 billion people worldwide through sequential technologies, and has become an essential part of our daily lives that cannot be abandoned. As it affects all areas of life, including residential, industrial, and many other uses, the generation of electricity used to be less problematic than it is today. This is due to the abundance of fuel and the absence of climate change effects.

The effects of climate change have become a global concern, and this issue has taken a toll on the environment. No society is completely immune to this rapid climate change, and its effects can be observed in rising sea levels, shrinking ice, and warming oceans. In recent years, changes in the climate have been noted through alterations in the seasons. Summers are longer and hotter, and winters are shorter and warmer than in previous years. Scientists have attributed these problems in climate change to man-made gas emissions such as carbon dioxide (CO2) and water vapor (H2O) in the atmospheric layers caused by the burning of huge amounts of fossil fuels.

This climate disaster is done by making a difference in the way energy is generated and used [1]. Therefore, adopting cleaner energy resources to mitigate global warming is as challenging as meeting the expanding demand for electricity.

As a result, more electricity needs to be produced from conventional and renewable resources. In addition to oil, coal, gas, and nuclear power plants, geothermal, wind, solar, and biofuel power plants will also be required. Figure 1.1 shows the growth of sustainable energy. Solar and wind energies are the fastest growing renewable energy sources in terms of percentage and capacity [2]. Based on the International Energy Agency, from 2010 to 2035, renewable energy generation will nearly increase, accounting for 31% of total global power production, with hydro, wind, and solar renewable electricity accounting for 50%, 25%, and 7.5% of total renewable energy production, respectively [3].

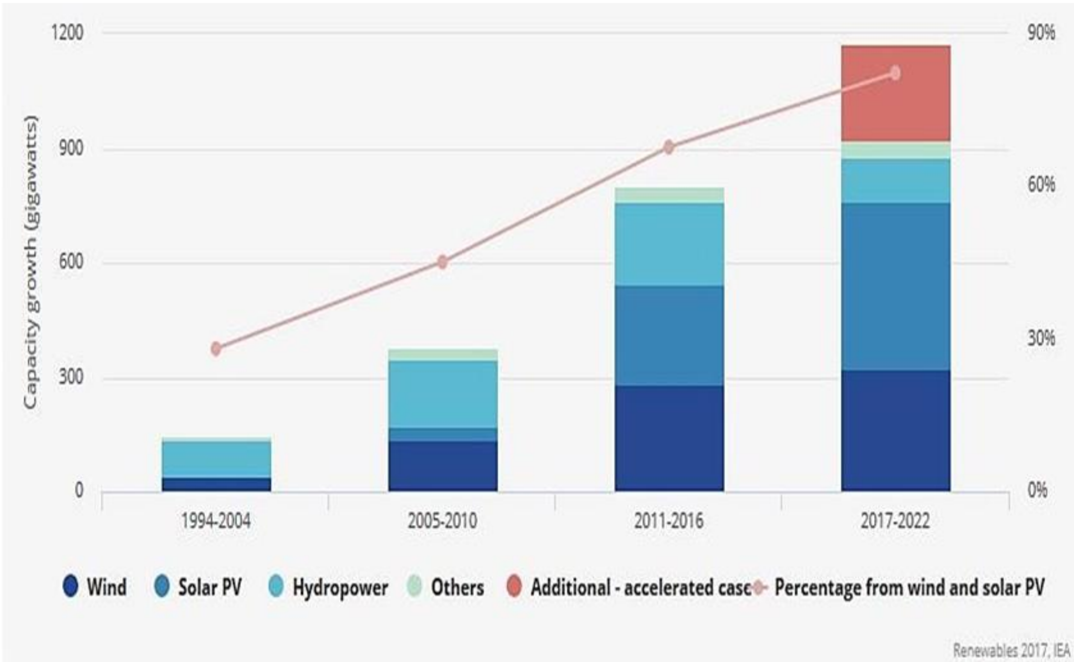

Figure 1-1 Worldwide capacity growth of the utilization of DER Systems

The intermittency of renewable power poses a challenge to its greater penetration into the current electricity network. The current solution is to incorporate this variability into the operating reserves of a centralized electric grid. While the objective is to have a more renewable and cleaner power infrastructure, renewable energy systems still rely on conventional electrical networks to function. Therefore, this operating arrangement cannot efficiently scale to achieve the desired net carbon benefit and reduce reliance on fossil fuel resources. Consequently, the question is: how can deep penetration of renewable generation be economically enabled using the current power system? The increasing consensus is that most of this generation must be distributed across the distribution system at hundreds of thousands of sites. The resulting intermittency can be absorbed through coordinated aggregation and regulation of distributed resources. However, integrating such time-varying distributed or embedded sources into a power system requires special considerations.

Distribution Energy Resources (DER's) are generally composed of small-scale generation and energy storage devices linked to distribution systems and may service local consumption or export electricity to the surrounding network if generation exceeds local demand [4]. Figure 1-2 depicts a comparison of the typical grid system layout and information flow with an integrated evenly distributed generation system [5]. Intelligent multidirectional communication among distributed energy resources is required.

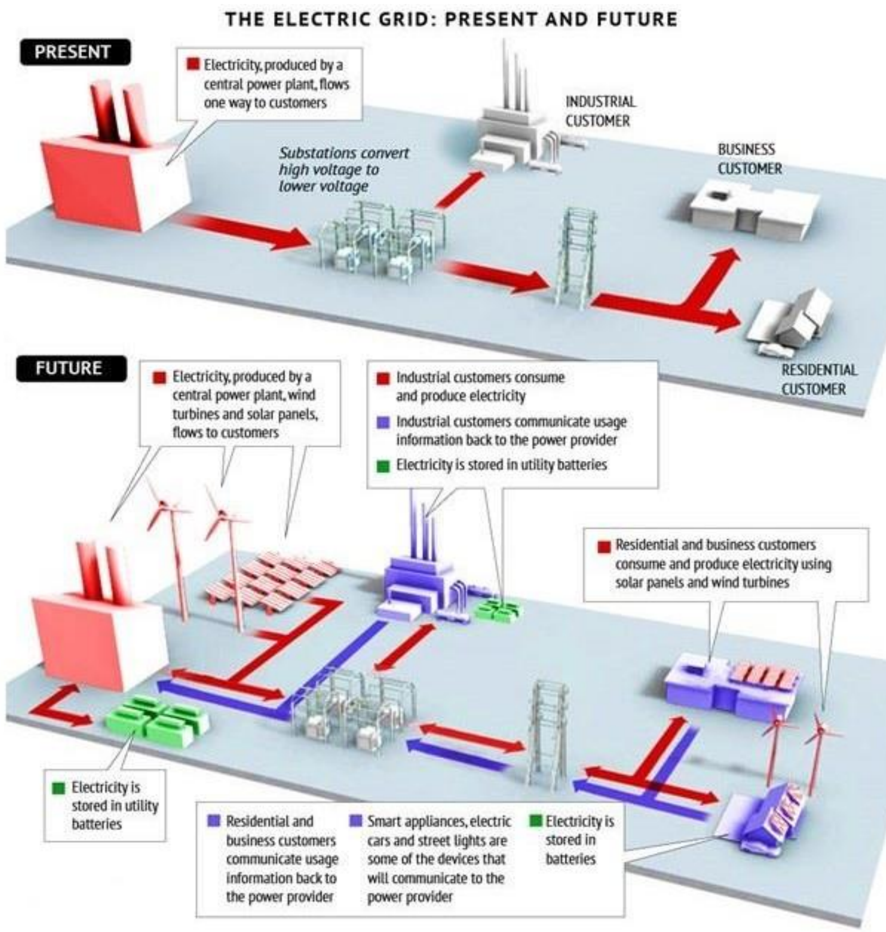

Figure 1-2 The Electrical Grid: modern and traditional Communication

In the face of renewables, consumers, and market uncertainty, distributed sources of energy connected to the grid need to be coordinated to effectively and reliably meet operational requirements (e.g., supplying energy on a regular basis at the lowest possible cost). As a result, inquiring about many of the benefits associated with distributed generation requires efficient energy operation. A considerable scientific effort has gone into adding strategies and procedures for the intelligent functioning of DGs within the power system.

The Palestinian economy has been affected and stagnated by the Israeli occupation of the Palestinian Territories (PT) since 1967. Neglect and destruction have affected all sectors of the Palestinian economy and infrastructure. The electricity industry is one of the most severely affected. Electricity consumption has increased considerably in the recent decade due to the overpopulation of the West Bank. However, the Israelis (who supply electricity to the West Bank) do not supply the required quantity to the Palestinians. Several variables impact energy planning in the West Bank, including demographics, economics, loads, fuel prices, fuel reliability, plant costs, and political issues.

1.2. Energy in Palestine

1.2.1. West Bank Sector Energy Overview

The general consumption of energy in the West Bank is insufficient by regional standards, let alone international levels, limiting the possibilities for economies of scale.

A. The West Bank has only one energy supplier, the Israeli Electricity Company (IEC).
B. The electricity system in West Bank is composed of several isolated distribution lines that are not linked to a distribution system, as well as a lack of generated electricity and a transmission system.
C. The West Bank and Gaza have no fuel storage facilities (Plans for certain storage facilities are being developed).
D. Even though industry and tourism are inactive, the service and residential sectors account for the majority of energy demand (75%).

Private companies or municipal councils typically supply electricity to cities. Meanwhile, both are supplied by the Israeli Electricity Company (IEC), the most significant and unique electricity source of the country. Figure 1-3 shows the amount of electric energy purchased from the neighboring country based on the data in Table 1-1 [6].

Table 1-1 Palestinian Energy and Natural Resources Authority, 2018. Monthly Electricity Purchases (GWh) in the Palestinian Territories

Table 1-1 energy in Palestine report 2018

Month	Energy source (GWh)				Total energy available
	IEC	from pec	from Egypt	From Jordan	
January	588.2	39.2	14.5	6.3	648.2
February	532.5	29.8	14.3	5.5	582.1
Mach	568.9	24.6	15.6	6.5	615.6
April	496.6	21.7	13.5	7.5	539.3
May	524.6	23	13.5	7.1	568.2
June	537.6	19.8	13.5	3	573.9
July	574.3	22.5	14	5.4	616.2
September	576.9	36.6	15.3	4	632.8
October	567.3	40	11	3.2	621.5
November	525.1	26.6	11.8	1.5	565
December	580	36.8	12	1.2	630

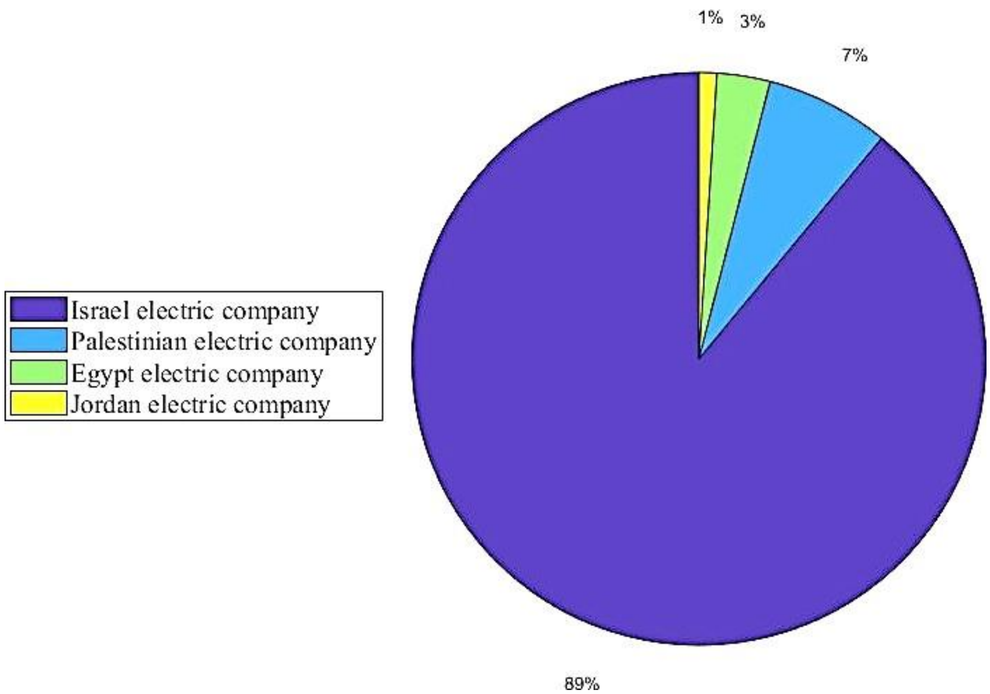

Figure 1-3 energy purchased from the neighboring country

It is noted from this figure that the majority of the electricity demand in the Palestinian Territories is supplied by the Israeli electricity company (IEC) with 89%,and only 7% of the electricity is provided by the ‘’Palestinian Electricity Company’’ (PEC). The absence of development in the electricity sector in Palestinian Territories (PT) and the normal increased demand for electricity have led to more purchases of electricity.

The transmission and distribution of electricity in Palestine undergo OSLO political Agreements that prohibit Palestinian to generate electricity with high restrictions on the forms of fuels and the amount of generated power in power stations. However, to serve Load demand for electricity, the country purchases the electricity from the Israeli Electricity Company IEC, or purchase from a neighboring country. The other option is to generate either using Gas/diesel, for instance, Jenin power station generates 450 MW/H and Gaza power station at 392 MW/H. Or using renewable energy sources with no more than 40% of the full load under authorization and license from the Israeli side like in Tobas, Jericho and Mythalon with accumulated power of 21.5 MW [7].

The IEC provides Palestinian distributors company around 88% (4702 GW/H) of total demand at around 600000 subscription between households or farms or factory loads with an annual growth rate of 4%. Jordan and Egypt with an assessment of power around 8% and Gaza power plant with 4% (392MW/H), after connecting the Jenin power plant the percentage of supplying electricity will be reduced [8].

After 2008, the municipalities planned to merge their distribution sectors by forming new electricity distribution companies. This effort results in the formation of 4 distinct electricity companies. According to a study by [6], the Northern Electricity Distribution Company (NEDCO) was the first to be established, followed by the Jerusalem District Electric Company (JDECO), the Hebron Electric Power Company (HEPCO), and the Southern Electric Company (SELCO). Each company is identified below:

a) SELCO, which was founded in 2002, provides Dura and Al-Thaheriyya in southern Hebron. It uses 400 V, 6.6 kV, and 33 KV ranges
b) HEPCO, which was founded in 2000,provides its services to Hebron City and North Hebron. It uses 400 V, 6.6 kV, 11 KV, and 33 KV ranges
c) NEDCO, which was founded in 2008 to serve Nablus, Tulkarem, Jenin, and other northern West Bank village councils, uses 400 V, 6.6 kV, and 33 KV ranges
d) JDECO, which feed central region of the West Bank (Jerusalem, Ramallah, Bethlehem, and Jericho with voltage ranges of 400 V and 11 KV
e) Other local municipalities purchase amounts of electricity from IEC at the medium-voltage 161/33 KV substation, where municipalities directly step down the voltage from 33 KV to 400 KV

There is no backbone power line in the Palestinian power system. A feeder serves every area from the Israeli grid, as shown on the map in Figure 1-4 [9]. This map shows that three IEC 161 KV portions that feed all West Bank areas require electricity. It has been observed that these lines do feed settlements in the first place and that these lines have complete control over these lines. It has also been discovered that IEC feeds our cities such as Tulkarem, Ramallah, and Hebron with 161 KV portions, whereas 33 KV feeders from Israel supply other cities.

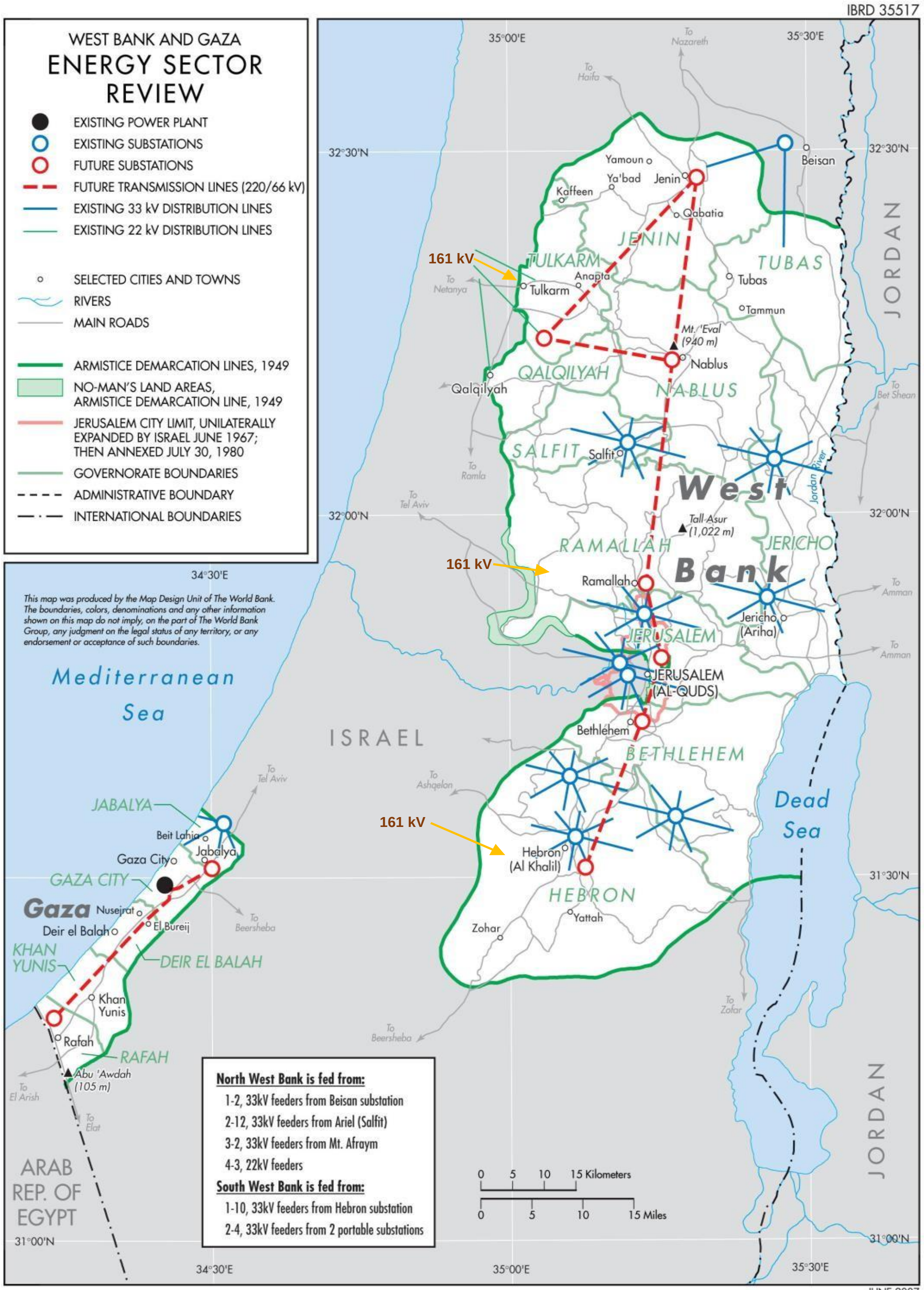

Figure 1-4 Main IEC Feeders to West Bank and DN

1.2.2. Case study

The case study of this research will be conducted in a small town in Hebron called Farsh Al-Hawa, located in the southern West Bank (31.55 degrees north latitude and 35.07 degrees east longitude). Figure 1.10 shows the map of this town and its location. According to the data provided by the Hebron Municipality Electricity Sector, the average hourly load of this town during each month of the year 2019 is shown in Table 1-2.

Table 1-2 Average hourly electricity power consumption in the different month

Month	Average consumption (MWh)
January	4.336
February	4.201
March	3.958
April	3.578
May	3.785
June	4.322
July	4.586
August	4.598
September	4.453
October	3.924
November	4.259
December	4.312

The area of interest in this study will focus on single tie connections of IEC in Hebron, there are 7 main tie connection fed directly from IEC to HEPCO distribution company as follow, i) Al-Ras, ii) Om Al Dalilah, iii) Al-Harayeq, iv) MPC, v) sports lounge, vi) Al Fahs, vii) West, viii) Al-Duhdah figure 1-5[10].substations are connected to tie point with 'IEC' at $161/33\ KV$ with a step-down transformer at each substation figure 1-6.

Figure 1-5 Hebron Main Substations

This study will analyze the case study of a partial network of the Al-Duhdah substation located in Farsh Al-Hawa. A partial of the system of 32 buses and a total of 109 connected loads with varied values and 294 terminals with single line diagram emulated by computerized digital simulators for load flow is illustrated in figure 1-7.

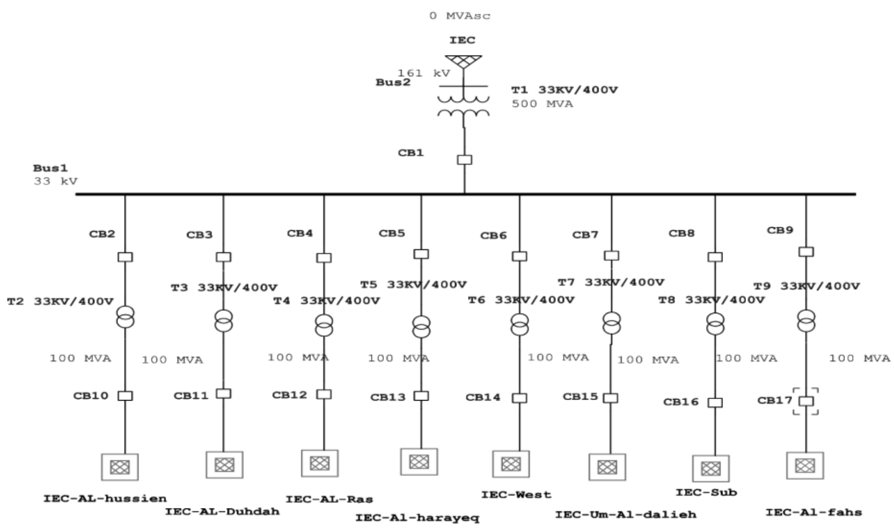

Figure 1-6 IEC to Hebron Main Substations

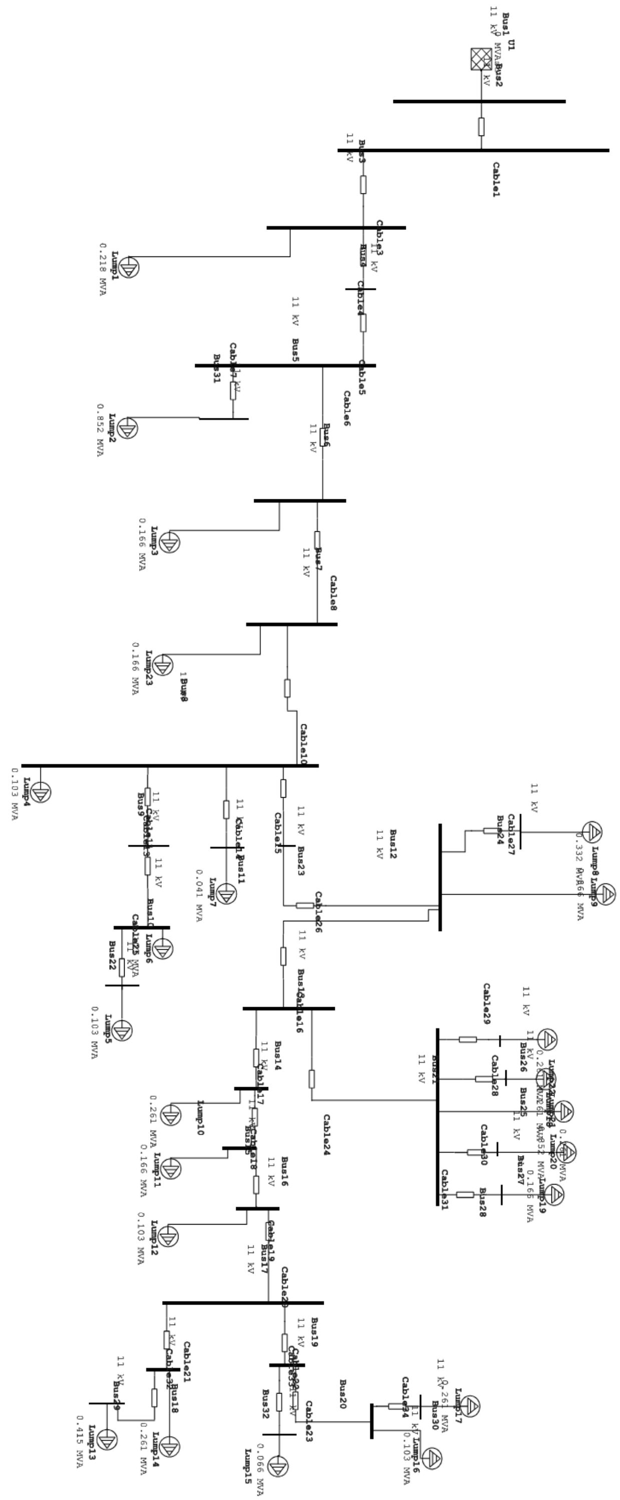

Figure 1-7 Case study single-line diagram

1.3. Potential of solar energy in West Bank Palestine

Palestine has average of 300 sunny days per year, with an average of 9 hours of sunshine per day. This country has significant hours of sunlight with solar radiation which can be converted into electricity. However, climate variability in Palestine can impact the amount of solar energy that is available. For example, during the summer months, the days are longer and hours of sunlight are more. However, during the winter months, there are fewer sunny days with less hours of sunlight and the amount of solar radiation is lower. This can reduce the amount of electricity that can be generated from photovoltaic PV plant.

Solar energy capabilities in general are affected by these factors:

- Seasonality: The amount of solar radiation available in Palestine varies depending on the season. Higher solar radiation in summer moth and lower solar radiation in winter months.
- Cloud cover: Cloud cover can also affect the amount of solar radiation available. On cloudy days, there is less solar radiation available for conversion into electricity.
- Temperature: Extreme temperature can affect the generation of solar energy due the heat produced on PV cells and decrease power generated of PV system.

Despite these challenges, Palestine still has a great potential for solar energy generation. With the right investment in solar technologies, the country could generate a significant amount of its electricity from solar power and reduce reliance on IEC company, increase energy security, and improve the performance electrical distribution networks.

1.4. A review on planning for optimizing DN

The optimization of DN has recently become an issue of current interest for research due to the expansion of DN and the increase in total connected loads. However, to improve the system losses and voltage profile of the DN, the promotion of integrating renewable energy source DG is necessary [11]. In addition to minimizing cost and increasing the reliability of the distribution network, a non-dispatchable DG such as Solar Energy must be added to the network to improve the DN.

Real power loss and voltage profile are impacted by the use of distributed generation, whether in a conventional or an intelligent way [12]. This installation is limited by constraints such as capacity and DG allocation. Several research studies have recently found the ideal position and sizing of the DG using variousapproaches, including i) Scalable programming to define the optimum distribution of the DG [13], ii) Analytical Algorithms used in DN optimization [14,15], iii) Numerical Algorithm methods designed to find the appropriate allocation for the DG and reduce power losses [16]. On the other hand, there are non-optimal power system solutions that have unintended consequences that we must avoid to maximize the advantage of DG, and hence the DN. An optimization approach will find the ideal allocation of DG as well as the capacity of DG to maximize the benefits of the DG.

1.4.1. Problem formulation

Normally DN faces power flow loss and fluctuation of voltage profile in radial networks without the existence of DG. This research is intended to analyze the electricity distribution network, by conducting load flow calculation to obtain the voltage profile and power flow losses of the DN in order to be improved by optimal placement and sizing of PV DG based on solar energy. The enhancement of the DN is considered for the average, maximum, and minimum load consumption of the existed electrical grid during January, April, August and October.

Recent researchers have implemented various loss reduction techniques including load management and reconfiguration of DN other than the installation of DG as solution to minimize power flow loss, this research is intended to integrate DG at best location using LRSF technique along with optimal size of the PV plant using metaheuristic techniques to attain objectives of this research. The Integration of PV plant is preceded with calculation of relevant parameter of the PV array to design the required electrical component for the PV DG.

1.5. Objectives:

Objectives of this thesis are as follow:

A- To assess the potential for solar energy to be integrated into Hebron substation located at Farsh Al-Hawa. This involves studying the amount of solar radiation in the area of study.

B- To analyze the Electricity Distribution Network of Farsh Al-Hawa that is connected to Al Duhdah substation and emulate network on computerized simulation tools for total system demand and total real power loss.

C- To determine the location of PV DG to minimize total real power loss.

D- To find the optimum size of the DG in term of minimum loss and improve the voltage profile taking into consideration the constraint of government regulation, load balance, and the allowable power generation from the DG's.

E- To compare the state of the case study before and after applying the proposed method.

1.6. Contribution

In optimal planning of DG, several previous researches have been searching to fill the gap of integrating RES in Distribution Network. It was found that the optimal operation of integrated DG is the most significant issue in the modern electrical system. It serves to reduce power flow loss, and improve the voltage profile. These researches have opened up the scope of FA as one of the efficient optimizing methods for planning to integrate PV grid connected plant. Which is applied along with loss reduction technique (minimum LRSF) on a real case study, the significant points of this study are listed as follows:

a) This research contributes to solving a real problem in PT by using renewable energy resources to improve the network performance.

b) The electrical grid of the case study undergoes a technical loss in the power system which is necessarily reduced with the use of numerical tool based on LRSF technique.

c) A Firefly algorithm is applied to a real-world case with real data to locate the optimal DG sizing for the DG integrated into the grid.

d) The optimum DG placement and sizing with optimum operation has been studied while the other studies they separated it into two subjects.

e) This study has taken leverage of the availability of solar energy in PT, specifically in the town of Farsh Al-Hawa during the 4 seasons.

1.7. Research questions:

When planning for optimal DG sizing and allocation using FA, LRSF techniques while minimize loss and enhance system efficiency, it is important to address key questions to ensure maximal benefits. This research addresses and answers these questions:

- Will the LRSF technique detect the candidate bus for optimization?
- What is the optimum location of the DG?
- Could the Firefly optimization technique predict the optimal sizing of DG?
- What is the optimal capacity (size) of the DG?
- Did the PV DG improve the system performance in term of Loss reduction without violating voltage profile?

1.8. Overview of the research flow

The research flow starts from a literature review that present recent studies on loss reduction techniques and examine the usage of modern optimization techniques for integrating the DG into an electrical grid. The research flow continues by collecting data about the case study that is intended to improve its performance, then simulating the DN on MATLAB for load flow, and then studying the availability of renewable energy source technologies for the system which is based on solar radiation and the effects of solar radiation and temperature of the sun on power generation for the location in Hebron city in Palestine for later designing the electrical PV plant. Afterwards, it analyses the results of the optimization technique for loss and voltage profile. Finally, it compares the results before and after the optimization of the PV DG and discusses the results.

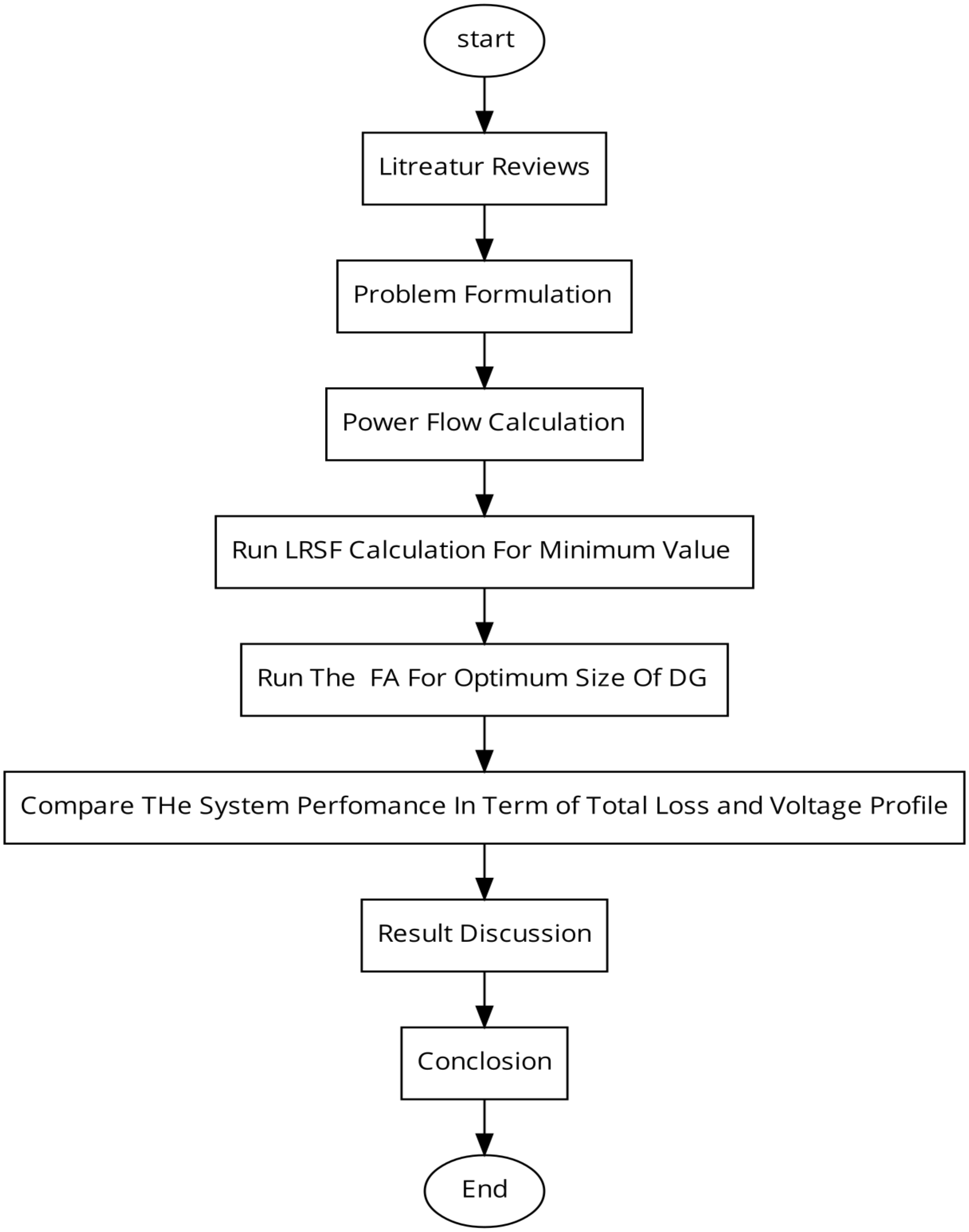

Figure 1-8 Overview of the research flow

A flowchart outlining the general overview of the research flow is shown in figure 1-8, which serves as a guide throughout the project execution.

This study utilizes the following methodology as a guideline to meet the objectives of the research.

a) Related research: which is including an explanation of RES Potential in Palestine and related research on loss reduction and optimal size techniques from prior research or technical papers, identification of research gaps, and determination of objectives.

b) Data collection and analysis: which is studying the electricity network involved in data collecting of the system line data, load data, and the topology of the case study from Hebron Municipality that inhabitant technical loss. Then, designing and analyzing using ETAP program and MATLAB for load flow to find the total loss and voltage profile .

c) Research development: which is applying loss reduction technique for the system to determine the efficient location for PV DG to be installed across the grid.

d) Utilization of Optimization Technique: Introducing the Firefly Algorithm and its methodology to solve multi constrains for our objective, which functions as follow: The initial stage involves creating programming codes for the FA in MATLAB command. Next, introducing the objective/fitness function, parameters, constrains and boundary settings for FA optimization.

e) Data testing: This testing requires valid resource data from a prior recommended research paper which is presented, with the consent of the author and supervisor. A test system on IEEE standards is applied on this methodology for validation. Detailed information regarding the test system is presented in Chapter 4.

f) Comparing the system before and after the addition of PV DG unit's 24-Hr of 4 seasons during the year, from two points of view: Active power loss and voltage profile.

Chapter 2. Literature review

2.1. Basic theory

The generation of electrical energy from conventional fuel sources have been increased due to ongoing increasing demand that corresponds to the increasing population year by year, this causes more fossil fuels to be burned to produce power, which has caused the world to look for ecologically friendly power sources. Researchers in this field called for proposals to obtain solutions for the generation of power that is cheaper and decreases the use of fossil fuel. Various types of clean RES e.g., wind energy, biogas, and solar radiation energy are the best choice to generate power depending on the reliable weather condition in different locations across the world. Utilizing RES such as solar energy by using solar photovoltaic (PV) systems has become widely used in power generation since it has advantages in grid-connected as a DG. The integration of PV plant offers low maintenance and operation costs, and reduces the need for fuel-operated DGs.

This chapter, provides a comprehensive analysis of the techniques and operational strategies implemented to address the challenges of integrating grid-connected (DG) units into power grids. Planning and distribution of DGs became a critical issue in this era. There are many constraints on the integration of DG such as economic, environmental, technical, and regulatory issues. Also, this chapter focusing on developing solutions for the integration of DG to grid-connected power loss minimization of power DN and DG placement technologies. Moreover, a brief discussion of the literature on strategic optimization planning is in the following section.

2.1.1. Electrical power system topology

The power system started from the need to organize the transmission of electrical power from the main substation which has a power generation plant to insert a different level of voltage transformers through interconnected transmission and sub-transmission lines to either radial or ring topology DN contains distribution substations to cover wide areas to reach end users in good performance; see figure 2-1.

Different types of power generation plants such as fossil fuel (Coal-fired, Diesel-fired, Gas-

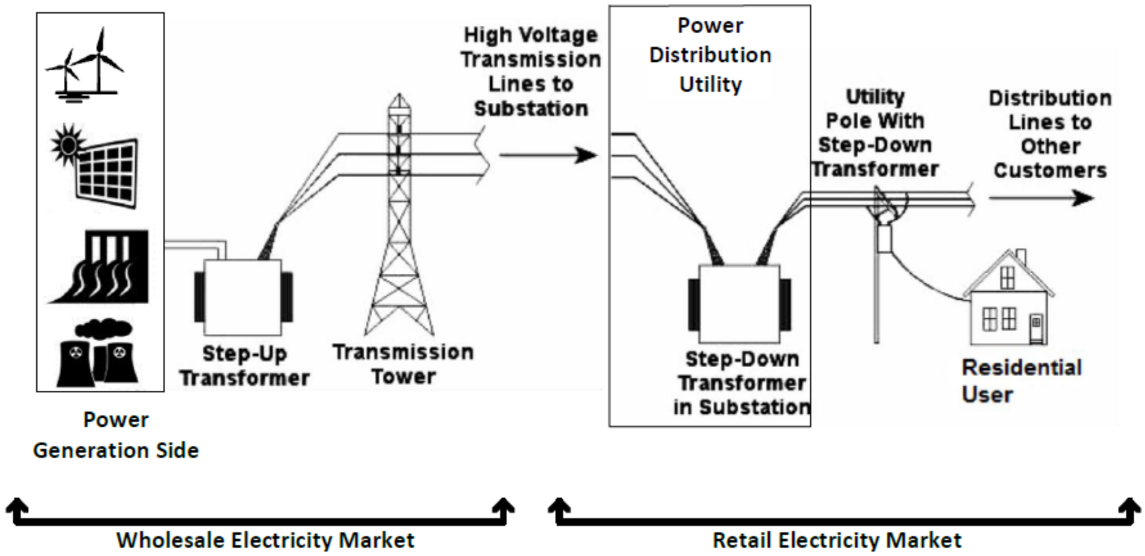

Figure 2-1 Energy flow from generation to end user diagram [17].

fired, radioactive material) are used as the main substations in different power distribution systems. In order to generate sufficient power to cover load demand. On-site generation is another term of DGs which rely on green power (Geothermal, Wind, solar, Tidal, and bio-mass) power plants with common capacities are ranging from 5 KW up to few MWs [18]. These DG sources have been set up near loads to serve a micro-grid (a smaller grid connected to a large electrical distribution system) as Decentralized Generators, where on a large scale are referred to as centralized DG such substation [19].

Each power plant type has its advantages and disadvantages depending on operation cost, carbon emissions, effective power, maintenance, and environmental changes; see table 2-1.

Table 2-1 features of generation plants.

Generation plants	Main Advantages	Main Disadvantages
Renewable energy sources	An infinite source of energy	Not fully carbon-free
	Clean energy with less carbon emission	Intermittent sources
	Low operation cost	Limited energy production
	Low maintenance cost	geographic limitations
Non-renewable energy sources	Cheap energy source	Dangerous to produce
	Reliable source	Limited energy source
	A large-scale power generation	Non-friendly to the environment and wildlife

Recently planning has shown that global power generation distribution systems rely on non-renewable energy sources as their main power source as illustrated in statistics up to the year 2019 in figure 2-2, due to its large-scale capabilities to produce a sufficient power for the DN. However, DGs tend to use renewable energy sources either to cover outages of loads or to enhance the network's voltage levels and reduce power flow loss.

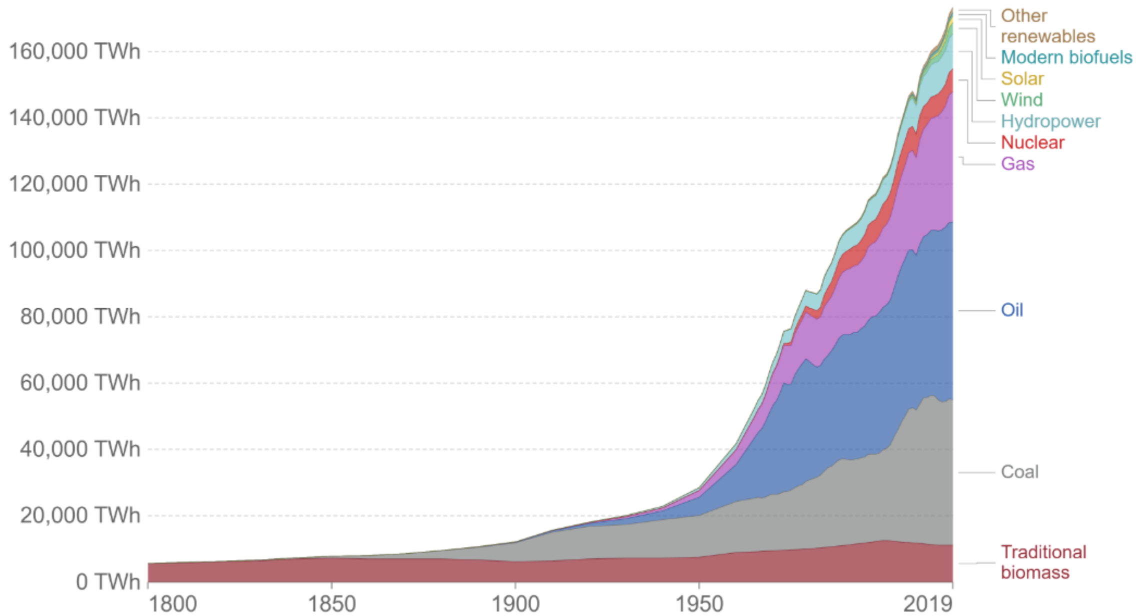

Figure 2-2 Renewable energy sources integration into Grid [20].

Conventionally, generation plants which were centralized in DN were limited to one location, whereas researchers in the field found that placement of small-scale capacity DGs can enhance overall DN performance within standards [21].

Transmission network

The maximum omnipresent part of the electricity distribution system is the main part to transmit the electrical power from one location to another in the grid. Electrical conductors in transmission networks, e.g. Transmission lines cables, sub-transmission lines, power transformers, and laterals, encompass the material specifications of the electric conductor of either copper or aluminum alloy. The insulation criteria of these conductors depending on voltage levels for overhead installation. However, for high voltages ranging between 110 KV up to 400 KV, there is no insulation due its weight effect without reduction of the transmitted power signal. The generated power regardless of the generation plant type is inserted into reliable step-up transformers to distribute over transmission towers at high, medium or low voltage via conductors' arrangement, to reach certain areas at end user with step down transformer with required protection component. These conductors are designed and sized to decrease voltage losses. However, main losses in the distribution system are caused as a form of voltage drop due to transmission line losses where line

Resistance R increases as the length of the line increases; also, conductors' specification has its own Reactance X due to conductors spacing, and the length of conductor will not change its reactance. However, if the diameter of the cable changes it will increase inductive reactance (X_L), and Capacitive reactance (X_c) [22].

Planning for transmission line conductors either installed overhead or underground. Some features constrain conductors' installation. See table 2-2 below defines the major installation of the conductor's properties.

Table 2-2 Transmission Line Cable Categories Features.

Features	Overhead	Underground
safety	Most high-voltage conductors are installed less safely overhead.	Safer when installing distribution wiring buried underground.
Startup cost	The initial cost is less than underground.	Require more cost since its high cost of trenching, conduits, manholes, and other special equipment.
Maintenance and Faults	Increased chances of faults appearing as weather conditions (wind, lighting) could cause interruption of service. However, easy to maintain.	Less chance of occurrences of faults however faults are rare in comparison to overhead and so less Maintenance but harder.
Durability	25 years.	More than 50 years

2.1.2. Planning for distribution generation

Small scale DGs are becoming a part in the DN where the flow of power is bidirectional from some points in the DN. Nonetheless, the increased demand of energy follows a significant increase of installing DGs randomly across the DN, which may create a reverse power flow to the main substation under certain amount that may cause the system to interrupt. DG planning search for modern solution to grid-connected DG challenges in the network, so that the measured amount of injected power from the DG source is called ‘the Penetration Level’. Each DG will inject an amount of energy related to the percentage of total power injected from the primary substation. The amount of penetration is not static since under light loads for small distribution systems, for example few megawatts will be a high level of penetration and may cause a voltage rise in the distribution’s network and reverse power flow, under high load demand a few megawatts will not significantly serve the same distribution system at best [23]. DG planners and operators seek to cover the demand of power in the downstream (load center) fed from the upstream (primary substation) not only coverage but also a reduction in the total power loss of the system, voltage drop, and improvement of the power quality of the grid. As a result, limiting reverse power flow, these are a major challenges in planning for integrating DG.

The recent integration of DGs is mainly renewable energy DG due to positive effects on the environment and suitable for its power capacities. Renewable energy DG requires studying the localization and size of DG, for example, solar photovoltaic PV DGs are affected by weather change and solar radiation. The placement of PV DG has an impact on PV plant generation on the grid [24].

2.1.3. Electrical power flow

Transmission and distribution networks are a set of three-phase lines with voltages ranging from 115 KV to 765 KV with complex power ratings varying from 50 MVA to 2000 MVA. The "network" term signifies the presence of multiple paths for electrical current between any two points of the system regarding the configuration of the network. Generally, primary distribution systems are operated in a radial power flow, i.e. power flows from a substation to reach different load points with each load being fed by one point from the T&D network.

Power flow analysis used to analyses the active power, reactive power, voltage magnitude, and phase angle for each bus of the electrical network. The network of the distribution contains three main buses classified below:

1- Slack bus is known as swing bus used as a reference to the system normally represented in voltage of $1pu$ at $0°$angular reference to balance the P, Q flow from the primary substation to the grid.
2- P-Q bus known as a load bus refers to a bus that has no voltage control switch device VCS, at this bus the (P), and (Q) are known for the load flow calculation. However, absolute the Voltage $|V|$ and phase angel δ to be calculated as variables.
3- P-V bus known as Generator bus or Voltage controlled bus where a generator connected to the network throws this connection bus. P and V are known for the load flow calculation Q, ∂ are variables.

In terms of mathematical equations to analyze system parameters the system is assumed to be working under a steady state in normal conditions with phases balanced for 3-phase transmission. Analysis can be done systematically by the node-voltage method formula [25]. However, in distribution systems, P, Q are the parameter rather than currents which lead to handling nonlinear equation that could be mathematically solved by iterative techniques. The admittance matrix (Y_{bus}) and impedance matrix (Z_{bus}) of the node-voltage method are formulated to define the power equation of the load flow equation. Thus, using MATLAB script and applying Gaussian elimination of matrix data for the equation of simple system shown in (2.2) for a balanced system of figure 2-3.

$$\mathrm{Ibus} = \mathrm{Vbus} * \mathrm{Ybus} \tag{2.2}$$

For the load flow calculation newton Raphson, Gaussian, and fast decupled are preliminary. Analyzing distribution is done for small networks using the load flow equation after classifying the grid for load bus and generator bus. Nevertheless, in a complex radial network, it is difficult to do calculations for the system as there are too many branches and nodes of the electrical grid which require increased loops to find the solution of nonlinear

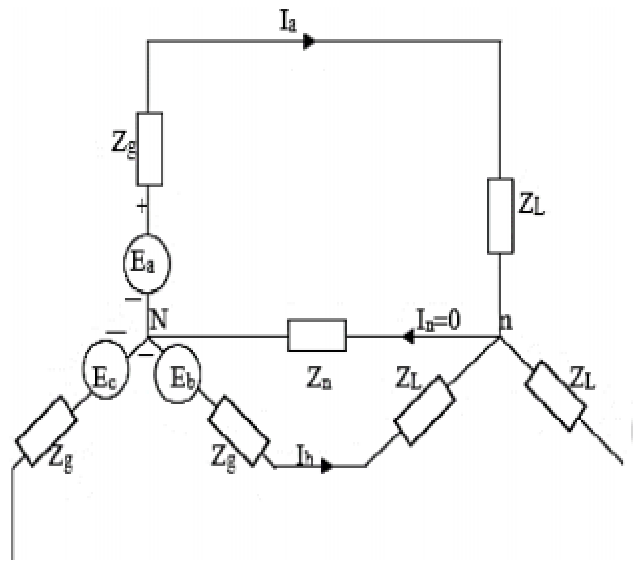

Figure 2-3 Three phase modeled system for load flow calculation

power flow equation using iterative methods.

For nonlinear systems, these power flow methods are applicable to a balanced electrical system:

- Newton–Raphson NR [26].
- Gauss–Seidel method [27].
- Holomorphic embedding [28].
- Backward-Forward Sweep (BFS) [29].
- Fast-decoupled [30].

Power flow studies became the base of designing and analyzing the power system in planning, operation, economic dispatch, and contingency studies. The common technique used for the iterative solution of the non-linear equations among mentioned techniques above is NR which is explained for one dimensional up to n^{th} dimensional equation e.g. Taking the NR method is efficient for large bus systems because of the quadratic convergence of the equation this mathematical representation of power in terms of the

Jacobian matrix, P, Q (scheduled) and calculated in equation (2.3) (2.4) [26] respectively below.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = [J]\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} \tag{2.3}$$

where:

$$[J] = \begin{bmatrix} J1 & J2\\ J3 & J4\end{bmatrix} \tag{2.4}$$

$$P_i(\text{scheduled}) - P_i^r(\text{calculated}) = \Delta P_i\text{^}r \tag{2.5}$$

$$Q_{iP}(\text{scheduled})\text{-}Q_i^r(\text{calculated}) = \Delta Q_i^r \tag{2.6}$$

Where ΔP_i^r , ΔQ_i^r are power residuals. The number of iterations for this method is expressed in equations (2.7) (2.8) respectively [26].

$$|V|_i^{(r+1)} = |V_i^r + \Delta V_i^{(r+1)}| \quad ; i = 2,3,\ldots., n \tag{2.7}$$

$$\delta(r+1) = \delta\, r + \Delta\delta\, r \tag{2.8}$$

r: number of iterations

NR Load flow is expressed as follows:

- Start
- Create Ybus matrix
- Make initial assumptions as the old values
- Substitute the old values into power equations for the next iteration
- Obtain the new value
- Subtract the New value from the Old value
- If the obtained value is less than a specified tolerance ; then end
- Otherwise return to step of obtaining new values.
- End

NR reduces iterations in comparison with Gauss–Seidel method and the Fast-decoupled method [31].

Another mentioned load flow method that is commonly used for radial networks is the Backward/Forward Sweep algorithm BFS by using the most known Kirchhoff voltage low and Kirchhoff current low, used here in DNs. This method took advantage of not using the Jacobian matrix and instead used fast convergence technique based on sweeping off the network backward and forward to generate the transformation matrix to obtain the solution of the next value of voltage whereas the current is still unknown; see equation (2.9) [29].

$$[V]=[V_1] - [BIBC][BIBV][I] \tag{2.9}$$

Where: [I] branch current matrix, [BIBC] is a transformation matrix of branches current, [BIBV] is a transformation matrix bus voltages matrix from branches currents, where [V1] is the upstream link voltage.

In the radial network, Backward/Forward Sweep algorithm BFS proved its convergence to the best solution with a reduced number of iterations with compare to other load flows as in the Gauss–Seidel which requires a high number of iterations [29]. This method later in this thesis will is used for load flow calculation for this study.

2.1.4. Overview of Loss Reduction techniques in Power Distribution Network

Planning in DN basically relay on load flow calculation to solve different issues in distribution, e.g. economic dispatch, technical, and regulatory issues when integrating DG in the grid. A loss minimization, cost minimization, and voltage stability of system proposed by planners in DN. DG planning techniques methods are in development starting from analytical methods, heuristic, and meta-heuristics approaches to organize and enhance the capabilities of the transmission network.

Management of power operations are the main level measures of the power quality of system in the grid. The power loss index is a crucial metric for planners in the optimization of distribution systems. Technical and management strategies are used in loss reduction depending on the level of the total loss in the grid system [32]. Management strategies depend on human factors.

There are several technical ways to reduce losses. Grid system operation and power equipment configuration are the two key topics discussed. An approach based on evolutionary programming for the optimization of renewable energy source DG in the radial distribution system proposed in [33]. This method is based on tabo?? search with the conjunction of Genetic Algorithm (GA) in search for the performance of an electrical grid system in which loss reduction is studied based on the allocation of the capacitor bank and DG depending on the stochastic nature of DG. The other solutions rely on grid system operation with dynamic reconfiguration to realize the electric grid. DN reconfiguration for loss reduction that uses the system's optimal reconfiguration network to reduce real power loss proposed in [34]. Therefore, the technological strategies of power loss reduction are:

- Analytical approaches.
- Heuristic Approaches
- Meta-heuristics

2.1.5. Analytical approaches.

Numerous analytical techniques for DG sizing and location investigations e.g., phasor current injection, Exact Loss Formula, and Rule of thumb ($2/3$ rule),". A succinct explanation of these techniques is:

1- Phasor current injection analytical approaches:

The analytical method for DG location and sizing is based on phasor current injection in radial systems to minimize power loss assuming DG uniformly increases and centrally on fixed load proposed in [35]. However, this analytical approach present assumptions that may cause inaccurate results.

2- Method based Exact Loss Formula

Another research for optimum DG sizing and location was proposed in [36] based on the Exact Loss Formula. this method requires load flow multiple times one for the base case and the other one to obtain the final solution including DG integrated the network assuming the DG injects real power into the grid to minimize the losses of the system at the level of one DG with fixed load level, where it leaks the effectiveness when injecting multiple DG.

3- Method based Rule of Thumbs (2/3 rule):

A technique used to integrate DG in radial configuration seeks for real power loss minimization based on the Rule of Thumps where 2/3 of DG size is injected at 2/3 of the distance from primary upstream has been proposed in Lee Willis et al [37]. This method applied for radial networks where meshed networks are is not applicable.

2.1.6. Additional Analytical Methods:

The analytical techniques for DG placement in radial and mesh distribution systems take into account both time-invariant and time-varying loads to minimize power losses were proposed in [38]. This analysis has a significant advantage because there is no requirement for iteration and no problem with convergence. Unfortunately, the issue of DG sizing is not addressed as proposed in [15]. Other than analytical tool, the loss reduction sensitivity factor LRSF, and it is based on historical data that takes in consideration the real power flow loss that occurred in previous iterations during load flow to accurately predict the potential power flow loss amount that could be reduced at certain bus location. This technique is relatively simple and straight forward technique in of loss reduction and in identifying were could be reduced optimally with DG as proposed in [39]. Table 2-3 discusses other analytical methods.

Table 2-3 Comparison of different analytical methods with various load conditions

References literature	Objective of research	Condition of Load	Studied system
[40]	Loss reduction	Constant/average load	30 ,33 and 69 bus system
[15]	Loss reduction	Constant/average load	16,33,69 bus system
[41]	To minimize Active power loss and to maintain voltage	Time-varying load	13, 69-bus system

2.1.7. Heuristic Approaches

Several researches [42, 43, 44, and 45] have proposed heuristic strategies for addressing DG sizing and location challenges. Another heuristic method that ensures the best possible use of the resources of a network is by putting forth an approach based on linear programming (LP) [42], in which the authors take into account voltage rise effects, various equipment capacities, and short-circuit faults as constraints. This study suggests that planning is necessary to allocate Embedded Generation (EG) in a way that maximizes generation capacity within the constraints outlined. Rather than using the "first come, first served" method. In [42], an LP-based technique chooses the best allocation plan for a constant load state during the peak load period. To maximize its benefits, however, load fluctuations and generation uncertainty must be considered. To allocate energy optimally, [46] takes into account potential energy sources, technological constraints, as well as other crucial DG placement limitations such as geographical availability, losses, and connection costs.

For DG placement, a continuous power flow-based approach is used in [47], where DGs are placed on the most sensitive busbars, depending on the margin for voltage quality and with the highest capacity available on the busbars. Additionally, it demonstrates how DG allocation affects the network power loss curve. Whereas the reliable DG size is not addressed, nor are fixed load circumstances taken into account by the authors, as the analysis mounts only one plant specified capacity with the best allocating at each iteration.

The Kalman filter algorithm is utilized in [48] to specify the best position and optimum capacity of the DG unit, and the suggested solution lowers the network's overall real power loss and computational complexity. In this study, the maximum load bus is assigned to DG, and DG planning accounts for peak load conditions without taking voltage stability and reliability measures into account.

A stochastic strategy for assigning wind DG sources in power distribution systems is proposed in [49]. Nonlinear Mixed Integer Programming is utilized for planning that targets to minimize the system's annual energy loss while observing voltage stability and other analysis-related constraints. Moreover, researchers use dynamic programming to determine Dg capacity while minimizing system loss under network constraints.

2.1.8. Methods based on Meta-heuristics

PSO, Genetic Algorithms (GA), fuzzy logic methods, and other techniques have been extensively used in DG allocation research. [50,51]. In [50] For DG siting and size, a GA-based approach was adopted. This planning strategy concludes optimal DG location. Selection can substantially lower total system loss. [52,53] also uses a GA-based algorithm. All of these analyses account for peak load and leave out DG based on renewable energy. The location of the available sources for electric power i.e., wind energy and solar irradiation greatly influence the installation of DG powered by sustainable energy sources DG’s.

Value-based research utilizing GA proposed in [54]. During the analysis, the increase in load growth is considered to be uncertain. The proposed strategy determines the optimum size and Allocation of DG to enhance system reliability while minimizing total system loss.

A fuzzy-based method for effectively allocating DG in [55]. In this study, a DG allocation algorithm was created to increase distribution firm (DISCO) profit and loading margin. Voltage limitations and feeder power flow constraints are taken into account throughout the optimization process. Given a specific demand level, the suggested technique can identify the ideal DG capacity. For DG design and integration GA with decision theory were utilized [56], and another approach for the uncertainty of the availability of renewable energy sources was considered in [57], which makes the study reliable because the existence of multi-objective optimization is carried out offering the planner with ideas about the optimal solutions.

DG placement based on the PSO method was utilized in research for deployment in a micro-grid, a developed inertia reinitialized social structure (IRS-PSO) that is structured and programmed on PSO in [58] while considering various available DG.

An algorithm population-based search built on the behavior of bees “the artificial bee colony” (ABC) proposed in [59]. Also, the ant colony optimization technique proposed in [60]. Subject to additional inequality limitations like the voltage stability limit, the study in [61] tries to reduce system losses under peak load conditions. As a result, compared to analyses utilizing traditional meta-heuristic methodologies, the analysis is significantly more effective and efficient. Based on the reliability index, the DG locations are selected using the ant colony approach [62]. Table 2-4 compares various research in the literature that uses meta-heuristic methods.

Table 2-4 various meta-heuristic techniques

References literature	Objective of research	Condition of Load	Studied system
[63]	Loss reduction, Voltage profile improvement	Constant/average load	Balanced 33 bus
[64]	Real power loss Minimization	Constant/average load	balanced 30 bus
[65]	Network efficiency enhancement and stability augmentation	Constant/average load	balanced 38 & 69 bus
[66]	The impact on real power loss - Voltage Profile	Time Varying Load	86-node distribution Network

A bio-inspired metaheuristic algorithm that was first proposed on [66]. The FA has been used to solve a variety of optimization problems, including the optimal placement of DG. In this application, the goal is to find the optimal size for DG in a power grid such that the total power losses are minimized as applied for integrating 2 DGs for the electrical grid where it is tested only on test system of IEEE 69-bus [10].

Chapter 3. Research Methodology

3.1. Optimum DG planning in term of Power Loss reduction

The power distribution system plays a vital role in the electricity supply chain, especially in regions where over 70% of all energy is consumed. This system is usually a low-voltage network and any issues such as low voltage drops and power losses in the distribution area can affect the efficiency and stability of the entire system. Therefore, efforts are made to minimize power losses and improve voltage profile. [67]. Additionally, industry and regulators have recently concentrated on the environmental effect, energy efficiency, and smart network capabilities of the distribution system. Now, it is more crucial than ever to evaluate its efficiency [68]. To enhance the efficiency of the distribution system, it is important to implement effective and efficient planning approaches that aim to control and reduce power losses within the system.

This chapter focuses on enhancing the efficiency of the distribution system through the proper planning of DG capacity and location. In this research, balanced 3-phase test distribution systems are considered, the tested system described in next sub-section.

3.1.1. Test System and Analytical Tools

The distribution system analysis is substantially more complicated than the transmission network analysis [69]. Power distribution feeders are often multiphase and asymmetrical in design. The distribution system comprises different types of multiphase overhead and underground lines, reactive power compensation devices (such as capacitor banks), voltage control devices (like voltage regulators), and various types of load configurations (such as constant current, constant power, constant impedance), and/or combinations with unbalanced loads, taken into account precise planning. Additionally, it is crucial to choose a program capable of emulating various test systems. This study addresses the issues of voltage drop and power losses in the power distribution system of a village located in Farsh Al-Hawa, which is connected to the Al Duhdah tie connection in a city, Palestine. The study focuses on a 32-bus system in the area. The rated system voltage is 11 KV, distribute around the city following the main streets. Transformers also step down the levels of voltage from 11 KV to 0.4 KV to feed the customers and various loads as is shown in Chapter 1 figure 1-7 single line diagram.

In this research, MATLAB 2018 is used to do the simulation of the system (analyses of the system). Power flow analyses MATLAB code is used to determine the voltage at each bus and the current in each branch also the power loss in the system.

3.2. Power Loss and Voltage Profile in DN

Both transmission and distribution systems are responsible for transporting electrical power from one voltage level to another. However, the resistance of the transmission and distribution lines results in energy loss throughout the energy path, from the power generation stations to the load centers. A distribution system has a higher resistance than transmission. This means the amount of current through the distribution is higher also, this implies that the amount of energy dissipated in the distribution system is greater than transmission network. In general, the loss of a power system is almost 7% of the total energy generation [67]. This loss is divided between the distribution system and transmission as 70% and 30% of the total loss respectively.

The high loss in the distribution system has a negative effect as the demand for energy increases which raises the cost of the operation (purchase or production) of energy; also, this loss might cause a rise in the current flow through the devices which need additional equipment, which further increases costs. As a result, it is worth reducing the loss to improve the proficiency of the grid energy and reduce the cost.

Losses in the distribution system are classified into two types: technical and non-technical [70]. The technical loss includes variable and fixed loss. The fixed loss is often referred to the iron loss in transformers and motors cores, while the variable loss is stated as the loss in copper which exists in delivery equipment like cables and lines, also the copper in the transformers. This kind of loss depends on the amount of power flowing through the equipment. Variable loss is a notable type of engineering loss that varies directly with the square of the current.

Actual power loss is the greatest loss in the system compared with other losses, and it depends on the resistances of the power delivery elements like distribution lines and transformers, motors cores. Real power losses are expressed $(I^2 R)$,which is the series resistance multiplied by the square of the current flow through this resistance. On the other hand, in the distributed system containing (n) number of branches, the total loss of power is given in eq (3.1).

$$P_L = \sum_{i=1}^{n} I_i^2 R_i \tag{3.1}$$

Where I_i magnitude of the current through the resistor R_i, the current flow in the system is obtained by doing power flow analyses in the grid.

In the case of consideration of a simple three-phase symmetric equivalent radial transmission line with the generation, as in Figure 3-1, then the losses become equal.

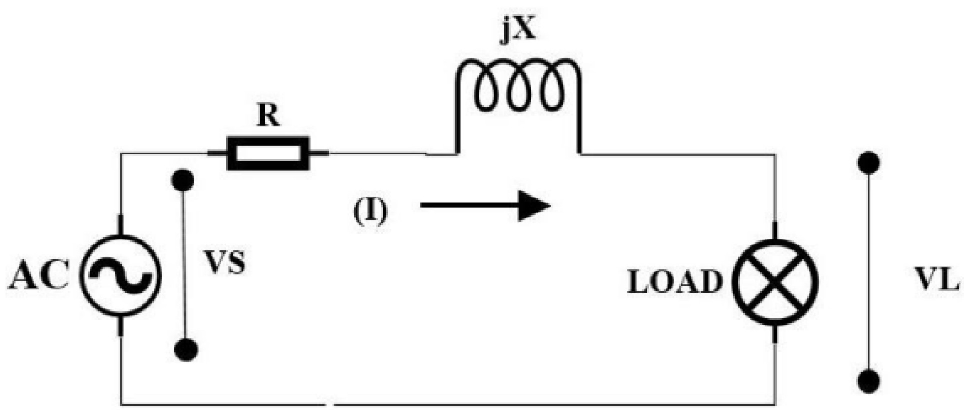

Figure 3-1 Simple equivalent circuit of per-phase

$$P_{Loss} = 3I^2R \tag{3.2}$$

Where (R) is per phase resistance of the line, (I) is the current across the line.

$$I = \frac{P_G}{[V_G(\cos\Theta_G)(\sqrt{3})]} \tag{3.3}$$

P_G: is the generated power.

V_G: is the magnitude of generated voltage.

Cos θ_G: is the power factor.

If we substitute the value of the losses power equation, we get

$$P_{LOSS} = \frac{R}{[(\cos\Theta_G)^2|V_G|^2]}(P_G)^2 \tag{3.4}$$

Assuming the power factor, the generated voltage is a fixed value the equation becomes as follow:

$$P_{LOSS} = BP_G^2 \tag{3.5}$$

Where,

$$B = \frac{R}{\cos(\Theta_G)^2 V_G^2} \tag{3.6}$$

The previous equation noted that energy loss is approximately a quadratic function of generation. [71],[72].

According to [72], the placement of DG in a distribution system can alter the energy loss within the system. The power loss curve takes the form of a quadratic function, due to the line loss perpendicular and I^2R, where (I) represents the line current, R represents the resistance.

Integrate DG to the grid at any point decreases total loss as the size of DG increase until reaching its minimum value, at that value we can see the optimum DG size. But increasing the penetration of DG in the grid upper than the value of optimum leads to increasing the system loss. The behavior of the loss changes versus the DG size in the system of distribution is explained clearly in Figure 3-2.

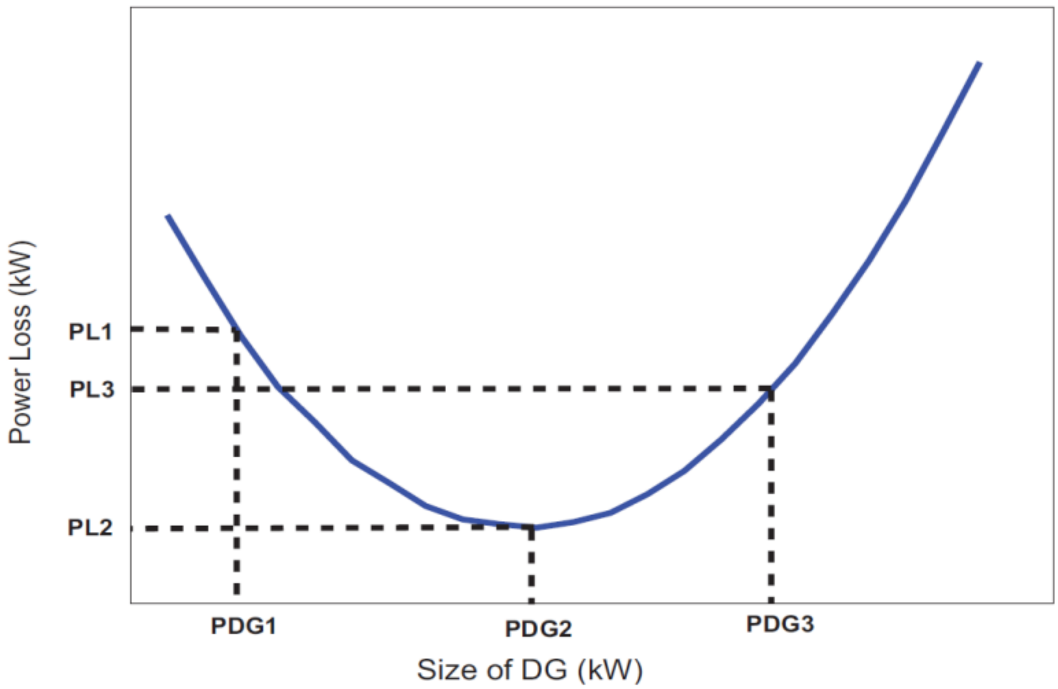

Figure 3-2 Power losses with changing the size of DG

The normal operation of the power electric network is the delivering power from the main substation to the load where the size of the conductors used affects the total loss [73]. The desirable placement of DG is near the highest load across the network or nears to the most loss at certain bus in the system of distribution to decrease the total power flow loss. But in the case of oversize (more than the optimum size), the excessive power from the DG will flow towards the transmission area (inverse the normal operation) which leads to more loss in the system network.

Frequency stability, angular stability, and voltage stability are considered in the power system. Voltage stability was a major focus of DG research in recent times to assure a dependable electrical system operation [74]. Voltage stability is the capacity of the system to keep the same voltage at all of its buses if there is a change in voltage magnitude following a disturbance, such as a modification in the way the system is operating or an increase in load demand [75]. This change in voltage may cause voltage collapse which means the system cannot control the voltage after this point [76]. Nonetheless, the distribution system is very susceptible to the phenomena of voltage collapse when the change happened on the demand side or insufficient reactive power supply. The solution to this problem is the integration of Distributed Generation (DG) with the power grid, which can improve the voltage profile. However, the effectiveness of this solution depends on the capacity of the DG, its location in the grid, and the technology utilized.

In general, the distribution system functions as power consumption and delivery as a passive network. Actually, in the transmission line, the ratio R/X is very low. But in the cable of the DN, the resistance is high, which leads to a voltage loss along the distribution line from the source to the center of the load. To make it easier to explain the effect of the voltage drops, a simple equivalent scheme of per-phase is presented in Figure 3.2. The pre-phase circuit diagram contains voltage source VS, and the load voltage L, both of them connected via conductors. These conductors have resistance R and reactance X. The voltage drop in this circuit is represented as in (3.7).

$$\Delta V = Vs - VL = (R + jX)I \sim Re(ZI) \tag{3.7}$$

'I' donated as the current flow across the circuit from the source to the load, and Z is the impedance of the conductor.

Reducing energy loss in the power system network highly depends on the DG capacity and location.

3.2.1. Allocation of Candidate bus with Loss reduction sensitivity method for DG placement

The research proposed in [77]. Introduced the loss reduction sensitivity factor method, which identifies candidate system buses that are appropriate for DG placement to achieve minimum loss. The (LRSF) resulting from DG injection at a given bus i, which is expressed as in eq 3.8

$$\mathrm{LRSF_i} = \frac{\Delta \mathrm{P_{Loss}}}{\Delta \mathrm{P_i}} = \frac{\mathrm{P^i_{Loss}} - \mathrm{P^b_{Loss}}}{\mathrm{P^{inj}_{DG,i}}} \quad (3.8)$$

Where P^{i}_{Loss} is the system loss with DG at bus i^{th}, P^{b}_{Loss} is the system loss without DG and $P^{inj}_{DG,i}$ is the power injected to the grid by the DG. In this study a DG unit with $1\ MW$ has been applied in each bus then the loss after adding this DG was obtained using the power flow analyses. The ranking of the buss Voltage magnitude is listed in appendix C. In this study, from 32 buses one bus from the ranking list are selected to be the place of the DG which have a minimum value of $LRSF$, the LRSF method is illustrated in figure 3-3 .

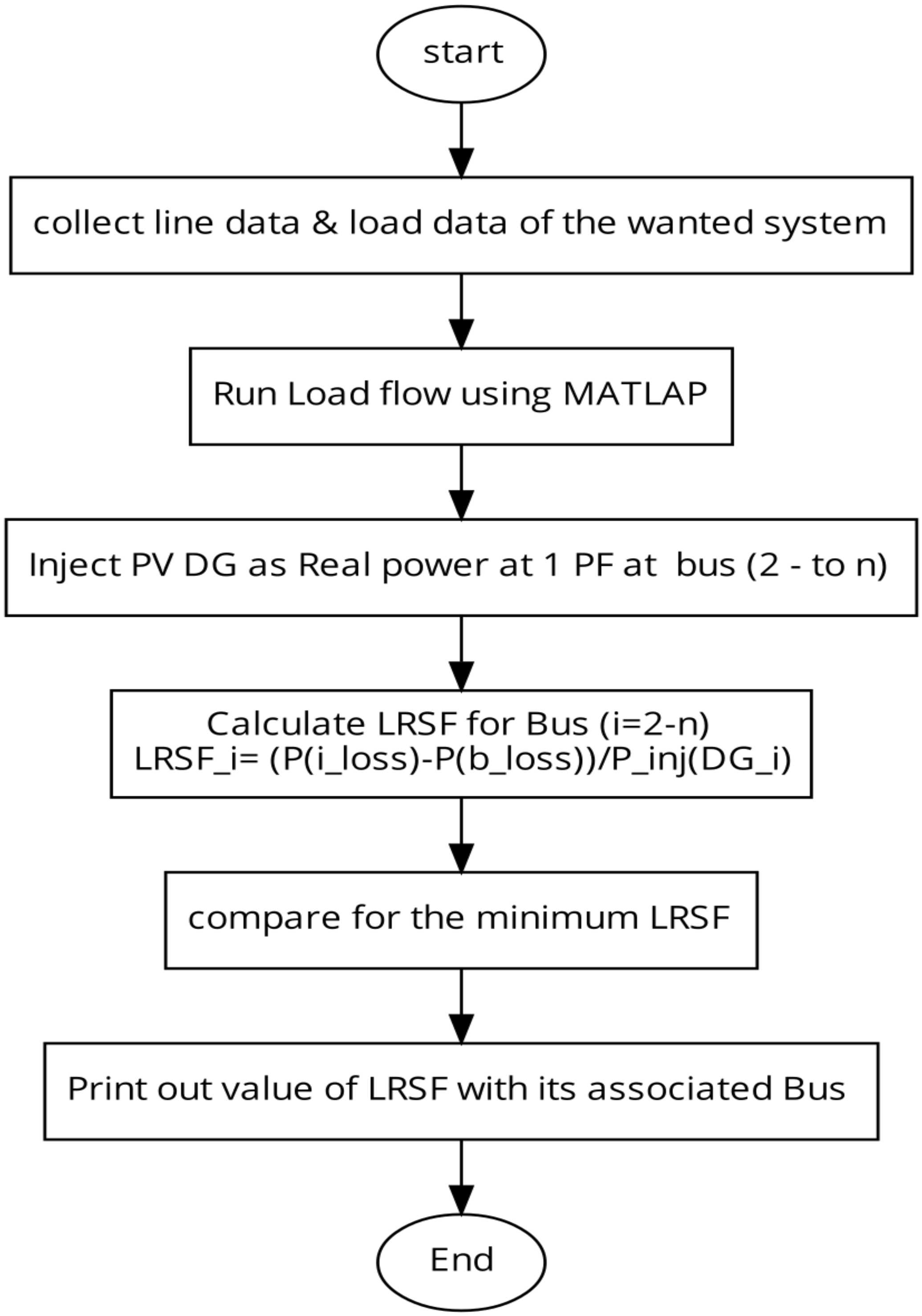

Figure 3-3 Flow chart of the Loss reduction method.

3.3. Utilization FA in Optimum sizing of DG unit

The process of selecting the best option from a group of accessible options that satisfies specific requirements or objectives is known as the optimization method. An optimization problem may be either linear, nonlinear, or a combination of both, and it can be either constrained or unconstrained. In this chapter, the optimization objective function is to minimize power loss of the system while maintain the network voltage profile within acceptable values. The optimization problem with nonlinear constraints is prepared using both equality and inequality constraints. Due to the existence of many types of variables and constraints, the complicated nature of functions, and the variety of the permitted search space, these optimization problems with restrictions are invariably challenging.

Determining the ideal zone for DG penetration and its size is crucial for the grid in power systems. A sub-zone of power transmission or distribution to the end user is indicated by each load bus in the power system. Throughout this research, a sensitivity factor depending on loss reduction was used to choose the load buses on which to install the DG. FA optimization technique is used to determine the optimum capacity of DG.

3.3.1. The Firefly Algorithm

The most charismatic of all insects, fireflies have inspired poets and scientists with their spectacular courtship displays. Fireflies are known for their flashes, which are produced through a biochemical process called bioluminescence. This behavior can be used as the primary indication for courting and mating with other insects. In addition, to attract the mating pairs, flashing lights can be used as a warning to potential predators. According to the flashing behavior of the fireflies, the Firefly Algorithm (FA) is a new meta-heuristic approach for optimization, the objective function needs to be optimized that can be assigned to the firefly behavior. The following idealization guidelines are suggested to make the firefly algorithm's description simpler [66]:

1. Fireflies chemically are attracted to each other since they are unisex.

2. The brightness and attraction are variable among the fireflies and each one is attracted to another according to this variable, when two fireflies blinks, the darkest insect will attract the brightest one. Brightness is proportional to attraction and affected reversely by the distance where it is located. Each firefly will move randomly if there is no brighter among both.

3. By the landscape of the objective function of this algorithm is determined and influenced by the brightness of the fireflies. The implementation of the FA is depicted in figure 3-4, as presented in [66].

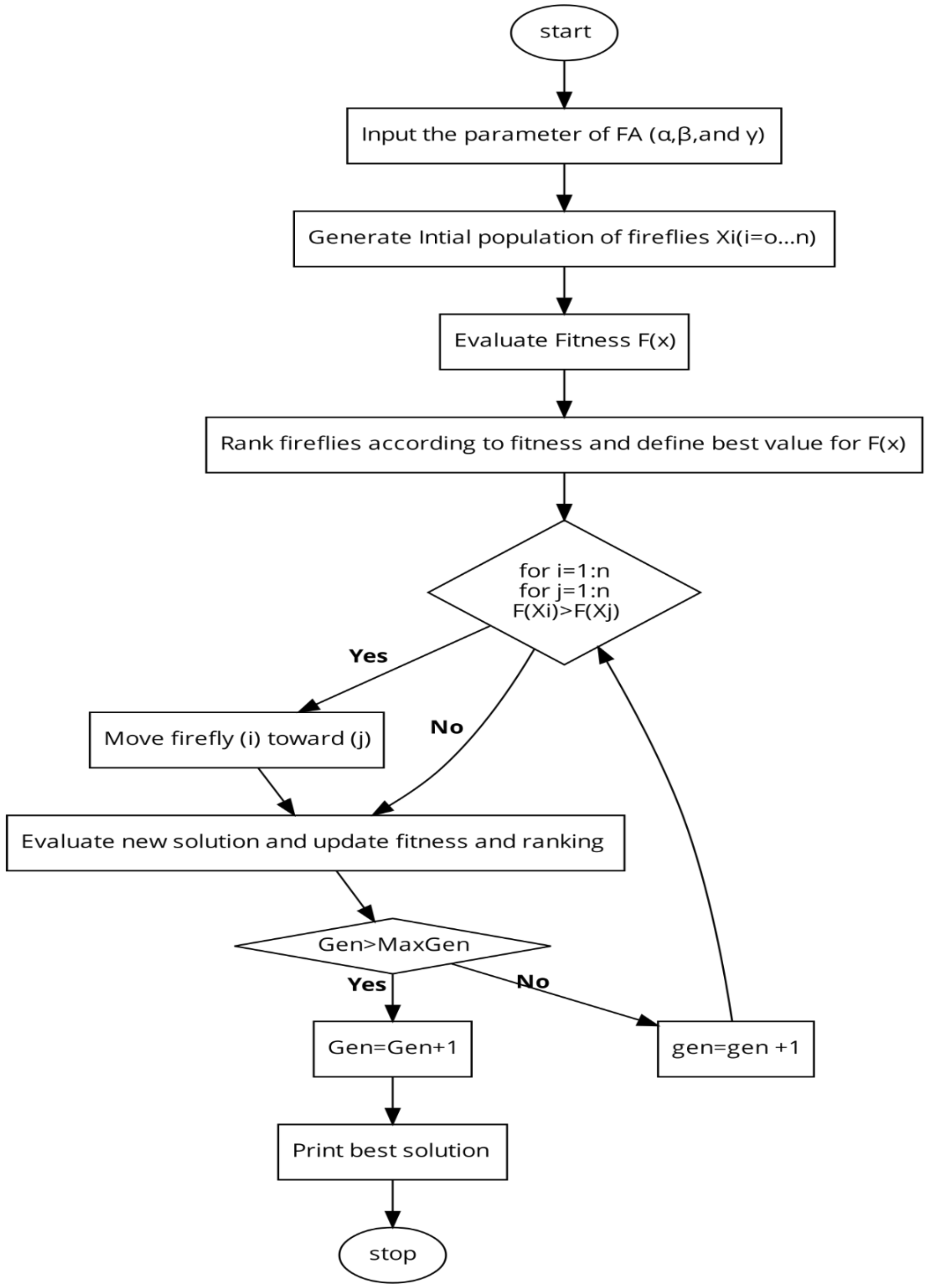

Figure 3-4 General flow chart of Firefly Algorithm

For a maximization function, the brightness variable is proportional to the objective function's solution. It is also hypothesized that the encoded objective function is related to the brightness variable to determine its attraction. [66].

The brightness variable “I” at position “x” could be selected as $I(x)\alpha F(x)$ in the most straightforward scenario for problems involving maximum optimization (x). Yet, since attractiveness is a subjective quality, it is measured by other Fireflies or through the subjective perception of the observer. Hence, its attractiveness value vary as the distance r_{ij} increases between i and j fireflies.

As light is affected by the medium specification of the light absorption factor may result in diminishing its intensity with distance from its source, the degree of attraction is permitted to change. The inverse square law in eq (2.10) describes how I fluctuates in its most basic form. [66]:

$$\mathrm{I} = \frac{\mathrm{I_s}}{\mathrm{r}^2} \tag{3.9}$$

Where I_s is the intensity of light at the source firefly and distance between two fireflies denoted r. The symbol γ is defined as fixed light absorption factor off intermediate that light cross, the light intensity I is varied with “r" in eq (3.10):

$$\mathrm{I} = \mathrm{I_0}\mathrm{e}^{-\gamma \mathrm{r}} \tag{3.10}$$

The initial light intensity is denoted by I_0 ,and the attractiveness of the firefly increases in proportion to the amount of light it emits.

$$\beta = \beta_0 \mathrm{e}^{\gamma \mathrm{r}^2} \tag{3.11}$$

The following criteria can now be used to determine a firefly's attractiveness “B” in (3.11)

when $r = 0$,attractiveness is denoted by β0.

The Cartesian distance is the separation between any two fireflies at positions x_i and x_j, respectively (3.12).

$$r_{ij} = \left\|x_i - x_j\right\| = \sqrt{\sum_{k=1}^{d}\left(x_{i,k} - x_{j,k}\right)^2} \tag{3.12}$$

Where, $x\ (i,k)$ denotes the k^{th} element of the i^{th} firefly's spatial coordinate, x_i. We can simplify the equation above to become in the 2-D case.

$$r_{ij} = \sqrt{(x_i - x_k)^2 + \left(y_i - y_j\right)^2} \tag{3.13}$$

The firefly i will move toward firefly j if the firefly j is brighter firefly determined by (3.14)

$$x_i' = x_i + \beta_0 e^{-yrij}\left(x_j - x_i\right) + \alpha\epsilon_i \tag{3.15}$$

Where the first item denotes the previous position, the second denotes attractiveness and the final term denotes the randomization parameter, which takes the value (0.1-0.9).

3.3.2. Problem formulation

One of the purposes of the current study is to minimize the loss of active power in the network. The complex power is donated by S. so, the complex power from node $i\ to\ j\ is\ S_{ij}$ and the complex power from node j to i is S_{ji} are declared in (3.16), (3.17).

$$S_{i_j} = V_i I_{ij}^* \tag{3.16}$$

$$S_{j_i} = V_j I_{ji}^* \tag{3.17}$$

where, V_i and V_j are the voltages at node $\boldsymbol{i}$ and $\boldsymbol{j}$ respectively, where I_{ij} and I_{ij} are the current flow from node $\boldsymbol{i}$ to node $\boldsymbol{j}$ and from node $\boldsymbol{j}$ to node $\boldsymbol{i}$ respectively. Therefore, writing the loss in any branch between any two nodes is the algebraic sum of the power flows. To assume branch (A) joins the two nodes $\boldsymbol{i}$ and $\boldsymbol{j}$, then the loss between those two nodes can be calculated as:

$$S_L(A) = S_{ij} + S_{ji} \tag{3.18}$$

After the load flow analyses are done and the voltage at each node is known and the current between every two nodes in the system is known, then the total loss in the system can be calculated as follow:

Assuming the system contains n number of branches then the total power losses in the system:

$$S_L(\text{total}) = \sum_{k=1}^{n} S_L(n) \tag{3.19}$$

The complex power losses S_L is comprising the active (real) power loss and reactive power loss. To calculate the total real power loss in the system, we can use the following formula:

$$P_L(\text{total}) = \mathbb{R}[L\ (\text{total})] \tag{3.20}$$

WhereP_L is the active power loss, R is a real part of the complex power S_L.

The objective function here is to reduce the actual energy loss of the system network for efficiency enhancement. The objective function can be written as in (3.21):

$$\text{Objective Function} = \min\ [P_L(\text{total})] \tag{3.21}$$

The Main objective function to ensure the stability of the voltage over the network is by sizing of DG.

In the present study, voltage stability is considered as a limitation ensuring stable system operation.

If we assume V_{min} and V_{max} are the maximum and minimum and voltage limits respectively and is the total number of nodes, then the constraint can be expressed as follows:

$$V_{max} > V_i > V_{min}\ ,\ \ i\ \forall\ N \tag{3.22}$$

The capacity of the cables and other equipment in the DN to the current through it is called the “ampacity” which means the limit of the maximum current that can through the conductor within permissible temperature [78]. If the current flow through the conductors is higher than its capacity that may lead to heating of the conductor, increasing the likelihood of damage to the conductor and thus could compromise public safety. In this case, the load should be shad or isolated from the network to manage the stability of the system.

Therefore, we should consider the limit of ampacity, in the current study the maximum limit of current for n number of branches is considered as a constraint that can be written as follows:

$$I_i < I_{rat,i} \quad , \quad i \, \forall n \qquad (3.23)$$

Since I_i is the current flow through I the conductor, I_{rat} ,i the current rate of the I^{th} conductor.

3.3.3. DG sizing based on firefly algorithm

Since the LRSF detected the Candidate Bus with minimum LRSF without predicting the optimum size of the DG as it may result with increasing loss if it exceeds certain amount of power injected at the candidate bus. However, the main objective of FA is to reduce loss at the optimum capacity of the DG. Utilizing the general formula of the FA in DG sizing must be preceded with resulting data from LRSF technique and setting all the necessary parameters and formula for the FA to model the algorithm for the system DG sizing, the following parameters were selected based on previous research of FA in DG sizing for minimization loss as in [66] and as applied by [79] to achieve a fast and robust result.

1-Number of fireflies = Maximum iteration

2- Scaling parameter $(\alpha) = 0.25$

3- Attractiveness value $(\beta o) = 0.2$

4- Absorption coefficient $(\gamma) = 1$

However. To ensure the operation for the FA in DG planning for the electrical DN there are limitation and constraints for the FA that are identified as follow:

I. Load demand balance: which means the total power generated from the grid and the combination of DG must equal the load demand, mathematically can be represented as follow:

$$\mathrm{P_{grid,t}} + \mathrm{P_{PV,t}} = \mathrm{P_{Load}} \tag{3.24}$$

II. Power generation: which means the generating power from each DG unit has minimum and maximum values this power should not exceed this limit. Mathematically can be represented as following inequality :

$$0 \leq \mathrm{P_{PV}} \leq \mathrm{P_{PV,max}} \tag{3.25}$$

III. The regulation constraint (the penetration level of DG): in this case study the regulation from the government about the integrated DG with grid cannot contribute more than 40% of the full load. Mathematically can be as the following inequality:

$$\mathrm{P_{PV,t}} \leq 40\% * \mathrm{P_{D,max}} \tag{3.26}$$

IV. Formulation of power flow restriction. In addition, the optimal solution should satisfy the limits of the voltage limits of the node, where V_{imin} and V_{imax} are the lower and upper limits of the voltage value on the bus, respectively.

A procedure for implementing the firefly algorithm to analysis distribution network in order to find the optimal sizing of distributed generation in the system are summarized in figure 3-5.

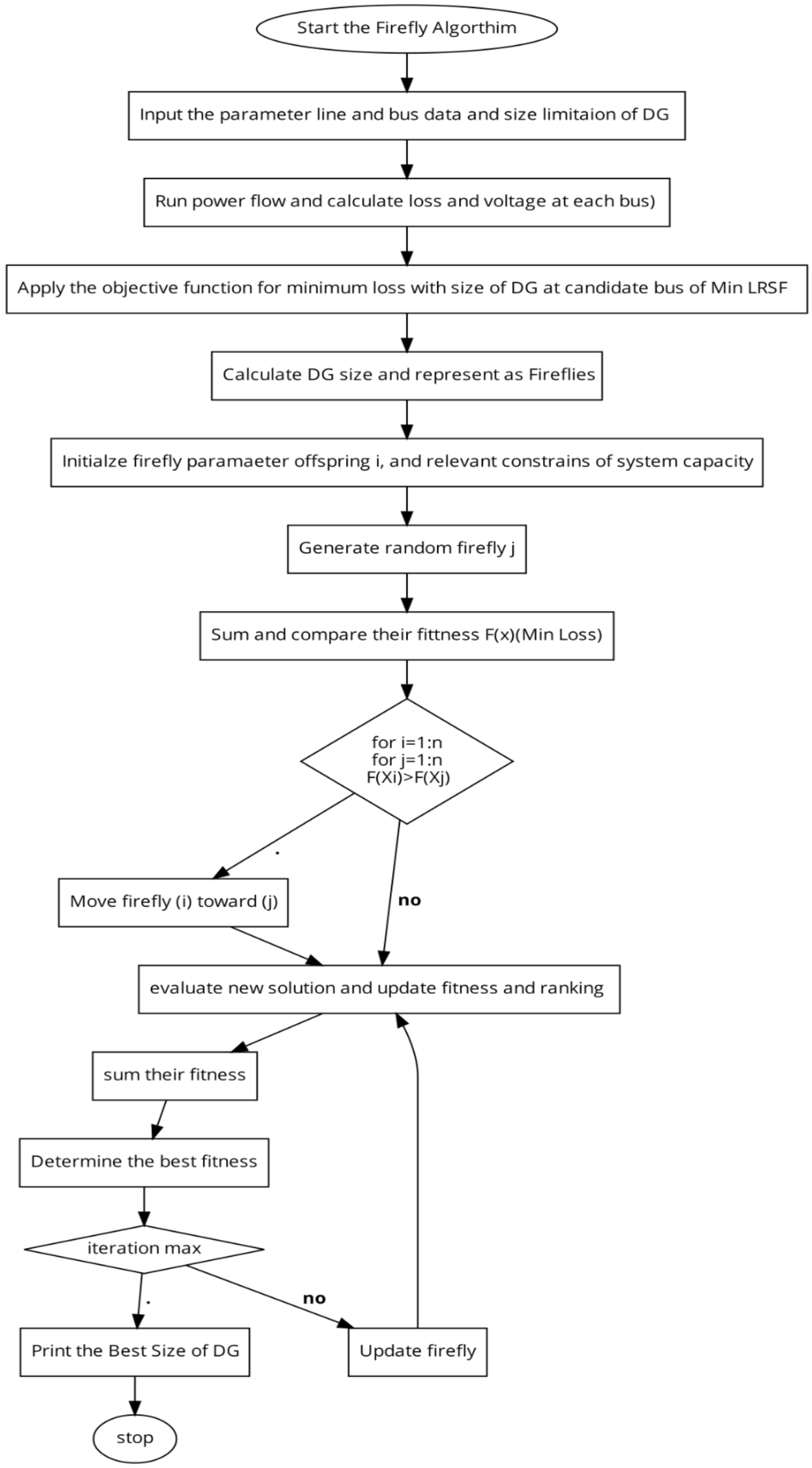

Figure 3-5 FA Flowchart (finding the of optimum size of DG)

In this research the types of DG were considered to be integrated with the grid-based in a suitable location described as a DG supplies and delivers real power only with power factor$(PF) = 1$, which means this kind of DG does not generate or consume reactive power. A Photovoltaic DG (PV plant) will suit the regulatory and technical issue, with its potential is considered for this study in Palestine.

3.4. Several cases of Load profiles and PV generation in the case study

The significant rise in the generation capacity of DG unit connected to grid has resulted in a necessity to optimize their generation to overcome loss related to oversize of DG. In order to meet the load demand while also minimizing the power losses, considering various limitations. As mentioned previously in this study a PV DG size is determined for average hourly load during day in a year.

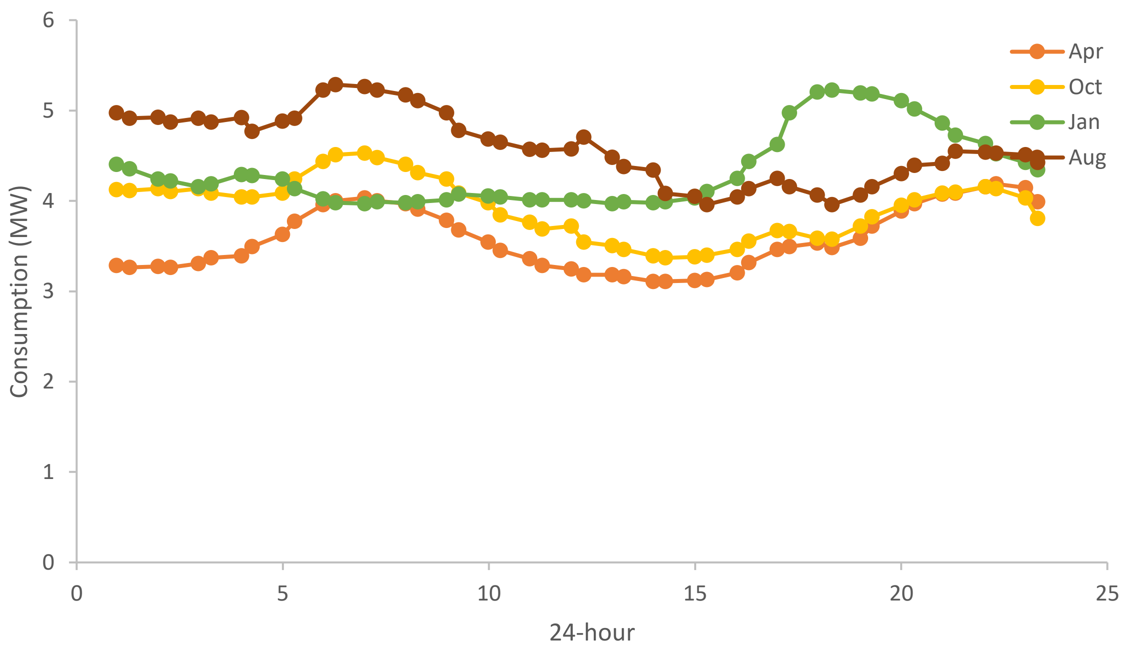

Figure 3-6 Hourly load demand for a day in different seasons

The operation for this combination of generation during 24 hours in different 4 seasons is proposed in this section.

In Figure 3.7, it is noted that the maximum load happens during January and August months as presented in appendix (D) that shows the maximum load in the DN. Since these months are the coldest and the hottest in the year, respectively. Load reach its average maximum hourly consumption in January as a form of heater devices, and in August as a form of cooling device. However, during April and October, the minimum average hourly load consumption is decreased due to less using of the heater units and HVAC units as presented in appendix (E). A summary of total load of these months is observed in table (3-1).

Table 3-1 summary of total load of (January, April, August, October)

	A day January	A day April	A day August	A day October
Average hourly daily load (MWh)	4.336008	3.577728773	4.5983	3.923527
Minimum hourly daily load (MWh)	3.970159	3.110056005	3.959797	3.369123
Maximum hourly daily load (MWh)	5.224046	4.187776094	5.286222	4.529745

The climate in the West Bank (Palestinian Territories) is influential regarding electric demand. This region is a Mediterranean climate zone with hot and dry summers and cool and rainy winters. These conditions are largely determined by altitude and latitude, and by its location between the subtropical aridity of Egypt and the subtropical humidity of the eastern Mediterranean. So, when looking for PV plant generation, it is important to study solar radiation and temperature condition of the location since it alternate the generation capacity of the optimum size of PV DG that resulted from the FA. The global irradiation map of Palestine is shown in figure 3-7.

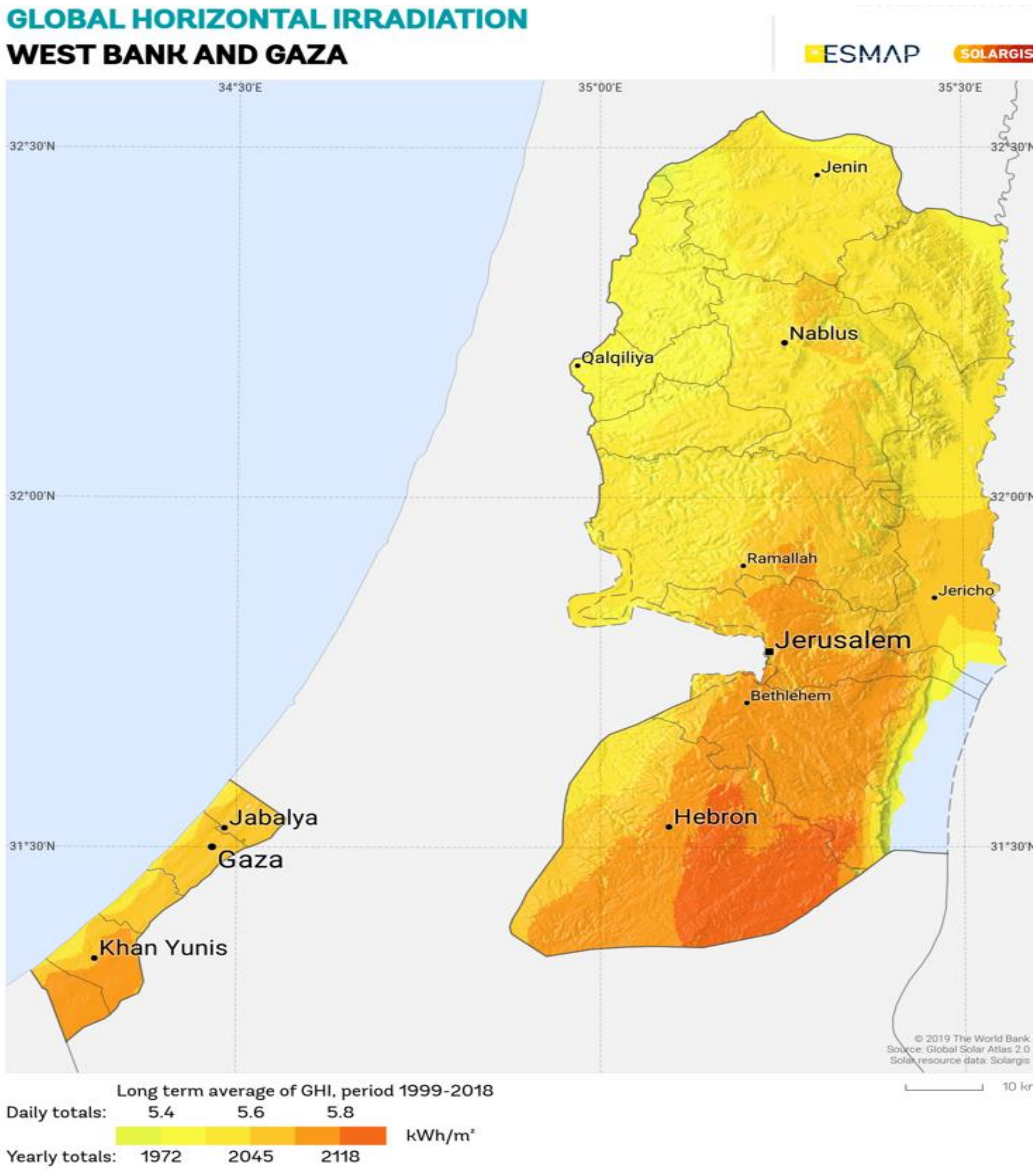

Figure 3-7 Global Irradiation map of Palestine [].

The average daily solar radiation on horizontal surfaces is 5.67 kWh/m^2. While each country in Palestine has its own solar irradiance potential dependently which provide clear perception of Palestine countries that in summer months (Jun-Sep) has its maximum average monthly radiation 9.9 kWh/m^2. Nevertheless, in winter months (Dec-Feb) has a minimum radiation of 5.3 kWh/m^2 as in figure 3-8.

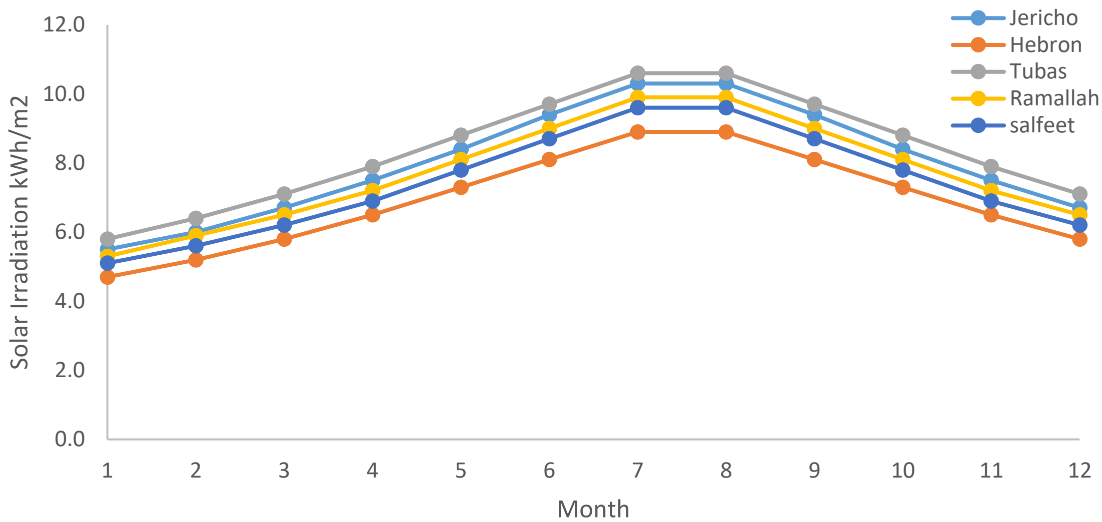

Figure 3-8 Monthly averages of solar radiation in different cities in the West-Bank

However, the average monthly solar radiation in Hebron 6.9 kWh/m^2 are quite high. This can be utilized as good solar energy generation in the city to rely on when planning for PV DG. The maximum average solar radiation is in August, with 8.9 kWh/m^2. Whereas the minimum average solar radiation in January, with 4.7 kWh/m^2. The overall monthly solar radiation is given In table (3-2). The actual amount of solar radiation that is available in Hebron can vary depending on the day, the time of day, and the weather conditions. However, the monthly averages give a good indication of the potential for solar energy generation in the studied location.

Table 3-2 Monthly averages solar radiation in Hebron West-Bank.

Month	Global Horizontal Irradiation (GHI)
January	4.7 kWh/m2
February	5.2 kWh/m2
March	5.8 kWh/m2
April	6.5 kWh/m2
May	7.3 kWh/m2
June	8.1 kWh/m2
July	8.9 kWh/m2
August	8.9 kWh/m2
September	8.1 kWh/m2
October	7.3 kWh/m2
November	6.5 kWh/m2
December	5.8 kWh/m2

The hourly solar radiation in Hebron varies significantly depending on the season. In the summer, the solar radiation is much higher than in the winter. This is because the days are longer and the sun is higher in the sky in the summer with the maximum daily hours of sunlight of around 18 hours daily in august with high solar radiation of 8.9 kWh/m^2 with respect to winter season, the minimum daily number of hours of sunlight in January is 6 hours per day at solar radiation of 4.7 kWh/m^2.The hourly solar radiation also varies depending on the time of day. The solar radiation is highest at noon with solar radiation reach its max in August at 950 W/m^2 and the lowest solar radiation is at lowest during

January 560 w/m^2 due to cloudy weather as in figure 3-9. It is lowest in the morning and evening, when the sun is lower in the sky and 0 w/m^2 at night or in the dark.

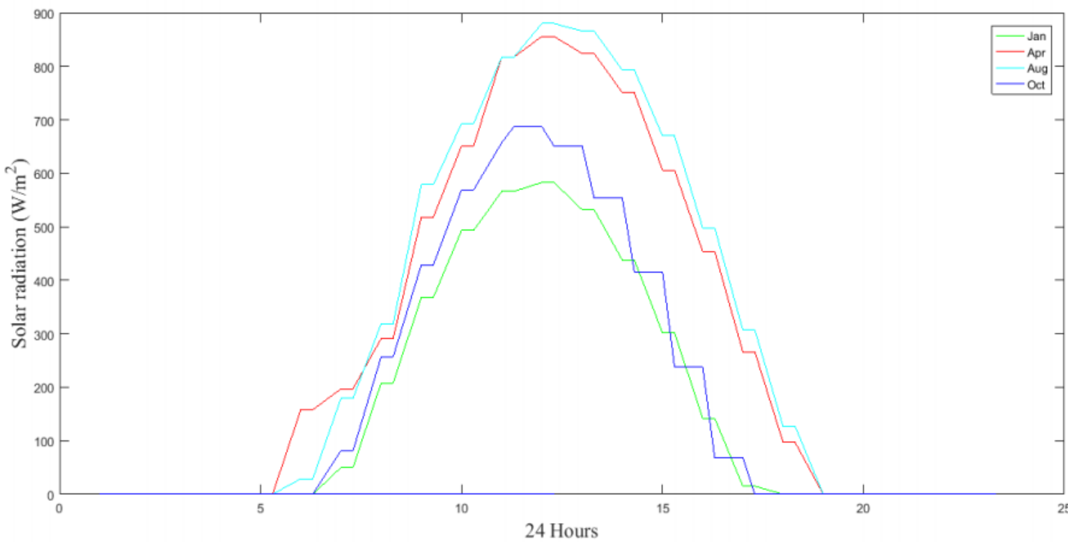

Figure 3-9 Solar radiation in different seasons for 24-Hours

Upon climate variance and load condition through the 4 seasons in the year the following scenarios will be applied:

A. The effect of the optimal DG generation during the cases of average daily load.
B. The effect of DG during the cases of maximum average daily load with respect to minimum, and maximum DG generation.
C. The effect of DG during the cases of minimum average daily load with respect to minimum, and maximum DG generation.

3.5. Renewable Energy Sources

DG units based on renewable energy have two forms these forms are dispatchable and non-dispatchable generation patterns, while the dispatchable renewable DG as a biomass generator can meet the increasing load demand (which means its controllable generator can turn on or off, and control the output power). In non-dispatchable renewable DG like photovoltaic systems and wind turbines, the output power cannot guarantee fixed value because of uncertainties in power availability [80].

Some advantages of photovoltaic systems based on power generation.

- Photovoltaic energy-based generation is very stable.
- The absence of greenhouse gas emissions implies that it has no adverse impact on the environment.
- Compared to traditional generators, it requires less maintenance.
- There are no running fuel costs.

However, it also has some disadvantages:

- The manufacturing of PV systems is expensive.
- The output power generated by the PV system is heavily influenced by its energy source and other factors, such as the geographic location and solar radiation.
- The reliability of the system is not always ensured, so another source as a backup should be included like a battery or fuel generator, which increases the cost.

Therefore, the biggest challenge in planning and operating such a system is its intermittent nature.

3.5.1. Photovoltaic system

A wide variety of different photovoltaic installations are currently available on the market, including network and autonomous systems with or without batteries as storage; hybrid systems, which are a combination of a photovoltaic system and another energy source (such as wind and hydroelectric power), are increasingly attracting attention. Figure 3-10 shows the types of Solar Photovoltaic Systems (SPV) configurations:

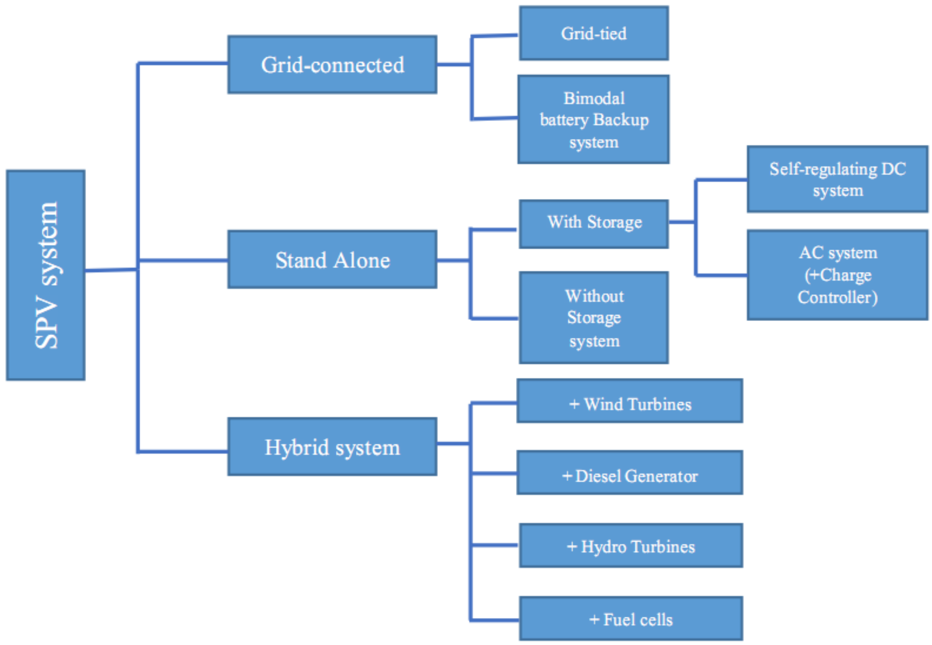

Figure 3-10 PV system configurations

For a photovoltaic system the instantaneous output power generated by a PV system is obtained by solar radiation (G_{til}), PV surface (APV), converter efficiency (η_{con}) and PV efficiency (η_{PV}) from it can calculate by the following eq. [81].

$$P_{PV}(t) = \eta_{PV} * A_{PV} * G_{til}(t) * \eta_{conv} \quad (3.17)$$

Regardless of configuration and power, the operation of any photovoltaic installation requires key components such as photovoltaic solar modules, transformers, utility meters, inverters, mounting systems, and performance control systems. Figure 3-11 depicts a simplified circuit diagram of a photovoltaic system that is linked to a network.

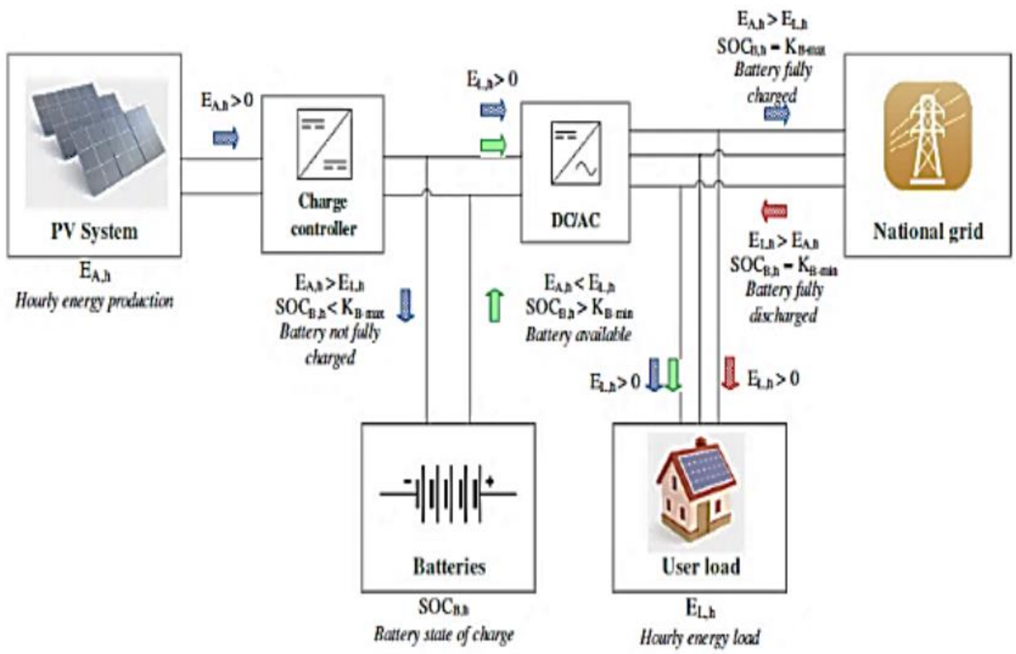

Figure 3-11 Simple diagram of grid-connected PV system

3.5.2. Solar photovoltaic modules

Solar photovoltaic modules, as an essential of any SPV system, produce electrical energy from incident radiation based on the photovoltaic effect. Table 3-3 shows the different photovoltaic technologies and some comparisons between them. Table 3-3 shows photovoltaic technologies.

Table 3-3 solar Photovoltaic technologies features

PV Technology	Specification
1. Monocrystalline silicon (mono-si)	1. Efficiency $15-20\ \%$ 2. Durability up to 25 years 3. The highest price 4. Sensitive to ambient temperature and shading issues.
2. Polycrystalline silicon (P-si or m-si)	1. Efficiency $13-16\%$ 2. Cost efficient 3. Insignificant intolerance to high ambient temperature.
3. Thin-film (TFSC) a) Amorphous silicon b) Cadmium telluride (Cd. Te) c) Copper indiumgallium selenide (CIS/CIGS)	1. Efficiency $9-12\%$ 2. Cost efficient 3. Flexible configuration (applicable to different Installation 4. Sensitive to shading issues

Palestine receives an average of seven hours of sunlight daily during the winter and thirteen hours during the summer, for a total of around 3000 hours of sunlight annually. Temperatures range from 5 to 10 ° C in the coldest month of January, and 18 to 38 ° C in the hottest month of August as shown in figure 3-12. The Mediterranean Sea helps to cool the area during the summer months and in April, May, and mid-June. In figure,

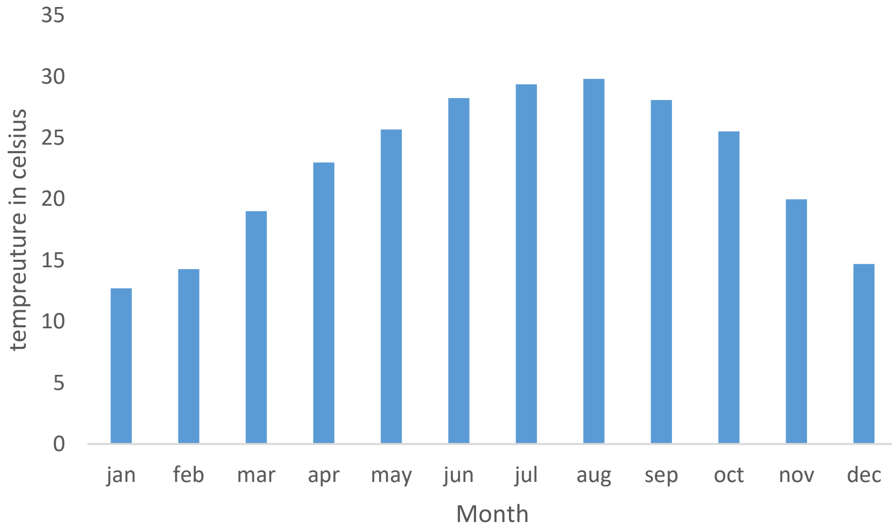

Figure 3-12 The average monthly peak daytime temperatures

temperature of the case study location has an average annually temperature 22.5 C, which correspond to the STC standards of the PV cell temperate operations limits.

The performance of a PV cell is affected by Irradiation and solar cell temperature. Since the cell convert irradiance of sunlight to electricity its temperature is increases and the cell generates heat which affect the efficiency of the PV cell. the relationship between irradiation and cell temperature is not linear as the cell reach its maximum operating temperature the cell no longer absorb the sun light, which result in huge decrease of its efficiency and the amount of generated power from the cell and the PV panel overall, the I-V curve of a general PV cell under variation of cell temperature and irradiation versus outputs power figure 3-12, and figure 3-13 [82].

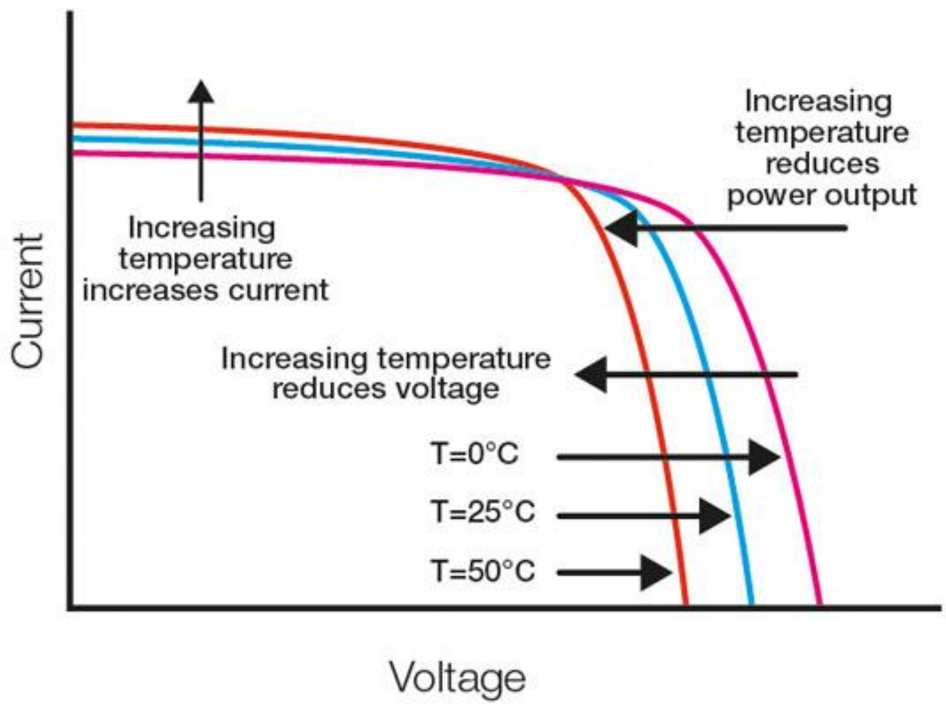

Figure 3-13 I-V curve of temperature on PV cell generated power

The figure 3-12 shows that the solar cell temperature increases linearly with irradiation up to a point, and then the rate of increase decreases. The point where the rate of increase decreases is called the (saturation point). The saturation point is different for different solar cells. It depends on the efficiency of the solar cell and the ambient temperature.

The effect of irradiation on the solar cell temperature is an important factor to consider when designing and operating solar cells. The solar cell temperature can affect the efficiency of the solar cell and the lifespan of the cell. I-V curve of solar irradiance on PV cell generated power.

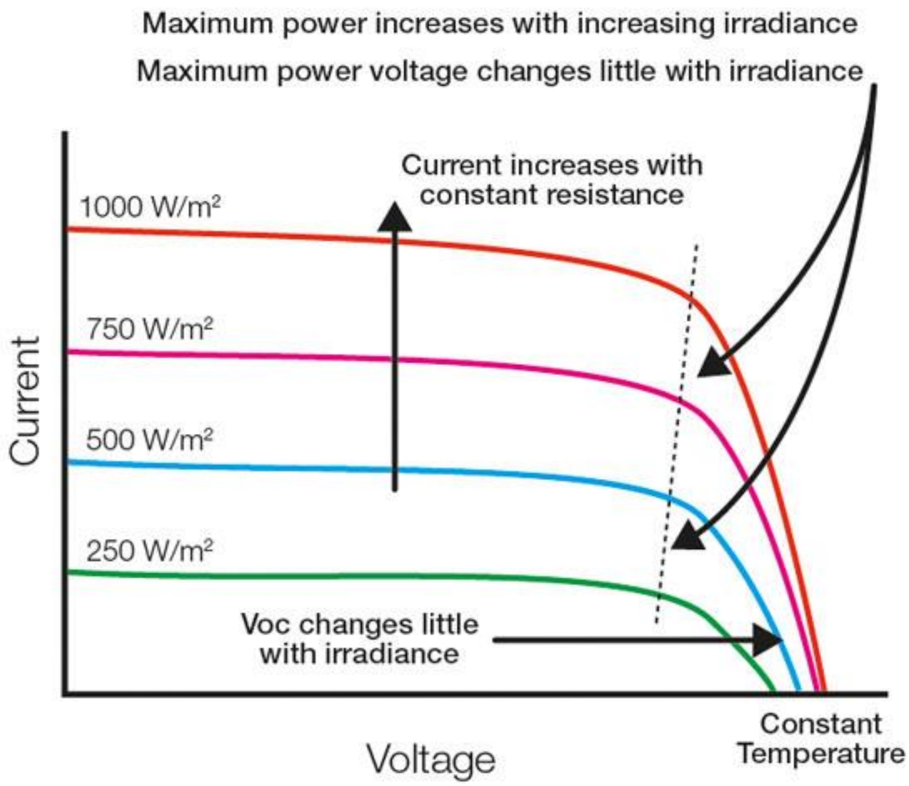

Figure 3-14 I-V curve of solar irradiance on PV cell generated power

The generated power from the PV system for $1000\ m^2$ under STC condition for location in Hebron is shown in figure 3-15.

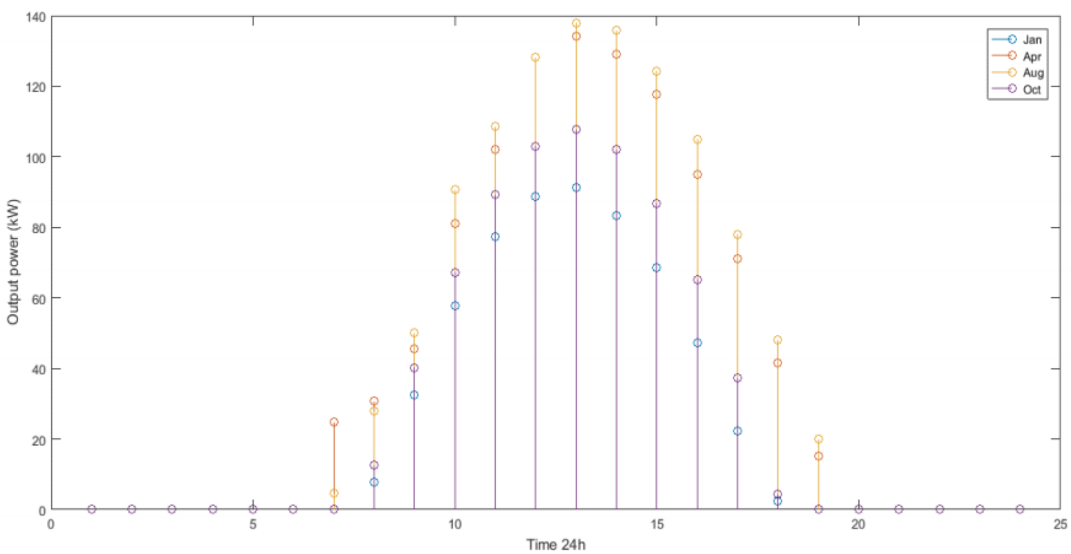

Figure 3-15 the generated power from PV in area 1000m^2

3.5.3. Inverter

The inverter is an important component of the interface that implements the supply function and converts direct current (DC) from the photovoltaic battery to alternating current (AC) so that the output of the system is compatible with the local utility in terms of voltage and frequency values (mainly 50 Hz and 60 Hz in the United States). Table 3-4 shows the different types of inverters most commonly used.

Table 3-4 Inverters type and specifications Feature

Inverter type	Specifications
1. String inverter	a. Numerous strings get linked to one inverter b. Recognized as a very secure inverter c. High sensitivity to shading problems d. Compatible with power optimizer e. Relatively cheap
2. Central inverter	a. Fewer components required b. Can support more module strings c. Suitable for large installations
3. Micro-inverter	a. Inverter connects to each module separately b. If any module gets shaded it does not affect the other module c. More expensive

	d. Suitable for high shading installations
4. Battery –based inverter	a. Bidirectional inverter included a battery charger b. Use for energy management between the array and the grid, while saving batteries charged. c. Monitoring battery charge status.

Transformer

In a system that is connected to the grid, a transformer or substation plays a vital role in power distribution. It adapts the alternating current voltage from the inverter to the grid voltage. Transformers can lower the utility voltage to individual loads or step up for wide-area transmission. The electromagnetic induction-based operating concept of the transformer.

Optimizer

The optimizer is a DC/DC converter connected to each module or built-in by the manufacturer into the module instead of a traditional junction box. By constantly monitoring the maximum power point (MPPT) of each module, they raise the output power of the whole system.

Utility Meter

Utility meters estimate how much energy is used by the system and how much is supplied to the grid. As such, when the demand exceeds the power generation, i.e., at night, the power from the grid is supplied automatically. Otherwise, the utility meter may rotate in the opposite direction to sell excess power to the grid.

Mounting System

The location and installation space determine the type of PV mount system. Different mounting system configurations, such as ground mounting, post mounting, and roof mounting with and without roof passage, can be placed to make the most of the project space depending on the site conditions.

Chapter 4. Result and Discussion

In this section, the result of the calculation process is presented and discussed. A Loss Reduction Sensitivity Factor (LRSF) is used to select the best location of DG in the system buses to minimize the loss. DG units are used in this study which is the PV DG system. To find the optimum size of DG a firefly algorithm has been used to minimize loss and improve the voltage profile taking into consideration the regulation from the government of the allowed injected power to the grid. Finally, an electrical design of PV plant is presented.

4.1. Electrical Grid of the case study (Located in Hebron DN)

The data of the system included the load of the buses and the cables data listed in tables of appendix A and B were used to model the DN and analyse the voltage of each bus. Power flow analyses have been done to know the status of the system before and after adding the DG unit in terms of loss and voltage profile. The loss Reduction Sensitivity Factor (LRSF) has been used to select the optimum location and the firefly algorithm is used to find the optimum size of DG.

4.1.1. Base case total system loss and voltage profile.

Initially, a load flow analysis of bus system determines the voltage at each bus, and calculates the real power loss in the system. The base case voltage is 11 KV and the power loss of the system before integrating the DG units with the grid was found to be

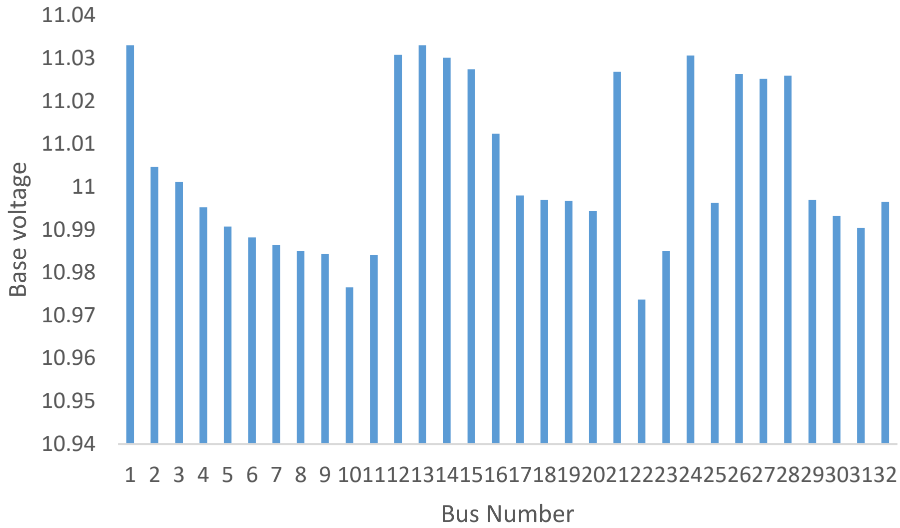

Figure 4-1 Voltage Profile of the base case

7.536KW, with a average total load demand of 4.12 MW, the voltage profile of the base case is drawn in figure 4-1, and shows an fluctuation of voltage around 0.54%.

4.1.2. Loss reduction sensitivity factor

Using equation 3.16. Mentioned in the previous chapter the buses of the system are arranged based on the minimum total loss as in Figure 4.2. This is done by adding mathematically a PVDG unit with 1 MW for each bus in the system and then calculating the LRSF, ignoring bus number 1 as it is the closest bus to the sub-station so, it is not candidate to be an appropriate location. Since the constraints from the occupational government prohibit the injection of no more than 40 % of the total demand of grid demand. Therefore, the maximum capacity of PVDG that could be injected is given:

$$P_{inj}^{pv} = 0.4 * P_{Grid} \tag{4.1}$$

Up to 1.64 MW could be injected as a solution to decrease the total system losses. However, to have the best size for the DG can be found by applying the firefly algorithm which found to be 0.475MW.

The minimum value of LRSF shows the suitable location for DG placement. In table appendix C the LRSF for each bus with ranking for the buses have been shown. From this appendix, it is noted that bus 18 has the minimum value of -0.00383 LRSF with the value of as in figure 4-3. At the optimal size of DG that was found 0.475 MW with a minimum of LRSF -0.0047.

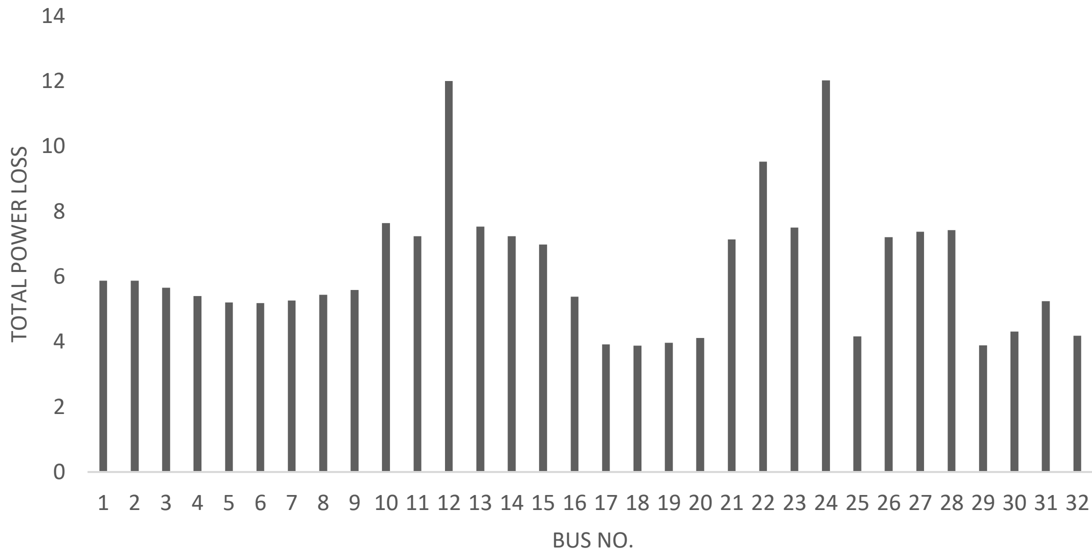

Figure 4-3 Total Power Loss when injecting at each bus

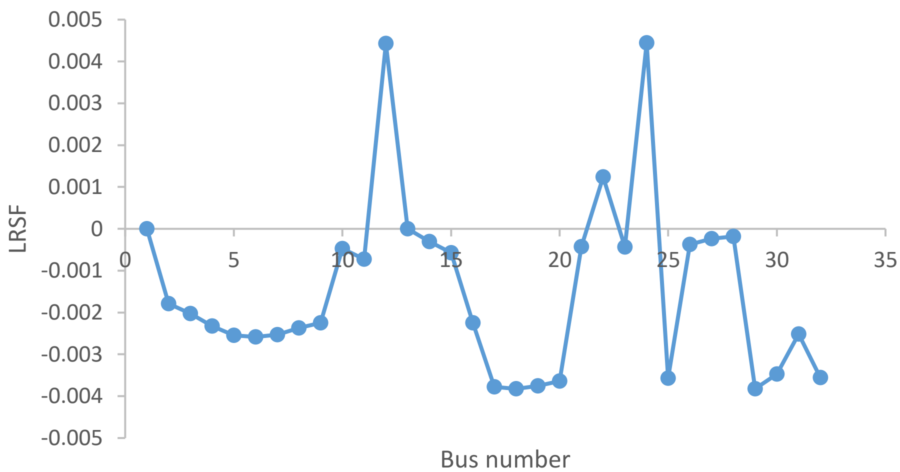

Figure 4-2 LRSF of the system buses

Applying DG randomly to the DN could result in unwanted effect on total power loss of the system as in figure 4-4 as if the PV DG generation exceed 1.64 MW the total loss is start

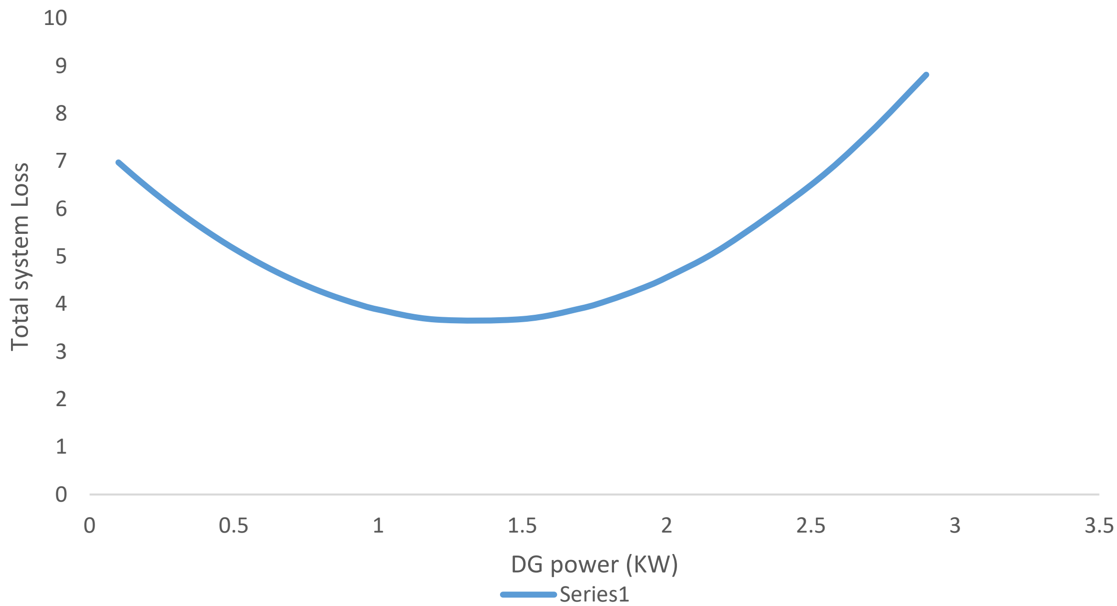

Figure 4-4 Active Power Injection on bus 18

to increase. The optimal size of DG must be considered when implemented on bus 18 with the efficient amount of active power injection of PV DG to be installed.

4.2. DG sizing using firefly

Since the candidate bus had been determined. A firefly algorithm is used to find the optimum size of the DG to minimize the loss. Following the regulation constraints from the government and other technical constraints had been added in the firefly code, which shows the capacity of DG in the candidate bus with bus 18 has the optimal capacity of 0.475 MW.

4.3. The effect of the optimal size of PV DG in system loss and voltage profile

Optimum DG placement and sizing have been already done as mentioned in the previous sub-section. After adding these DG units in their optimum location with the optimum size. It is noted that the amount of the real power loss in the system decreased to 30.66% of the base case loss scenario. With a total system loss of 5.258KW. In addition, the system has a good voltage profile of the system to be within 0.04%.

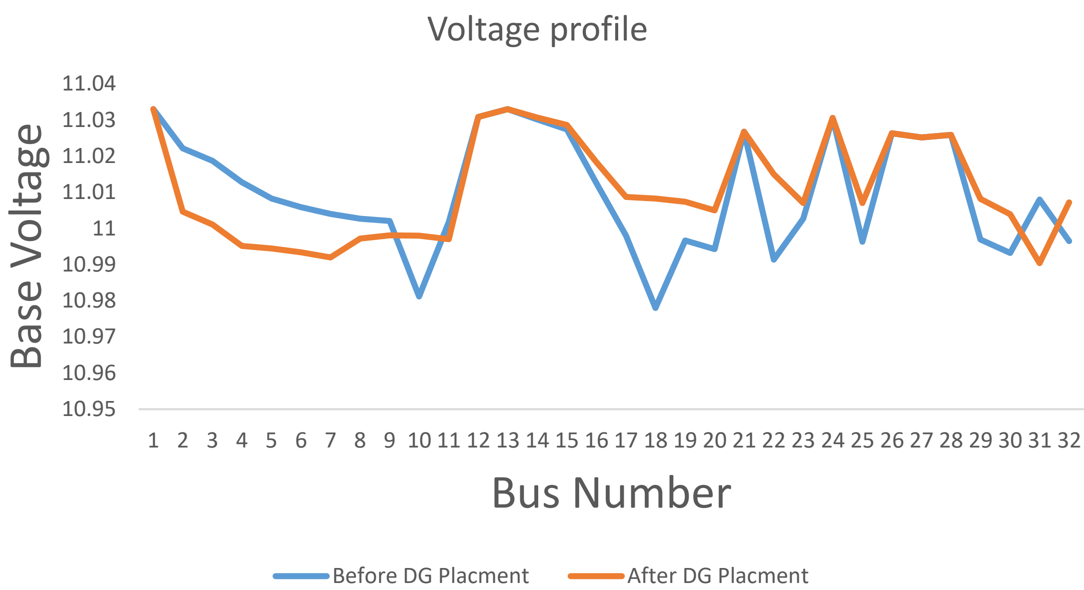

Figure 4-5 Voltage profile improvement-based DG

In terms of voltage profile, a comparison between the base case voltage and the voltage at each bus after adding the DGs. Figure 4-6 shows how the voltage profile improved by adding the DGs into the system. In figure 4.6, it is noted that the voltage drops in the system after adding the DG has an accepted value which is less than 0.07% of the base voltages.

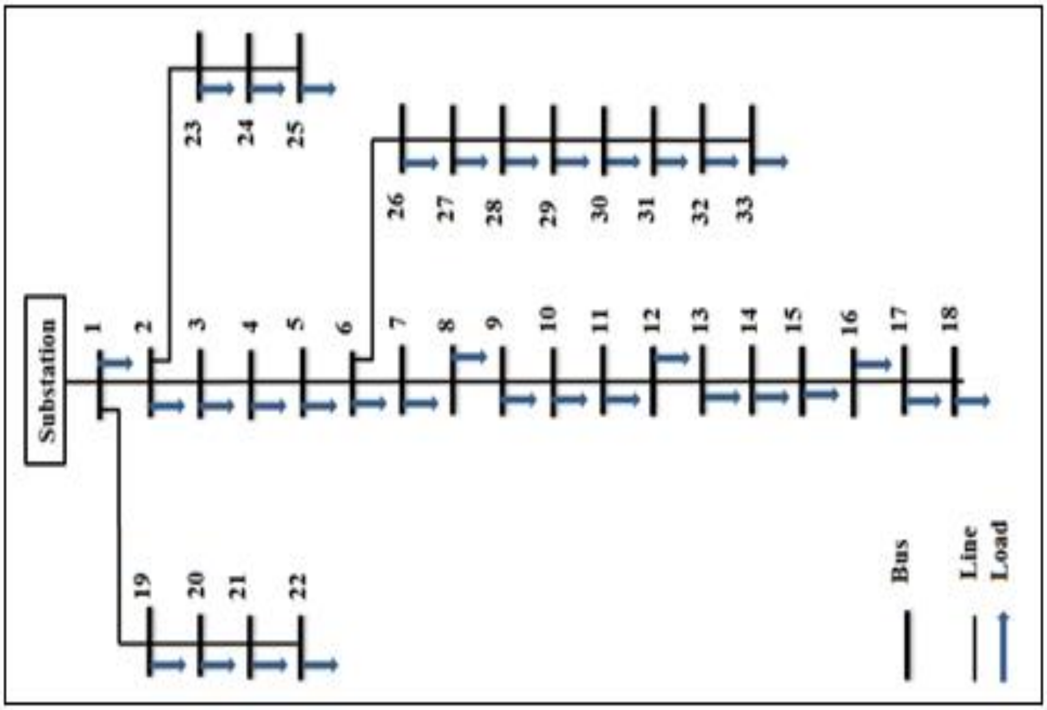

Figure 4-6 IEEE 33 Bus Radial DN

The same methodology has been tested on network of IEEE 33-bus 12.66 KV at 10 MVA of a radial DN will be presented to justify the results of the to study on the voltage drop and total system loss before adding DG and after for the test system shown in figure 4-7.

The system has been implemented for load flow and it is found that total system losses were 202.7 KW, where the profile of the voltage for the system is drawn in figure 4-8.

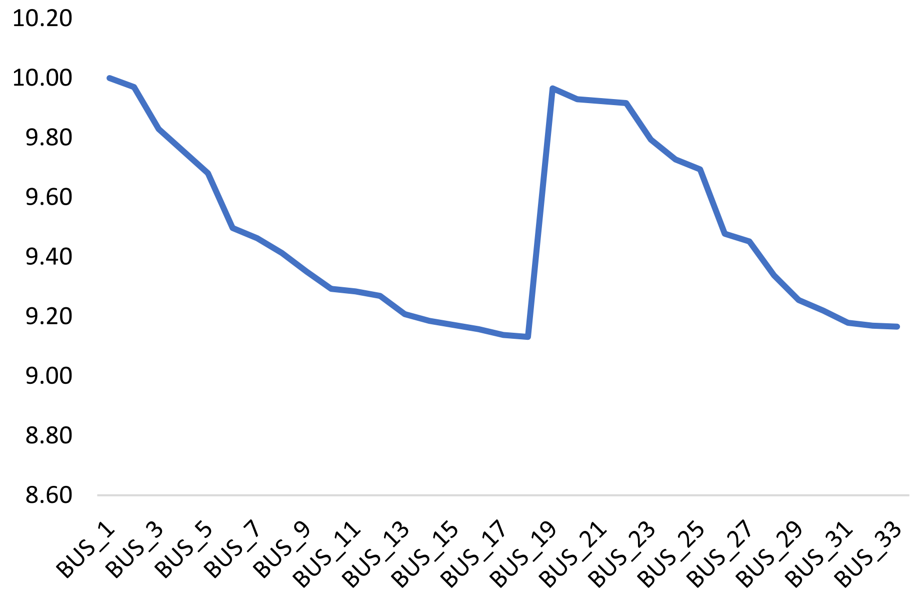

Figure 4-7 Voltage profile of IEEE 33 bus

Interpretation of the result of voltage profile and losses for the load flow. As it is shown that the system undergoes fluctuation of voltage in Pu between values of 0.91 at bus 18 to 1 at upstream and about IEEE standards voltage stability should be no more.105% to

95% in the variance of +/- 5% as the system may inhabitant an outage for loads connected at bus 18 and for load growth planning as well. As planning intends to decrease total real power loss. A PV DG with unity power factor 1 is installed. Figure 4.9 DG capacity

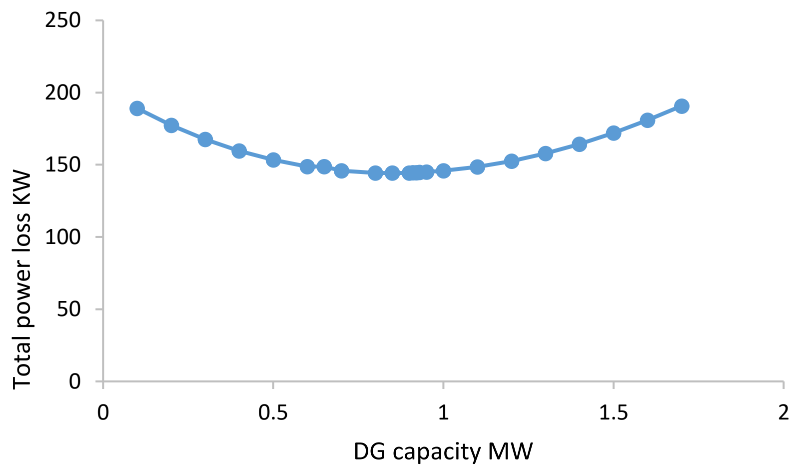

Figure 4-8 DG active power injection at bus 18 of the IEEE 33 bus

impact on Total loss at bus 18. This DG will be integrated on bus 18 as LRSF technique predicted. The minimum LRSF happens at bus 18, so that the candidate bus is bus 18, with a high chance to minimize power loss of the grid.

Different penetration levels PV DG when integration affect the total power loss at bus 18 as in figure 4-10.

applying the FA on the system for the bus 18 results with optimum size at 0.859 MW that gives the minimum loss of 144.235 KW, the injection of this amount of PV DG on the voltage profile has better performance as it enhanced as in figure 4-10.

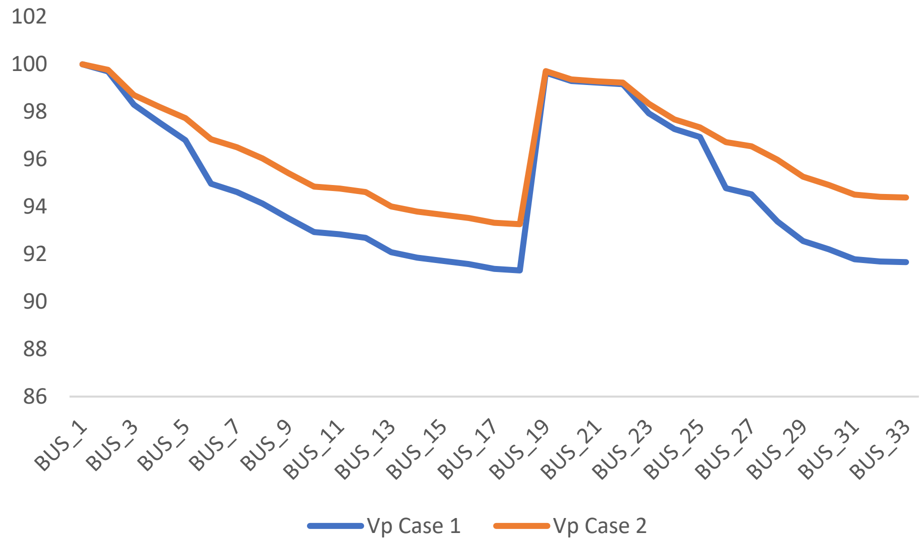

Figure 4-9 Voltage Profile before and after adding DG

4.3.1. Selection of DG type based on the availability of installation for the case study.

In this study, a PV DG has been selected to achieve optimum size and location and also taking into consideration the voltage profile limits and Power loss of the system. As the PV system have the best size and location to achieve the goals of this study, and it is selected as average generation unit of DG capacity. Bus 18 have been selected. During the study of the geographical situation, it is noted that the PV system can be installed in the candidate bus.

Based on the eq. (3.17) [81] of the generated power from the PV system, the area that needed to install the system can be calculated as follow:

1- The average solar radiation is in April and October has the value of 730 w/m2 at a day.

2- The required capacity of the PV DG is 0.475MW

3- The efficiency of the PV system at average is 17% for monocrystalline cell, and the efficiency of the micro inverter is 98%.

4- Applying the equation of PV system generation

$$P_{PV} = \eta_{PV} * A_{PV} * \eta_{inve} * G_{til} \tag{4.2}$$

By substituting the parameters in the equation above we can calculate the needed area which is equal to 3873.8 m².

For better understanding the effect of several cases of load and generation capacity during different seasons the following case scenarios have been tested:

Case 1) the effect of maximum and minimum generation of the PV DG during the maximum load at different buses and at the optimal location.

Case 2) the effect of maximum and minimum generation of the PV DG during the minimum load at different bus and the optimal location.

Case 1) for maximum load profile.

For the case of maximum loads with total load consumption of 4.788 MW the power loss of the system has increased to 9.696 KW this also affect the voltage profile as well. The effect of PV DG with optimal capacity of 0.475 MW are varied during August at maximum solar radiation of 8.9 kWh/m^2, 935 w/m^2, PV cell efficiency 19% inverter efficiency 98% with generation increases to 683 KW and decreases to its minimum generation of 321 KW in January with average daily solar radiation drops to 4.7 kWh/m^2, 583 w/m2, PV cell efficiency 15% inverter efficiency 98% using eq. (4.2). This change of generation is tested for power loss and voltage profile on 3 different location bus 8, bus 18, and bus 29.

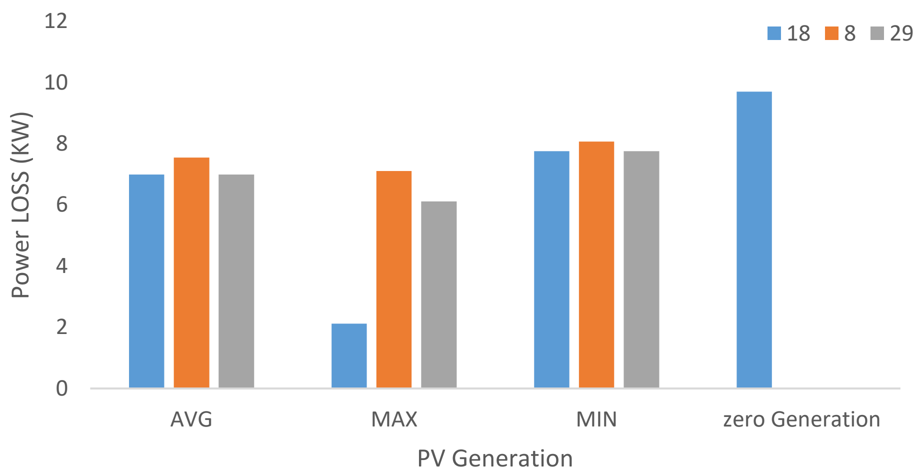

Figure 4-10 Total loss for several generation capacity in different location

From figure 4-11. The total power loss during the minimum generation is above the normal operation of the PV DG when at bus 18, 8 and 29 in compare with the absent of generation. The system loss at the optimal bus 18 is always giving a reduction of its value in each case during the maximum load. Nevertheless, when comparing the generation of PV during maximum generation of 0.683 MW, the total losses are decreased and the best value happens at bus 18 of 2.11 KW with respect to 7.102 KW for bus 8 and 6.119 KW at bus 29. For the minimum generation of 0.321 MW, the total losses are increased to 7.758 KW at bus 18, 8.063 KW at bus 8, 7.7586 KW at bus 29 but still gives a good result for power loss among other locations with the total losses with no generation of 9.696 KW in compare with optimal bus 18.

Also, the performance of the DN voltage profile has been affected by the variation of generation. During the maximum load the voltage profile of the DN under average, minimum, and maximum is changed where its best performance is at the maximum generation of PV at August and summer months. However, when no generation the voltage profile drops to reach to 10.96 KV and when injected at the optimal bus in the maximum generation the voltage profile has its best performance at bus 18 in figure 4-12, although the minimum generation happens but it gives satisfying result with maintaining the voltage profile around 11 KV figure 4-13, figure 4-14.

The best performance of grid for the voltage profile happen when the PV DG is connected at bus 18 in figure 888. With optimum operation when the PV DG at its maximum operation in August at average solar radiation of a day in month at 8.9 kWh/m^2 , whereas it is still within acceptable value and improving voltage profile in January at average solar radiation reach its minimum of the year with average day for a month of 4.7 kWh/m^2.

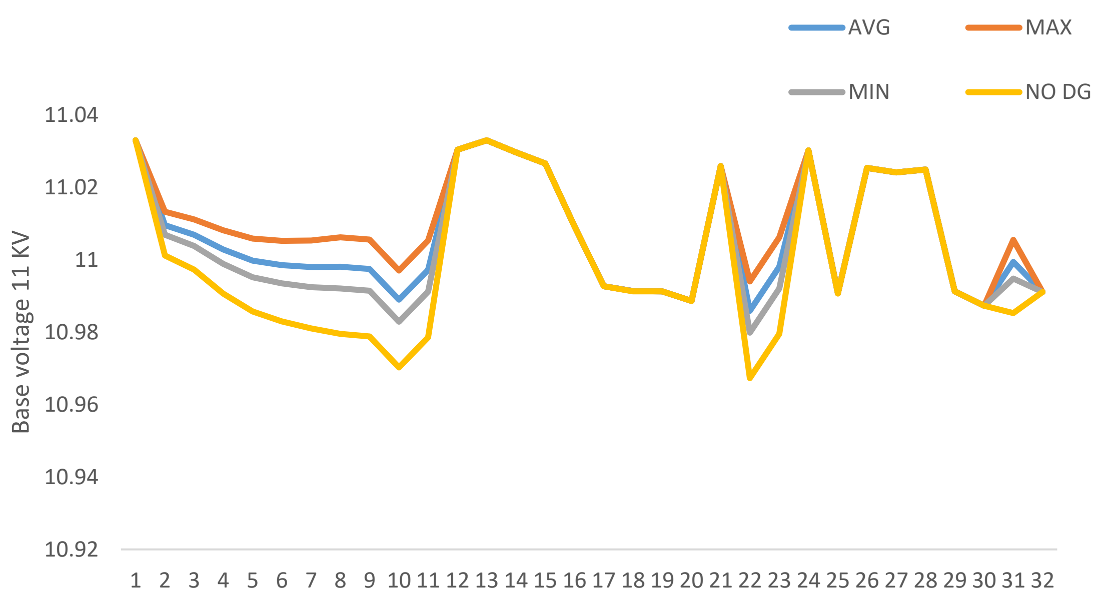

Figure 4-11 Voltage profile at optimum bus with several generation capacity

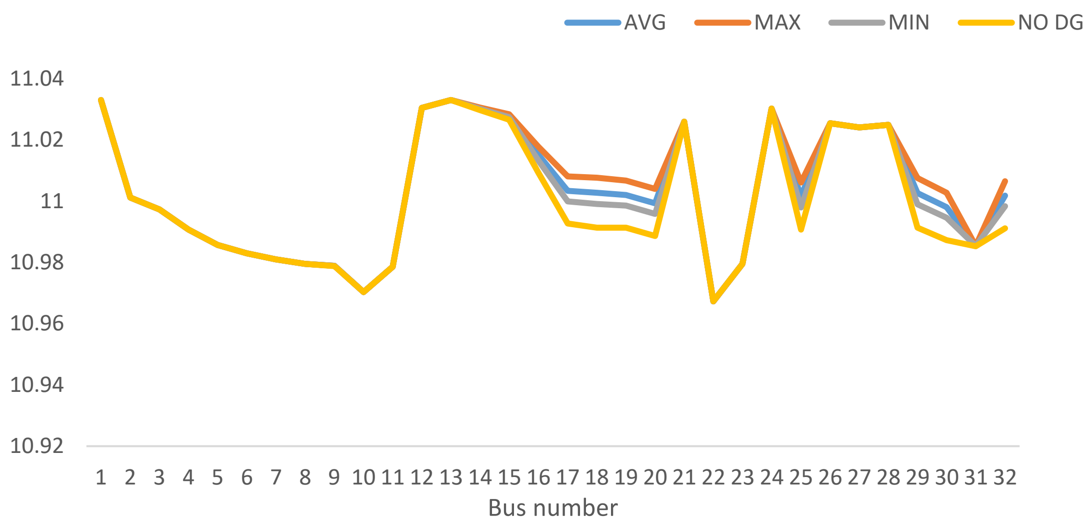

Figure 4-12 Voltage profile at bus 8 with several generation capacity.

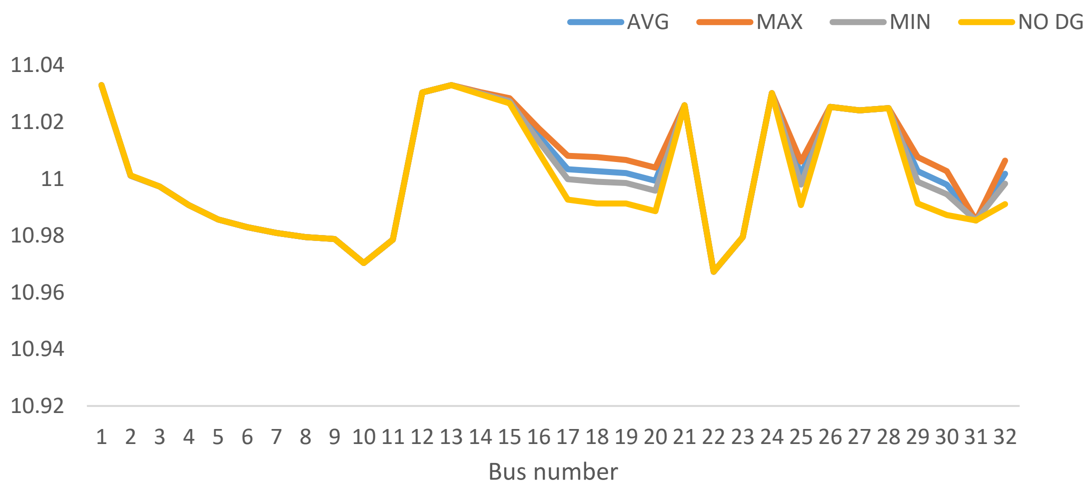

Figure 4-13 Voltage profile at bus 29 with several generation capacity.

Case 2) Minimum load profile.

For the case of minimum loads with total load consumption decreased to 3.3226 MW the power loss of the system has decreased to 4.1879 KW, this also affect the voltage profile as well. The effect of PV DG with optimal capacity of 0.475 MW during August at maximum generation increases to 683 KW and decreases to its minimum generation of 321 KW in January.

The power losses at max, minimum, average and no generation at different location including the optimal bus. Figure 4-15, where the total power losses at optimal bus are slightly decreases to 2.537 KW, for maximum generation, it is 2.119 KW, and at

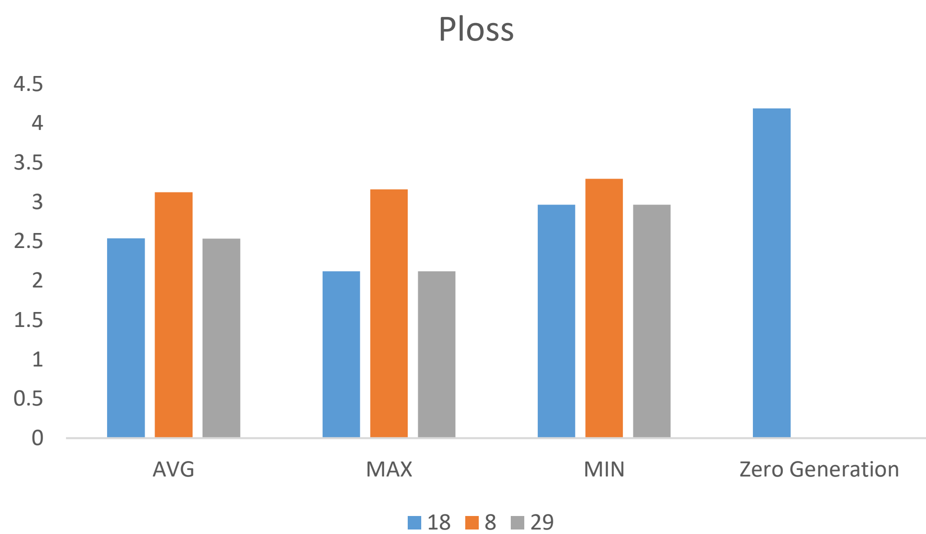

Figure 4-14 Total loss for several generation capacity in different location.

minimum generation raises to 2.964 KW. However, buses 8, 29 are showing good loss reduction but not optimum operation in compare with the case of no generation from PV DG at the state of minimum load in the DN.

Studying the voltage profile during the minimum load the voltage profile of the DN under average, minimum, and maximum is changed where its best performance is at the maximum generation of PV. However, when no generation the voltage profile drops to reach to 10.96 KV and when injected at the optimal bus in the maximum generation the voltage profile has its good performance at bus 18 in figure 4-16, although during minimum generation happens, but it still gives satisfying result with maintaining the voltage profile around 11 KV.

However, The best performance of grid for the voltage profile occurs when the PV DG is connected at bus 8 in figure 4-18. With optimum operation when the PV DG at its maximum operation in August, whereas it is still within acceptable value and improving voltage profile in January at reach its minimum generation in compare with optimal bus 18 and bus 29 in figure 4-17.

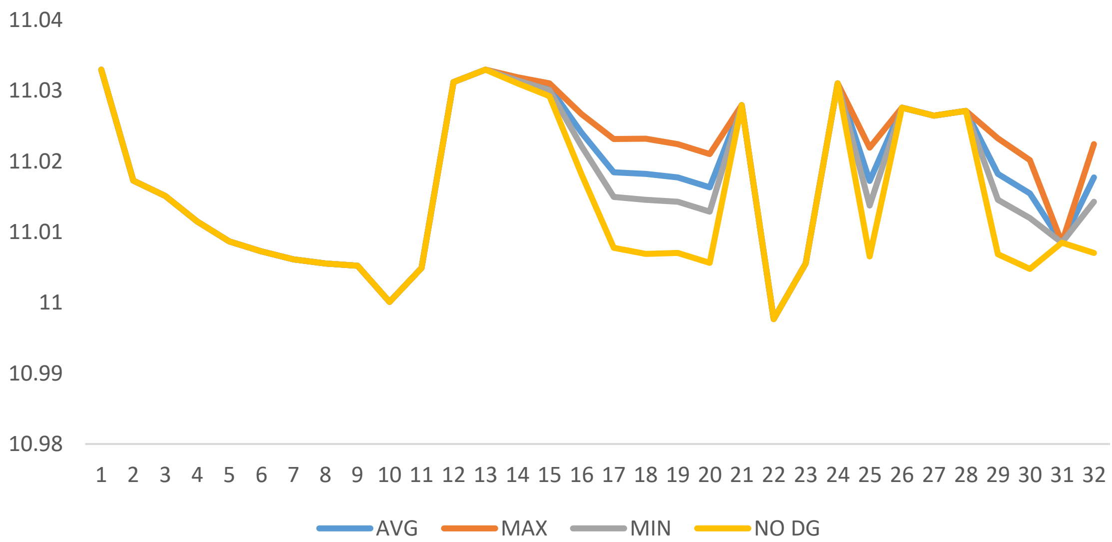

Figure 4-15 Voltage profile at bus 29 location with several generation capacity.

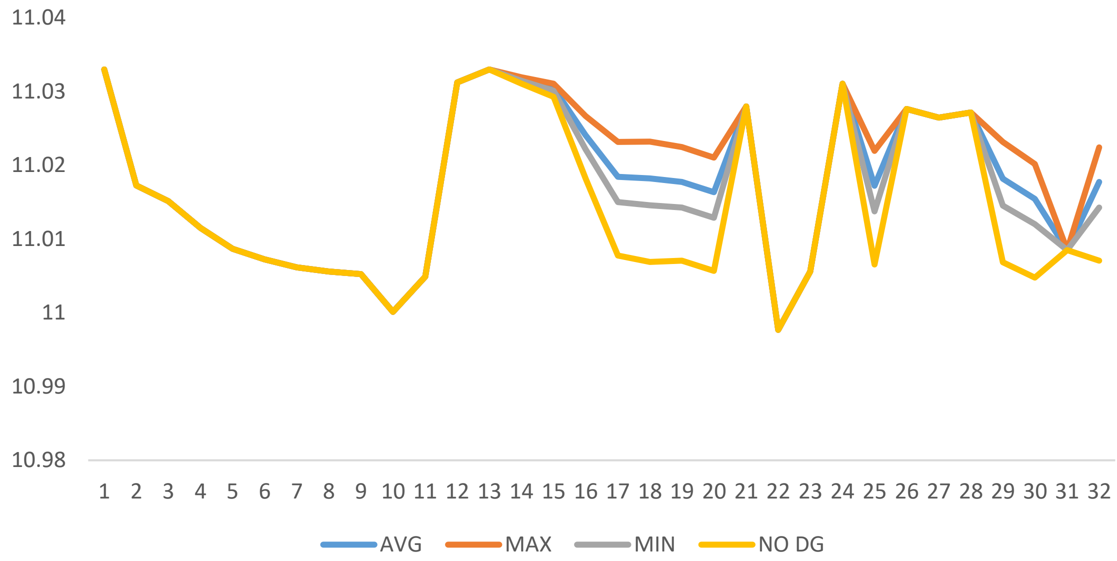

Figure 4-16 Voltage profile at optimal bus location with several generation capacity.

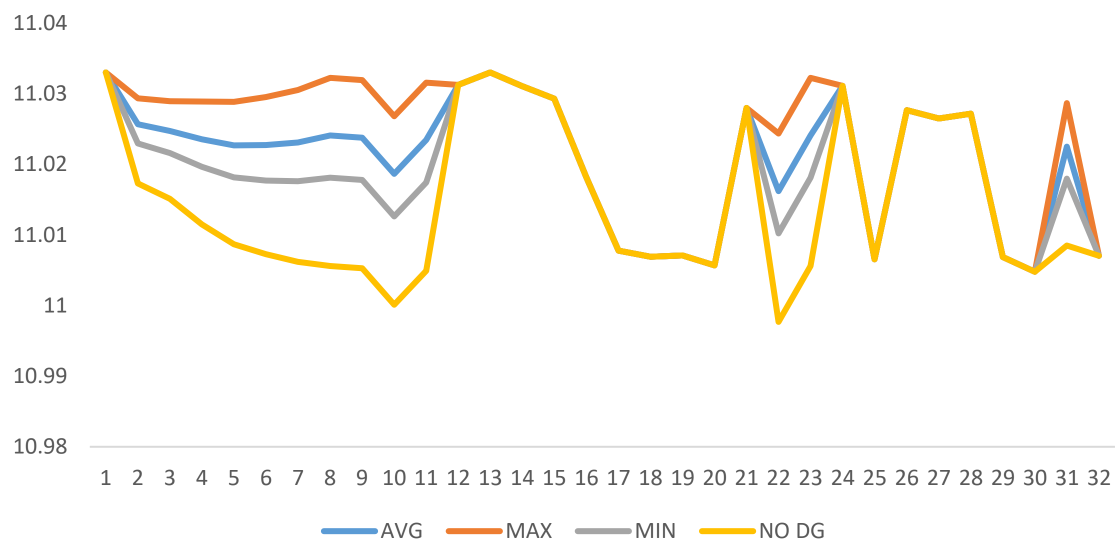

Figure 4-17 Voltage profile at bus 8 location with several generation capacity.

4.4. System design

In order to design PV plant with required component in the mentioned location for the case study with respect to PV DG at 0.475 MW, the peak power is required. A common factor is panel generation factor, which depends on the intensity of radiation, sun hours, and location is used to estimate the number of PV modules for later design of strings and inverters rating of the grid connected PV shown in eq (4.3)[83].

$$Panel\ generation\ factor\ = \frac{solar\ irradiation * sun\ hours}{irradiation} \tag{4.3}$$

$$= \frac{583 * 12}{1000} = 6.996$$

The average daily needed for the PV plant to inject power to grid is approximately 2.28 MWh/day, with approximate PV system loss of 30%. The required energy that cover PV system loss is found in eq. (4.4):

$$E = 1.3 * 2.28 = 2.964 \text{ MWh/day} \tag{4.4}$$

The peak rating power of PV modules to generate is given in eq. (4.5):

$$\text{Peak rating} = \frac{\text{E}}{\text{panel generation factor}} \tag{4.5}$$

$$= \frac{2.964}{6.996} = 0.432 \text{ MW}$$

The total number of PV module required N is from eq. (4.6):

$$N = \text{Total peak}\frac{\text{rating}}{\text{PV module rating}} \quad (4.6)$$

$= \frac{0.432}{320} = 1323.9 = 1350$ Pv panel

Since we have to design the inverters for the grid connected PV on 11 KV at the optimal bus, two types of inverters are used 6 inverters of rating 50 KW with maximum DC voltage 600 V each inverter is connected to PV array containing 5 stings and each string contains 20 PV panel, and 5 inverters of 27 KW rating with maximum DC voltage 400 V power each is connected to PV array of 5 strings each string contain 12 PV panel. Figure (4-19) shows the electrical design of PV Plant of 0.475 MW.

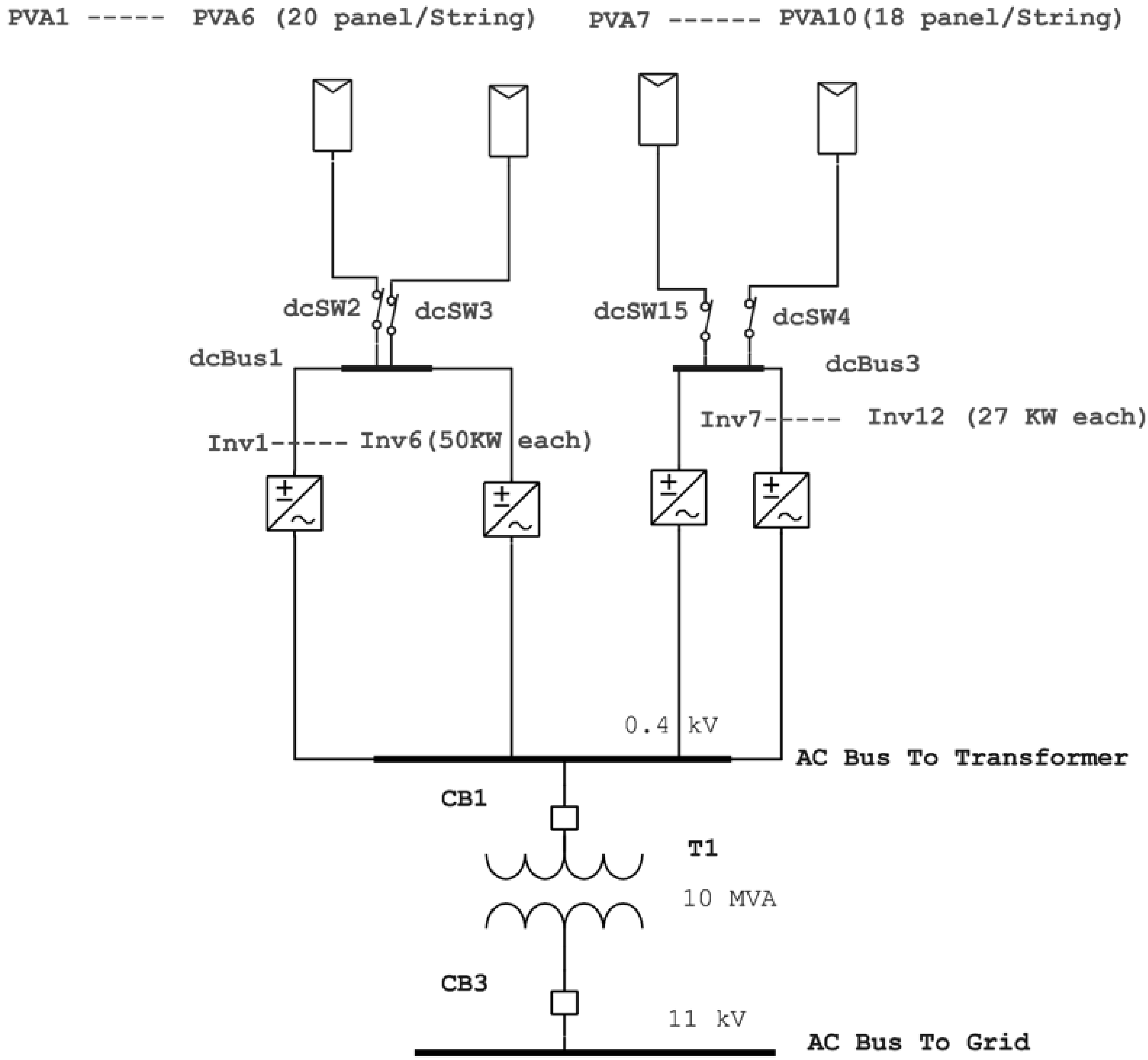

Figure 4-18 electrical design of PV Plant

4.5. Required land and Mounting system of PV

Using google maps (satellite option), a photograph of the location of bus 18 is taken as shown in figure 4-20. While this bus is close to Al-Ahli Hospital, 3873.8 m2 this land can be purchased by Hebron municipality to acquire suitable land to implement PV plant on a ground-mounting racking.

Figure 4-19 Recommended Location of DG in Hebron city.

Chapter 5. CONCLUSIONS AND SUGGESTIONS

This research has proposed a Loss Reduction Technique called (LRSF) to select the optimal bus for DG placement and utilized the Firefly Algorithm to search for the optimal sizing of grid connected photovoltaic system of 0.475 MW in a radial network of 32 buses, in Farsh Al-Hawa, a small town in Hebron-Palestine for tie connection Al-Duhdah. The system performance has been studied under different cases of load (average, maximum, minimum) and tested for several cases of PV generation (at optimal size, maximum generation, minimum generation) for 3 locations (18,8,29) in DN. The result has been compared for power flow loss and voltage profile. A test for the ability of the methodology is applied in this research for IEEE 33 radial bus system for optimal sizing and location of DG in terms of power losses and voltage profile.

The results have shown a good reduction in the power loss, while the loss of the system before adding the DG units was reduced to 30.66% at case study optimal bus with optimal size during average load consumption, and 27.9%, 37.9%, 19.9% at average, maximum and minimum generation respectively, when installing power plant during maximum load for maximum generation in August and minimum generation in January, and tested for other location shows good reduction in power flow loss at bus 8,29, where in case of minimum load the loss reduced at optimal bus 18 39.4%, 49.3% , 29.2% at average, maximum and minimum generation respectively when installing power plant during minimum load for maximum generation in August and minimum generation in January and the average generation of PV assembled in April and October months.

The solar radiation and temperature of different seasons in Hebron has the impact on the operation of the power plant and the study proved overall enhancement on the power flow loss of the system when installing PV grid connected system.

In terms of voltage profile the system has been improved in reference to load under investigated condition with respect to generation capacity. However, the maximum increase of voltage profile is 0.54% at optimal location and improved nearby buses. And the result shows good enhancement of voltage profile on different locations in compare to the state of system when PV plant is off service.

Finally, this research presented a solution for a real case study using loss reduction technique with the use of a metaheuristic firefly algorithm to predict the best sizing of PV plant in one research and proved its capability to reduce total power loss of the case study with improving voltage profile. And predicated the best operation of PV plant at summer months in comparing different months.

5.1. Recommendations

According to the findings of this study, the future works that can be considered as an extension of this research are listed as follow:

a. A Firefly Algorithm is highly dependent on its parameters, so the optimization of these parameters can be done by hybrid the firefly with another optimization algorithm to optimize firefly parameters.
b. For the same case study, it is possible to use other kinds of renewable energy in the system like a wind turbine, and bio-fuel to reduce the absence of PV contribution during the night.
c. This study can be applied overall to the grid with 7 tie connection system for both grid-connected and isolated system (standalone).
d. In future work, FA could suggest the best grid operation strategy with suitable Economic Dispatch from main substations (IEC) and other DGs.

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Appendix A.

---------- Line DATA -------			
branch		branch impedence	
bus to			
bus		r	x
1	2	0.1922	0.301907
2	3	0.02728	0.02354
3	4	0.05766	0.049755
4	5	0.04402	0.037985
5	6	0.03348	0.02889
6	7	0.03348	0.02889
7	8	0.0372	0.0321
8	9	0.02976	0.02568
9	10	0.41622	0.08521
8	11	0.23784	0.008221
23	12	0.056573	0.02115
13	14	0.01364	0.01177
14	15	0.0148	0.01284
15	16	0.10703	0.0321
16	17	0.110088	0.0327
17	18	0.01488	0.01284
17	19	0.03085	0.01114
19	20	0.05952	0.05136
13	21	0.05885	0.050894
10	22	0.29323	0.08527
8	23	0.18585	0.050894
12	24	0.006116	0.001155
21	25	0.0598	0.050825
17	25	0.05952	0.05136
21	26	0.01674	0.014445
21	27	0.05518	0.047615
21	28	0.0496	0.0428
18	29	0.00124	0.00107
20	30	0.047568	0.00856
5	31	0.00992	0.00856
19	32	0.03058	0.01134

Appendix B.

-------Bus DATA--------			
Bus	P(MW)	Q(MVAR)	Type LOAD
1	0	0	0
2	0	0	0
3	0.207	0.068	0
4	0	0	0
5	0	0	0
6	0.158	0.0518	0
7	0.158	0.0518	0
8	0.0978	0.0322	0
9	0	0	0
10	0.0978	0.0322	0
11	0.041	0.001	0
12	0.0627	0.0206	0
13	0	0	0
14	0.248	0.0815	0
15	0.158	0.0518	0
16	0.0978	0.0322	0
17	0	0	0
18	0.248	0.0815	0
19	0	0	0
20	0.0978	0.0322	0
21	0.248	0.0815	0
22	0.103	0.0009	0
23	0	0	0
24	0.315	0.104	0
25	0.248	0.0815	0
26	0.248	0.0815	0
27	0.248	0.0815	0
28	0.158	0.0518	0
29	0.394	0.13	0
30	0.248	0.0815	0
31	0.248	0.0815	0
32	0.0627	0.0206	0

Appendix C.

Bus No.	Volt mag
1	11.033
2	11.0046
3	11.0011
4	10.9952
5	10.9907
6	10.9882
7	10.9864
8	10.985
9	10.9844
10	10.9765
11	10.9841
12	11.0308
13	11.033
14	11.0301
15	11.0274
16	11.0124
17	10.998
18	10.9969
19	10.9967
20	10.9943
21	11.0268
22	10.9737
23	10.985
24	11.0306
25	10.9963
26	11.0263
27	11.0252
28	11.0259
29	10.9969
30	10.9932
31	10.9904
32	10.9965

Appendix D.

-------Bus DATA--------			
Bus	P(MW)	Q(MVAR)	Type LOAD
1	0	0	0
2	0	0	0
3	0.23805	0.0782	0
4	0	0	0
5	0	0	0
6	0.17854	0.058534	0
7	0.1738	0.05698	0
8	0.10758	0.03542	0
9	0	0	0
10	0.10269	0.03381	0
11	0.04305	0.00105	0
12	0.065835	0.02163	0
13	0	0	0
14	0.2976	0.0978	0
15	0.1738	0.05698	0
16	0.10758	0.03542	0
17	0	0	0
18	0.2976	0.0978	0
19	0	0	0
20	0.10269	0.03381	0
21	0.2852	0.093725	0
22	0.1133	0.00099	0
23	0	0	0
24	0.378	0.1248	0
25	0.28024	0.092095	0
26	0.28024	0.092095	0
27	0.2852	0.093725	0
28	0.1738	0.05698	0
29	0.4728	0.156	0
30	0.28024	0.092095	0
31	0.2852	0.093725	0
32	0.065835	0.02163	0

Appendix E.

-------Bus DATA--------			
Bus	P(MW)	Q(MVAR)	Type LOAD
1	0	0	0
2	0	0	0
3	0.157	0.018	0
4	0	0	0
5	0	0	0
6	0.108	0.0018	0
7	0.148	0.0418	0
8	0.0478	-0.0178	0
9	0	0	0
10	0.0478	-0.0178	0
11	0.031	-0.009	0
12	0.0527	0.0106	0
13	0	0	0
14	0.198	0.0315	0
15	0.108	0.0018	0
16	0.0878	0.0222	0
17	0	0	0
18	0.198	0.0315	0
19	0	0	0
20	0.0478	-0.0178	0
21	0.198	0.0315	0
22	0.093	-0.0091	0
23	0	0	0
24	0.265	0.054	0
25	0.198	0.0315	0
26	0.198	0.0315	0
27	0.238	0.0715	0
28	0.148	0.0418	0
29	0.344	0.08	0
30	0.198	0.0315	0
31	0.198	0.0315	0
32	0.0127	-0.0294	0