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"Developing and improving the electrical network in the Bir Al-Ghanam area using renewable energies"

By

Ali Mohamed Salem Rhoma

Supervised by:

Dr. Rajab Al-Arabi Ebseem

202

الشكر والتقدير

الحمد لله رب العالمين والصلاة، والسلام على أشرف الأنبياء والمرسلين، سيدنا محمد وصحبه أجمعين.

وبالتالي: فإنه لا يسعني إلا أن أعبر بخالص شكري وتقديري واحترامي إلى أولئك الأخيار، الذين مدوا لي يد العون، من أساتذة فضلاء، وأصدقاء كرماء، لإنجاز هذا البحث، وفي مقدمتهم، أستاذي الفاضل، الدكتور/ رجب العربي ابسيم لما أسداه لي من نصح وإرشاد وتوجيه.

وأيضاً أتقدم بالشكر والتقدير والاحترام إلى الأخ منسق قسم الهندسة الكهربائية والإلكترونية، الأخ/د. هشام بن عياد، لقبوله حضور هذه المناقشة.

كما أتوجه بالشكر والتقدير إلى أساتذتي أعضاء لجنة المناقشة، لما قدمه من نصح وإرشاد خلال فترة الدراسة، ولما سيبديه من ملاحظات وتوجيهات ترفع من قيمة هذا العمل المتواضع، وأسأل الله أن يجازيهم عني أحسن الجزاء.

كما لا أنسى أن أشكر كل من ساهم وأعان في إعداد هذا البحث، من أصدقاء وزملاء في الدراسة، والشركة العامة للكهرباء، وأسأل الله أن يجازيهم عني أحسن الجزاء.

وأخيراً أتوجه بالشكر والتقدير إلى كل الحضور الكريم، والذين تكبدوا عناء حضور هذه المناقشة، لهم مني جميعاً خالص الشكر والتقدير.

الباحث

Dedication

To my dear father

To my beloved mother

To my dear wife

To my precious brothers and sisters

To my faithful friends

To every one concerned in this side of science

This research is dedicated.

Acknowledgment

First of all I would like to specify to my supervisor Dr. Rajab Al-Arabi Abseem my sincere thanks and gratitude for his intensive supervision, guidance and continuous help during the study and the preparation of this research, great thanks wishing from god to pless him.

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ABSTRACT

This research deals of the 30 kV medium-voltage power grid in Libya necessary to improve its efficiency and ensure its ability to meet growing energy demand driven by population and economic growth. The integration of solar panels into Libya's power grid, particularly in the Bir el-Ghanam region, is crucial to addressing current and future challenges. Currently, this network segment suffers from high energy losses and voltage fluctuations due to the ever-increasing load. To overcome these challenges, a systematic redesign and redevelopment of the existing infrastructure is necessary.

This research should incorporate innovative methods utilizing renewable energy sources, particularly solar power, to minimize environmental impact and improve energy efficiency. Through an innovative approach, the modernized grid will be able to meet global standards and integrate advanced solutions, such as smart grid technologies. This research focuses on the redesign of the 30 kV power grid in the Bir el-Ghanam region using advanced engineering methods and photovoltaic power generation technologies. Analyzing this data, reflecting load growth, using ETAP software modelling techniques will enable us to assess its effectiveness in addressing current issues and forecast future loads over the next decade.

Integrating photovoltaic energy is not just a solution to current efficiency problems, but a strategic step towards a sustainable energy future in Libya.

الملخص

أصبحت دراسة نظام الجهد المتوسط (30 ك ف) الكهربائي بالشبكة الكهربائية الليبية ضروريا لتحسين أداء الشبكة الكهربائية لكي تواكب وتتحمل النمو المستمر للطلب على الطاقة الناتج من النمو السكاني والنمو الاقتصادي في البلاد.

يعتبر دمج الألواح الشمسية في شبكة الكهرباء الليبية، وخاصة لمنطقة بئر الغنم، أمرًا حيويًا لمعالجة التحديات الحالية والمستقبلية وهذا الجزء من الشبكة حاليًا يعاني من ارتفاعًا في فقد الطاقة وتذبذب ملف الجهد بسبب التزايد لمستمر في الاحمال.

للتغلب على هذه التحديات من الضروري إجراء إعادة تخطيط منهجية وإعادة تصميم للبنية التحتية الحالية. يجب أن تتضمن هذه العملية منهجيات مبتكرة تستفيد من تقنيات الطاقة المتجددة، وخاصة الطاقة الشمسية، للتقليل من التأثيرات البيئية وتعزيز كفاءة الطاقة. من خلال اعتماد نهج مبتكر، يمكن للشبكة المحدثة أن تتماشى مع المعايير العالمية وتدمج حلولًا متقدمة مثل تقنيات الشبكات الذكية.

يركز هذا البحث على إعادة تصميم شبكة الكهرباء 30 كيلو فولت في منطقة بئر الغنم، باستخدام منهجيات هندسية متطورة وتقنيات توليد الطاقة الكهروضوئية. سيوفر تحليل هذه البيانات، المتمثلة في نمو الأحمال، باستخدام طرق المحاكاة برمجيات(ETAP) ، رؤى حول فعاليتها في معالجة المشاكل الحالية، مع التنبؤ بأحمال المستقبل على مدى العقد القادم.

Contents

List of Contents

Subject	Page
Dedication	II
Acknowledgment	III
Abstract	IV
List of contents	VI
List of tables	IX
List of figures	X
Chapter One:	
INTRODUCTION	
1.1 INTRODUCTION	2
1.2 Hysterical review	3
1.3Research problem	5
1.4 Research Objectives	6
1.5 Methodology	6
1.6 Research Lay out	7
1.7 Motivation	8
Chapter Two:	
Renewable Energy Benefits and Planning Methodologies Explained	
2.1 Literature review	10
2.2- Distribution system	12
2.2.1 Transmission and distribution system.	14
2.2.2 -Present (T&D) system planning techniques.	16
2.2.3- T&D system planning models.	17
2.2.4- Power system mathematical model	18
2.2.5- Short line mathematical model	18
2.2.6-Power flow and efficiency of short transmission line.	20
2.3 The Benefits of Renewable Energy	21

2.3.1 Environmental Protection	22
2.3.2 Economic Growth	24
2.3.3 Energy Security	27
2.3.4 Health Improvements	29
2.4 Renewable Energy Integration with the Grid	29
2.4.1 Hybrid Systems	30
2.4.2 Grid-Tied Systems	31
2. 4. 3 Energy Storage Systems	31
2. 4. 4 Distributed Generation	32
2.4.5 Microgrids	33
2.4.6 Smart Grids	34

Chapter Three:

Integration of renewable energy into the distribution system and Master Plan

3.1 Introduction	36
3 .2 The Photovoltaic Effect	38
3 .2.1 Key Components of a Photovoltaic Energy System	39
3 .2. 2Types of Photovoltaic Systems	41
3 .2.3 Applications of Photovoltaic Energy Systems	42
3 .2. 4 Advantages of Photovoltaic Energy Systems	43
3 .2 .5. Future Trends in Photovoltaic Energy Systems	43
3.3 PV technologies	44
3.4 The Plan assumptions	47
3.4.1 Methodology and Master plan for PV penetration method.	48

Chapter Four:

Optimization and redesign of the 30 kV Bir Al-Ghanam network and analysis of the results.

4.1 INTRODUCTION	52

4.2 Bir alghanm (30kv) network case study. 53
4.3 Case studies on improving and redesigning the electrical network of Bir Al-Ghanam (30kv) circuit. 55
4.3.1 Current Situation in2024 56
Case i: Considering actual peak loads of 2024. 57
Case ii: Consider the actual maximum loads for the year 2024 after the network improvement. 58
Case iii five years load growth (the year (2029) is considered. 59
Case iv: Consider the actual maximum loads for the year 2029 after the network improvement 61
Case v: Circuit performance after ten years (2034) 62
Case vi: Consider the actual maximum loads for the year 2034 after the network improvement. 64
4.4 Summary of results 66
4.5 Discussion of results 66
4.6 Operations of Solar PV Systems 67
4.7 Designing grid-connected PV system 68
4.8General Cost Estimates (Commercial Solar in 2025) 70

Chapter Five:

Conclusion and future work

5.1 Conclusions 73
5.2 Recommendations for future work 73
5.3References 75

List of Tables

№	Table No.	page
4.1	Load data2034	65
4.2	Data on the photovoltaic panels	66

List of Figures

№	Figure	page
2.1	A (30 kv) sub-transmission network	14
2.2	short line circuit representation	19
2.3	two-port representation of transmission line	19
2.4	victor diagram for different line loads	20
2.5	Renewable energy is a catalyst for economic growth	27
2.6	Integration methods are grid-tie systems	30
2.7	Hybrid systems	31
2.8	Types of Battery	32
2.9	Microgrid system	34
3-1	photovoltaic systems	39
3-2	Types of solar panels	39
3-3	Inverters electrical	40
3-4	Demands for PV power conversion system	41
3-5	Types of solar cell panels	45
3-6	poly silicon solar panel	46
3.7	master plan using PV perforation	48
4-1	the current state of the ring network2024	55
4.2	Current status of the Bir al-Ghanam ring network with problems occurring	57
4.3	showing the network status after optimization for year 2024.	59
4.4	showing the network status before optimization in 2029	60
4.5	showing the network status after optimization in 2029	62
4.6	showing the network status before optimization in 2034	63
4.7	showing the network status after optimization in 2034	64
4.8	Examples of performance monitoring displays (Courtesy of Phoenix Solar)	67

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Electricity has become an indispensable part of modern life, powering homes, industries, and transportation systems. The historical significance of electrical energy can be traced back to the late 19th century when the first electric power plants were established. Thomas Edison and Nikola Tesla were pivotal figures in this revolution, with Edison developing the first practical incandescent light bulb and Tesla promoting alternating current (AC) systems, which allowed electricity to be transmitted over long distances efficiently. This marked the beginning of the widespread adoption of electrical energy, fundamentally transforming society by enabling advancements in technology, communication, and infrastructure.

As the demand for electricity grew, so did the complexity of electrical networks. The integration of renewable energy sources, such as solar and wind, has become increasingly important in recent decades due to the urgent need to address climate change and reduce reliance on fossil fuels. Renewable energy sources are not only sustainable but also contribute to energy security and economic development. The global shift towards renewable energy is driven by technological advancements, policy support, and public awareness of environmental issues. The integration of these sources into existing electrical networks presents both challenges and opportunities, necessitating the development of smart grids that can manage diverse energy inputs and optimize energy distribution [1].

The importance of developing local electrical networks cannot be overstated. Local networks enhance the reliability and resilience of electricity supply, particularly in remote or underserved areas. They facilitate the integration of Distributed Energy Resources (DERs), such as rooftop solar panels and small wind turbines, which can reduce transmission losses and lower energy costs for consumers. Moreover, local networks can empower communities by providing them with greater control over their energy sources and consumption patterns. This decentralization of energy production aligns with global trends towards sustainability and energy independence [2].

In regions like Bir Al-Ghanam, the development of a robust electrical network is crucial for supporting local economic growth and improving the quality of life for residents. A well-developed electrical network can attract investments, create jobs, and enhance access to essential services such as healthcare and education. Furthermore, it can facilitate the adoption of energy-efficient technologies and practices, contributing to overall sustainability goals.

The integration of renewable energy into local electrical networks also plays a significant role in voltage regulation and reducing infrastructure investments. As renewable energy technologies continue to evolve, their integration into local networks will become increasingly feasible and beneficial.

In conclusion, the historical significance of electrical energy and the ongoing development of local electrical networks are intertwined with the global transition towards renewable energy. The challenges posed by integrating diverse energy sources into existing systems can be addressed through innovative technologies and strategic planning. As communities like Bir Al-Ghanam work towards enhancing their electrical networks, they will not only improve their energy security but also contribute to a more sustainable and resilient future [3].

1.2 Hysterical review

Electricity has become a cornerstone of modern civilization, influencing nearly every aspect of daily life. The journey of electrical energy began in the late 19th century, marking a significant turning point in human history.

Electricity is an integral part of all modern economies, supporting a range of critical services from healthcare to banking to transportation. The secure supply of electricity is thus of paramount importance. The power sector is going through fundamental changes decarbonization with fast growth in variable renewable sources, digitalization expanding the surface for cyberattacks, and climate change leading to more extreme weather events. In response, governments, industries and other stakeholders will need to improve their frameworks for ensuring electricity security through updated policies, regulations and market designs. Electricity's share of final energy consumption is set to grow. Having increased from15% in 2000 to 20% today, it is set to grow to 24% by 2040 if countries stay on their present course as in the Stated Policies Scenario of the IEA World Energy Outlook Efficient electrification of a range of energy uses could make electricity our most significant energy source.

If countries turn towards a diverse, cost-effective mix in line with the Paris Agreement, as in the IEA Sustainable Development Scenario, the role of electricity becomes even stronger, reaching 31% of final energy consumption by 2040. While the share of electricity in final consumption is less than half that of oil today, it overtakes oil by 2040 in the Sustainable Development Scenario [4].

This shift necessitates the development of smart grids that can manage diverse energy inputs and optimize energy distribution.

Modern electrical grids face many challenges, including the need for resilience to extreme weather events and the integration of distributed energy resources (DERs).

An intense heatwave covering much of the western US and bone-dry conditions across California forced rolling blackouts for the first time in a decade and fueled wildfires that threatened thousands of homes.

Electrical demand surged on Friday as residents dialed up air-conditioning units and fans, prompting the California Independent System Operator, the body that manages the state's power grid, to declare a "stage 3 emergency" that evening, forcing utilities to cut power to hundreds of thousands of residents in the state. This shift necessitates the development of smart grids that can manage diverse energy inputs and optimize energy distribution.

Modern electrical grids face many challenges, including the need for resilience to extreme weather events and the integration of distributed energy resources (DERs) [5].

In regions like Bir Al-Ghanam, developing a robust electrical network is crucial for supporting local economic growth and improving residents' quality of life. A well-developed electrical network can attract investments, create jobs, and enhance access to essential services such as healthcare and education. Furthermore, it can facilitate the adoption of energy-efficient technologies and practices, contributing to overall sustainability goals.

The historical significance of electrical energy and the ongoing development of local electrical networks are intertwined with the global transition towards renewable energy. The challenges posed by integrating diverse energy sources into existing systems can be addressed through innovative technologies and strategic planning. As communities work towards enhancing their electrical networks, they will not only improve their energy security but also contribute to a more sustainable and resilient future.

1.3 Research problem

Transmission and distribution systems, needs continuous improvement and periodic redesign to meet the demands of load growth.

The Bir Al-Ghanam area network, established over 20 years ago, has experienced rapid Load growth due to significand "population and economic expansion, Positioning the city as an important industrial hub in

Western Libya. The growth necessitates the development of the supplying 30 KV Sub-transmission network. Currently, this network suffers from typical issues such Ba such as irregular Vellage profiles and Increased power Losses.

1.4 Research Objectives

The main objectives of this research are to re-plan and redesign of the network of Bir Al-Ghanam city to solve the regularly and to meet the future 10 years load growth. The objectives can be satisfied through the summarized steps in the following:

1- To collect real data for Bir Al-Ghanam network for configuration sizes of components, loads, rated values of equipment and system lines and cables.

2- To simulate the network for performance using ETAP software analysis to identify at the present and find system weakness.

3- To study the forecast of future loading and check for system performance and find the best solution for the system configuration.

1.5 Methodology

The methodology for this research focuses on analyzing the 30kV electric network, a vital link between high-voltage transmission and distribution systems. By examining current power losses and load demand fluctuations, the approach aims to identify key areas for improvement. This analysis will serve as the foundation for developing sustainable solutions to enhance network performance.

1.5.1 Data Collection

1.Load Demand Analysis: Collect historical data on electricity consumption patterns in the Bair Al-Ghanem region, focusing on the 30 kV sub-transmission network.

2.Population and Economic Data: Gather demographic and economic data to project future load demands. This data will help in modeling expected growth trends.

3.Solar Resource Assessment: Analyze solar radiation data for the region to estimate the potential energy generation from photovoltaic (PV) panels.

1.5.2 Reporting and Dissemination

Compile the research findings into a comprehensive report that includes:

1.Analysis of Results: Detailed analysis of the simulation results and their implications for the future of the Libyan electricity grid.

2.Recommendations: Provide actionable recommendations for policymakers and energy planners.

3.Publications and Presentations: Share findings through academic publications, conferences, and community presentations to promote awareness and encourage further research.

1.6 Research Lay out

In this research, the study will be presented through the following layout of the chapters:

Chapter One: provides an introduction to the research, reviewing the system, defining the problem, and its structure.

Chapter Two: Renewable Energy Benefits and Planning Methodologies Explained.

Chapter Three: Integration of PV system into the distribution system

Chapter Four Optimization and redesign of the 30 kV Bir Al-Ghanam network and analysis of the results.

Chapter Five presents the conclusions and recommendations of this research.

1.7 Motivation

The integration of solar energy panels into the Libyan electricity grid, particularly in the Bair Al-Ghanem region, is essential for tackling both current and future energy challenges. The 30kV electric network, which acts as a crucial sub-transmission system, connects high-voltage transmission to distribution networks, enabling power delivery to consumers. However, this network suffers from significant power losses, primarily due to the medium voltage level and an increasing load demand resulting from population growth and economic development.

In light of the country's ambitious energy goals and the pressing need for modernization, this study highlights the importance of renewable energy in improving grid reliability, promoting energy security, and ultimately contributing to Libya's long-term economic prosperity.

CHAPTER TWO

Renewable Energy Benefits and Planning Methodologies Explained.

2.1 Literature review

Climate change is a highly concerning problem that humanity is now grappling with [6]. Undoubtedly, the notable increase in worldwide temperature, as shown by the HadCRUT4 global temperature data, necessitates an immediate shift towards sustainable energy sources. Consequently, there is a need for updated climate models that can incorporate the effects of climate change into energy strategies [7].

The main cause of global warming is greenhouse gas emissions, but deforestation accounts for over 24% [8], has demonstrated a very close relationship between renewable energies, CO2 emissions and economic growth in African oil-producing countries, making the energy transition to renewable sources paramount in order to mitigate global warming and stimulate economic growth. On the other hand, recent literature [9] has clearly presented the impact of globalization, technological innovation and economic growth on air quality in 60 of the world's most open countries between 1960 and 2020, making renewable energy policies crucial to ensuring a healthy and sustainable global environment.

The transition to renewable energies, dominated by wind and solar power, requires electricity storage to manage the existential variability of production, which calls for in-depth research and appropriate energy policies [10].

Solar power and water power are technologies that can be used as the main sources of renewable energy so that the target of decarbonization in the energy sector can be achieved. However, when compared with conventional power plants, they have a significant difference.

The share of renewable energy has made a difference and posed various challenges, especially in the power generation system. The reliability of the power system can achieve the decarbonization target but this objective often collides with several challenges and failures, such that they make achievement of the target very vulnerable, even so, the challenges and technological solutions are still very rarely discussed in the literature [11]. The share of renewable energy is increasing because of environmental concerns and favorable economic conditions. The majority of the distributed energy resources, connected to the low-voltage grid, are inverter-connected units. These inverters are controlled by using specially developed control strategies to determine the power injection between the primary source and the grid. In the recent years, the share of the distributed energy resources (DER) in the distribution grids has been growing continuously, due to environmental and economic concerns. The decreasing cost of photovoltaic (PV) systems accelerates the penetration of DER even more compared to previous years [12].

The increased utilization of distributed renewable energy sources in low voltage grids leads to power quality problems such as over voltages and voltage unbalance. This imposes challenges to the distribution system operators to maintain the power quality in their grids. To overcome these issues, energy storage systems could be integrated together with the distributed energy resources and the stored energy could be used when needed to better improve power quality and achieve better grid performance. Because of environmental and economic concerns, the share of the distributed energy resources (DRES) in the distribution grids is growing continuously. The decreasing prices of the photovoltaic (PV) panels accelerates the penetration of DRES even more compared to previous years [13].

Integrating renewable energy sources into existing power grids presents considerable challenges, especially with the intermittency of wind and solar power. This issue is particularly acute in developing countries like Nigeria, where grid infrastructure is often weak, significantly limiting the potential for RE penetration. This study explores strategies to enhance RE integration in Nigeria by employing Flexible Alternating Current Transmission System (FACTS) devices. By leveraging the reactive-power sensitivity index through modal analysis, the optimal location for the FACTS device can be determined [14].

In recent years, there has been a proliferation of studies focusing on sustainable energy sources aimed at delivering reliable power with reduced greenhouse gas emissions. Among these endeavors, electrification of urban areas through incorporation of renewable energy sources (RESs) stands out as a pivotal application of RES. Increasingly, the integration of RESs like PV and wind into the power grid is being pursued as an alternative to traditional centralized power stations, offering a means to ensure continuous power supply during peak demand periods while simultaneously managing unit costs, thereby providing a systematic and readily accessible power supply to consumers. [15].

In paper [16] will be determined the power losses for the steady-state condition of the system and for the whole day, the buses voltages, the active power supplied by the generators and the active power used by the loads for a test system for a whole day, considering the loads profiles.

2.2- Distribution system

The definition for distribution system and transmission system is interfered, especially when sub-transmission is considered, since it’s the part that connecting the distribution system with transmission.

According to the general definition for distribution system, "That is the electric system between sub-transmission" and customers and this including. The distribution substation, distribution primary feeder, distribution transformers, secondary feeder and service outlets. The definition of sub transmission is "The system that connects the transmission system with distribution system" that system including bulk power station, medium and short transmission lines, and distribution substations. Also, the system can be defined by voltage levels for distribution and sub-transmission systems. The distribution system usually considered as a low voltage that ranges between 0.4 kv to 35kv level, even though in some countries the voltage level of 30 kv and above is not considered as distribution system it's a sub-transmission system.

In Libya, the 30kv and 66kv are considered as medium voltage levels, and then 30kv system is a sub-transmission system. The voltages under 30kv are a distribution system or low voltage level systems.

In this dissertation, the 30kv system is considered as a sub-transmission system. Figure (2.1) shows a general line diagram for sub-transmission system.

The function of sub-transmission system is to transfer electric energy to the high-density load areas. Usually, high voltage transmission lines transfer power to faraway distance areas which considered long lines that are above (250km), but close to dense population areas in the cities the power transferred by medium line length between (80-250) km. The sub-transmission goes around and inside the cities to distribute power among the loads and to be close to distribution substation to reduce power losses and maximize the power transfer.

In this research, the description and analyses will be about Transmission and Distribution (T &D) system as a whole.

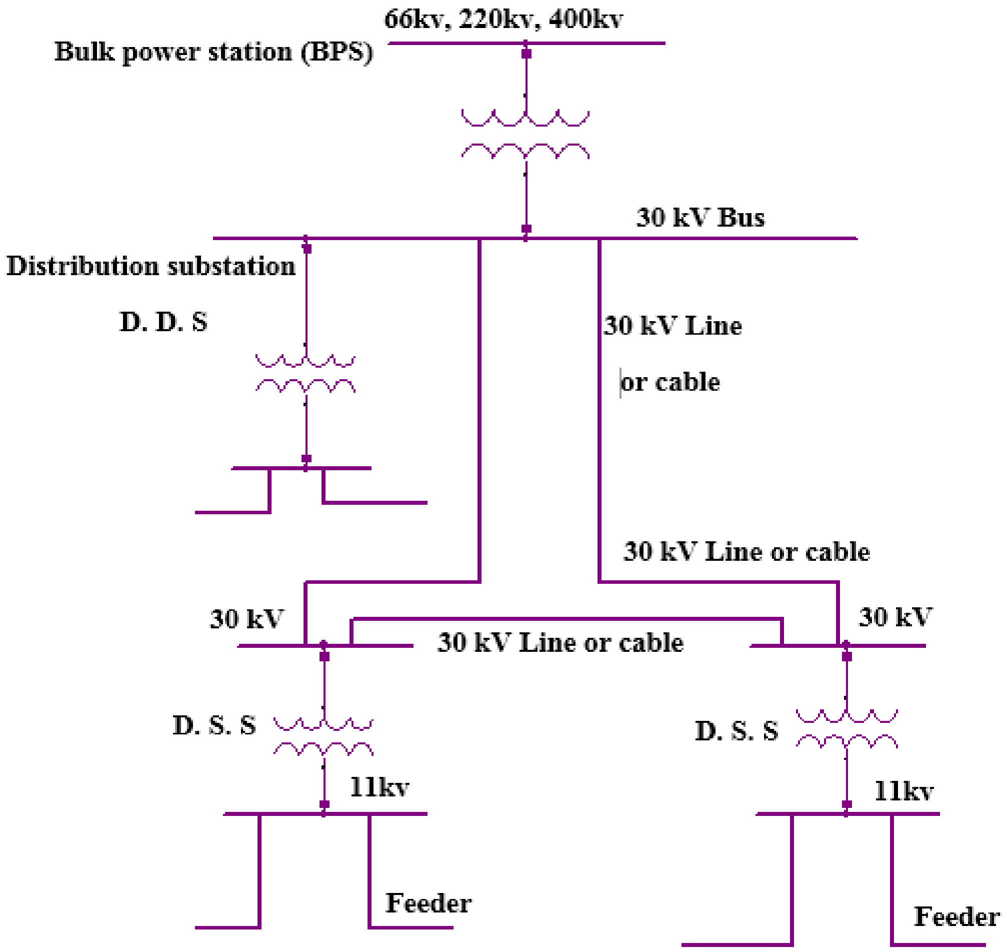


Figure (2.1) A30 kv sub-transmission network.

2.2.1 Transmission and distribution system.

The load forecast is the first issue in the planning process for designing the (T&D) system. The load forecast at the system level is based on econometric models, that developed on the basis of weather-normalized and weather-probabilistic.

Also load forecast can be developed for specific load areas using load data acquirements from energy system authority. The resultant load forecast is used in three of planning studies that assessing the ability of the (T&D) system to meet the future customer load requirements.

Long –range transmission studies are completed for the 20-to-25-year forecast time frame to determine the underlying build out architecture and address the bulk transmission system and the underlying sub-transmission system, which supplies substation. Individual transmission and distribution investment decisions are usually made on a shorter (5 to 15) year timeframe.

Area studies are generally for a 3-to-10-year forecast time frame and address specific load areas, including the area transmission system, substation and distribution feeders. Interconnection studies are designed to determine the required interconnection facilities and system reinforcements required specific generation and transmission projects to enable them to be effective over the life of project [17].

Load flow analyses studies are used to determine expected circuits overloads and voltage violation and to evaluate alternatives for system reinforcements based on the results of the load flows. These studies are discussed in more detail in chapter of this research. These studies enable the (T&D) manager to recommend the most appropriate, cost-effective projects to meet system needs.

The load growth for the geographical area served by a utility company is the most important factor influencing the expansion of the (T&D) system. Therefore, forecasting of load increase and system reaction to these increases is essential for the planning process. There are two common time scales of importance to load forecasting; long range, with time horizons in the order of 15 or 20 year away, and short- range, with time horizons of up to 5 years away. Ideally, these forecasts would predict future loads in detail, extending even to the individual customer level, but in practice, much less resolution is sought or required. Some of the factors which influence the load forecast are:

1-Geographical factors.

2 -Historical data.

3 -Population growth.

4 -Load density.

5 -Alternative energy sources.
6 -Community development plans.
7 -Industrial plans.
8 -City plans.
9 -Land use.

As one would expect load growth is very much dependent on the community and its development. Economic indicators, demographic data, and official land use plans all serve as raw input to the forecast procedure. Output from the forecast is in the form of load densities (kilovoltampers per unit area) for long-range forecasts. Short-range forecasts may require detail. Densities are associated with a coordinate grid for the area of interest. The grid data are then available to aid configuration design. The master plan presents the load forecasting data, and it provides a useful planning tool for checking all geographical location and taking the necessary actions to accommodate the system expansion patterns [18].

2.2.2 -Present (T&D) system planning techniques.

Today, many electric T&D system planners in the industry utilize computer programs, usually based on ad hoc techniques, such as load flow programs, radial or loop flow programs, short-circuit and fault-current calculation programs, voltage drop calculation programs, and total system impedance calculation programs, as well as other tools such as load forecasting, voltage regulation, regulator setting, capacitor planning, reliability, and optimal sitting and sizing algorithms. However, in general, the overall concept of using the output of each program as input for the next program is not in use. Of course, the computers do perform calculations more expeditiously than other methods and free the distribution engineer from detailed work. The engineer can then spend time reviewing results of the calculation, rather than actually making them. Nevertheless, there is no substitute for engineering judgment based on adequate planning at every stage of the development of power systems, regardless of how calculations are made. In general, the use of the aforementioned tools and their bearing on the system design is based purely on the discretion of the planner and overall company operating policy [19].

2.2.3- T&D system planning models.

In general, T&D system planning dictates a complex procedure of a large number of variables involved and the difficult task of the mathematical presentation of numerous requirements and limitations specified by systems configuration. Therefore, mathematical models are developed to represent the system and can complied by T&D system planners to investigate and determine optimum expansion patterns or alternatives, for example, by selecting:

1- Optimum substation location.
2- Optimum substation expansions.
3- Optimum substation transformer size.
4- Optimum feeder routes and sizes to supply the given loads subjects to numerous constraints to minimize the present worth of the total costs involved.

Some of the operation research techniques used in performing this issue including:

1- The alternative-policy method, by which a few alternative policies are compared and the best one is selected.
2- The decomposition method, in which a large problem is subdivided into several small problem and each one is solved separately.
3- The liner-programming, integer-programming, and mixed-integer programming methods, which linearize constraint conditions.
4- The quadratic programming method.

5- The dynamic programming method.

6- Genetic algorithms method.

7- Fuzzy logic and neural network method.

2.2.4- Power system mathematical model

For T&D re-planning and re-design, load flow analysis is the main tool to measure the system performance at different operating modes, using computer and software's for simulation of the system need to have a mathematical model and certain methodology of solving for different system conditions and modes, of operation.

In this research the sub transmission short line model will be considered since the length of sub transmission line are less than 80 km. Also, newton Raphson (N R) method will be used for solution analysis, since this method is the best up to now, that give accurate results and fast in analysis.

2.2.5- Short line mathematical model

Capacitance may often be ignored without much error if the lines are less than (80km) or (50 miles) long, or if the voltage is not over 69kv, the short line length as represented in Figure (2.2).

$$
\begin{aligned}
Z &= (r + jwL)l \\
&= R + jX \qquad (2.1)
\end{aligned}
$$

Where r and L the per-phase resistance and inductance per unit length, respectively and given at the line basis as shown in figure (2.2), **V**s and Is are the phase voltage and current at the sending end of the line and **V**r and **I**r are the phase voltage and current at the receiving end of the line.

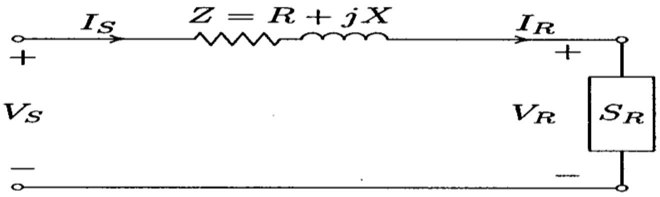


Figure (2.2) short line circuit representation

If three-phase load with apparent power $S_{R(3\phi)}$ is connected at the end of the transmission line, the receiving end current is obtained by:

$$I_R = \frac{S^*_{R(3\emptyset)}}{3V^*_R} \qquad (2.2)$$

The phase voltage at the sending end is:

$$V_s = V_R + ZI_R \qquad (2.3)$$

And since the shunt capacitance is neglected the sending end and the receiving end current are equal:

$$I_S = I_R \qquad (2.4)$$

The transmission line may be represented by a two-port network as shown in finger (2.3) and above equation can be writer in terms of the generalized circuit constant commonly known as the A B C D line constants.

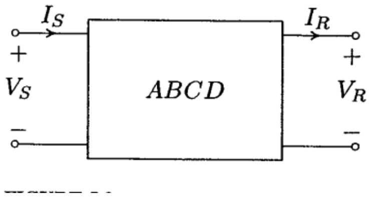


Figure (2.3)Two-port representation of transmission line.

$$V_s = AV_R + BI_R \qquad (2.5)$$

$$I_s = CV_R + DI_R \qquad (2.6)$$

Or in matrix form:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \qquad (2.7\ )$$

According to circuit Kirchhoff low and wimped equations the values of line constant for short line are:

A=1 B=Z C=0 D=1

Voltage regulation of the line may be defined as the percentage change in voltage at the receiving end of the line (expressed as percent of full load voltage) ingoing from no-load to full load.

$$Percent\ VR = \frac{|V_{R(NL)}| - |V_{R(FL)}|}{|V_{R(FL)}|} \times 100 \qquad (2.8)$$

At no load:

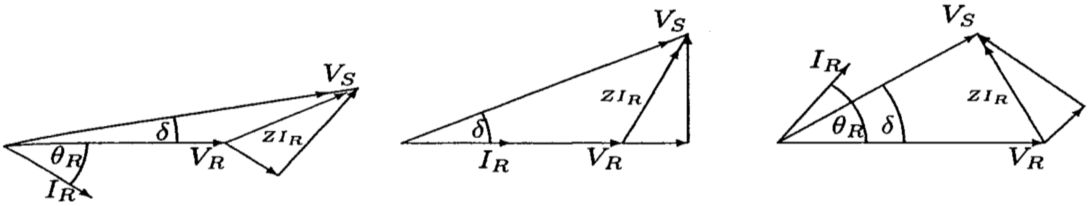
$$I_R = 0 \tag{2.9}$$

$$V_{R(NL)} = \frac{V_S}{A} \tag{2.10}$$

$$V_{R(NL)} = V_S \tag{2.11}$$

for a short line A=1 and

Figure (2.4) shows the victor diagram for different line loading.



(a) Lagging pf load **(b) Upf load** **(c) Leading pf load**

Figure (2.4) Victor diagram for different line loads.

2.2.6-Power flow and efficiency of short transmission line.

The input powers for short transmission line:

$$P_{in} = 3V_S I_S cos\theta_s = \sqrt{3}V_{LL.S} I_S cos\theta_s \quad . \tag{2.12}$$

$$Q_{in} = 3V_S I_S sin\theta_s = \sqrt{3}V_{LL.S} I_S sin\theta_s \tag{2.13}$$

$$S_{in} = 3V_S I_S = \sqrt{3}V_{LL.S} I_S \tag{2.14}$$

And the output powers for short transmission lines are:

$$P_{out} = 3V_R I_R cos\theta_R = \sqrt{3}V_{LL.R} I_R cos\theta_R \tag{2.15}$$

$$Q_{out} = 3V_R I_R sin\theta_s = \sqrt{3}V_{LL.R} I_R sin\theta_R \tag{2.16}$$

$$S_{out} = 3V_R I_R = \sqrt{3}V_{LL.R} I_R \tag{2.17}$$

Efficiency can be calculated by:

$$\eta = \frac{P_{out}}{P_{in}} . 100\% \tag{2.18}$$

The given short line model will be used for system simulation studies by applying ETAP software media, and Newton-Raphison for system solution to measure the performance.

2.3 The Benefits of Renewable Energy

Renewable energy sources, including solar, wind, hydroelectric, and geothermal power, have increasingly captured global attention in recent years, primarily due to their numerous benefits and the urgent need for sustainable alternatives to fossil fuels. As the world grapples with the escalating impacts of climate change and the finite nature of fossil fuel reserves, the transition to renewable energy has become a paramount priority for governments, businesses, and individuals alike. The urgency is underscored by the growing awareness of the environmental degradation associated with traditional energy sources, such as air pollution and greenhouse gas emissions, which threaten both human health and the planet's ecosystems.

One of the foremost advantages of renewable energy is its potential for environmental protection. Unlike fossil fuels, which release significant amounts of carbon dioxide and other pollutants into the atmosphere when burned, renewable energy sources offer a cleaner, sustainable alternative. By harnessing the natural power of the sun, wind, and water, we can drastically reduce our carbon footprint and minimize environmental harm. This shift is crucial for mitigating climate change and preserving biodiversity, which is increasingly threatened by human activity.

In addition to environmental benefits, renewable energy also serves as a catalyst for economic growth. The green energy sector has seen exponential growth over the past decade, creating millions of jobs worldwide in areas such as manufacturing, installation, and maintenance. As countries invest in renewable technologies, they stimulate local economies and promote innovation. Furthermore, with the decreasing costs of solar panels and wind turbines, renewables are becoming more economically viable than traditional energy sources, making them an attractive option for both consumers and businesses.

Energy security is another critical benefit of renewable energy. By diversifying energy sources and relying less on imported fossil fuels, nations can enhance their energy independence and stability. Renewable energy resources are abundant and can often be harnessed locally, reducing vulnerability to geopolitical tensions and market fluctuations. This shift not only helps stabilize energy prices but also fosters a more resilient energy infrastructure capable of meeting future demands.

Renewable energy has significant health benefits. The combustion of fossil fuels is a major contributor to air pollution, which is linked to a range of health issues including respiratory diseases, heart problems, and premature mortality. By transitioning to cleaner energy sources, we can improve air quality and public health outcomes, leading to a healthier population.

The transition to renewable energy is not merely an option but a necessity for a sustainable future. The environmental, economic, energy security, and health benefits of renewable sources underscore the importance of adopting these technologies. As we move forward, a collective commitment to renewable energy will pave the way for a healthier, more prosperous world for generations to come.

2.3.1 Environmental Protection

One of the most significant advantages of renewable energy is its positive impact on the environment. Unlike fossil fuels, which release large amounts of Green House Gases (GHGs) when burned, renewable energy sources produce little to no emissions. For instance, according to the International Renewable Energy Agency (IRENA), the use of renewable energy could lead to a reduction of global GHG emissions by up to 70% by 2050 (IRENA, 2021). This reduction is crucial in mitigating the effects of climate change, protecting ecosystems, and preserving biodiversity.

As the world faces escalating environmental challenges, including climate change, air pollution, and the depletion of natural resources, the transition from fossil fuels to renewable energy sources has become increasingly urgent. Renewable energy encompasses sources such as solar, wind, hydroelectric, and geothermal power, all of which offer sustainable alternatives that help mitigate the adverse effects of traditional energy production [20].

Fossil fuel combustion is a primary contributor to greenhouse gas emissions, which trap heat in the atmosphere and drive global warming. According to the Intergovernmental Panel on Climate Change (IPCC), the energy sector is responsible for approximately 73% of global greenhouse gas emissions. In contrast, renewable energy sources produce little to no direct emissions during their operation. For instance, solar panels convert sunlight into electricity without releasing harmful pollutants, while wind turbines harness wind energy without emitting carbon dioxide. This fundamental difference positions renewable energy as a critical tool in the fight against climate change.

The renewable energy significantly reduces air and water pollution. Traditional energy production often involves the extraction, processing, and burning of fossil fuels, which leads to the release of toxic substances into the air and water bodies. These pollutants can harm wildlife, damage ecosystems, and pose serious health risks to humans. Transitioning to cleaner energy sources can substantially improve air quality, reducing respiratory illnesses and other health issues associated with pollution. Studies have shown that a shift to renewable energy can prevent millions of premature deaths each year by improving air quality alone.

Renewable energy promotes biodiversity conservation. Fossil fuel extraction and infrastructure development often lead to habitat destruction and fragmentation, threatening various species and ecosystems. In contrast, renewable energy projects, when thoughtfully designed and implemented, can coexist with natural habitats. For example, solar farms can be built on previously disturbed lands, and offshore wind farms can provide habitats for marine life.

Renewable energy contributes to sustainable resource management. Unlike fossil fuels, which are finite and depleting, renewable energy sources are abundant and replenishable. This sustainable approach to energy generation helps protect natural resources for future generations, ensuring that ecosystems remain healthy and resilient.

The positive environmental impacts of renewable energy are substantial. By reducing greenhouse gas emissions, improving air and water quality, protecting biodiversity, and promoting sustainable resource management, the transition to renewable energy is essential for preserving the planet and fostering a healthier future. Embracing renewable energy not only addresses current environmental challenges but also lays the groundwork for a sustainable and resilient world [21].

2.3.2 Economic Growth

Renewable energy also contributes to economic growth. The sector has been a significant source of job creation. The Global Wind Energy Council reported that the wind energy sector alone employed over [1.2 million] people worldwide in 2020 (GWEC, 2021). As technology advances and production costs decrease, the renewable energy sector is expected to continue expanding, creating more job opportunities in manufacturing, installation, maintenance, and research and development.

Investing in renewable energy can stimulate local economies. By harnessing local resources, communities can keep energy expenditures within their regions. This can lead to increased investments in local infrastructure and services, further enhancing economic resilience.

Renewable energy is increasingly recognized not only for its environmental benefits but also for its significant contributions to economic growth. As countries around the world strive to transition away from fossil fuels, the renewable energy sector has emerged as a powerful engine for job creation, investment, and innovation. This transformation is reshaping economies, fostering resilience, and driving sustainable development.

The renewable energy industry encompasses a diverse range of technologies, including solar, wind, hydroelectric, and biomass. Each of these sectors provides unique opportunities for economic expansion. For instance, according to the International Renewable Energy Agency (IRENA), the global renewable energy sector employed over 11 million people in 2018, with numbers projected to grow as investments in clean energy technologies increase. The job creation potential spans not only direct employment in manufacturing and installation but also indirect jobs in areas such as supply chain management, maintenance, and research and development.

The investment landscape for renewable energy is rapidly evolving. Governments and private investors are directing substantial funds towards clean energy projects, recognizing their long-term viability and profitability. This influx of capital stimulates local economies, leading to infrastructure development, technological advancements, and enhanced competitiveness. For example, countries that prioritize renewable energy attract investments that can catalyze further economic activities, such as the development of new industries and innovations in energy storage and grid management.

In addition to job creation and investment, renewable energy contributes to energy independence and security, which are crucial for economic stability. By harnessing local resources, countries can reduce their reliance on imported fossil fuels, mitigating the risks associated with volatile global energy markets. This energy independence fosters economic resilience, enabling nations to maintain stable energy prices and protect themselves from geopolitical tensions that can disrupt energy supplies.

The renewable energy sector encourages innovation and technological advancement. As demand for cleaner energy sources grows, companies are incentivized to invest in research and development, leading to breakthroughs in efficiency and cost-effectiveness. These innovations not only enhance the competitiveness of the renewable energy sector but also have ripple effects across other industries, fostering a culture of sustainability and creativity.

Renewable energy can drive economic growth by improving public health and reducing healthcare costs associated with pollution. Cleaner air and water contribute to a healthier workforce, which in turn enhances productivity and economic output. By investing in renewable energy, societies can create a sustainable economic model that prioritizes both environmental health and economic prosperity.

The transition to renewable energy is a catalyst for economic growth, and as Figure (2.5) illustrates, it offers significant benefits beyond environmental protection. By creating jobs, attracting investment, encouraging innovation, and promoting energy independence, renewable energy is a cornerstone of sustainable economic development in the 21st century. Embracing this transition will not only address pressing environmental challenges but also pave the way for a more prosperous and resilient future [22].

Figure (2.5) Renewable energy is a catalyst for economic growth

2.3.3 Energy Security

Another essential benefit of renewable energy is enhanced energy security. Fossil fuels are often subject to volatile markets and geopolitical tensions, which can lead to supply disruptions and price fluctuations. In contrast, renewable energy sources are abundant and widely available, allowing countries to reduce their dependence on imported fuels. For example, countries that invest in solar and wind energy can harness their natural resources, leading to greater energy independence. This diversification of energy sources also helps stabilize energy prices, benefiting consumers and businesses alike.

Energy security is a critical concern for nations worldwide, particularly as they strive to ensure a reliable, affordable, and sustainable energy supply. The integration of solar energy into traditional electricity grids has emerged as a pivotal strategy for enhancing energy security. By diversifying energy sources and reducing dependence on fossil fuels, solar power plays a vital role in creating resilient energy systems capable of meeting growing demand while mitigating risks associated with energy supply disruptions.

The increasing volatility of fossil fuel markets highlights the importance of energy security. Geopolitical tensions, natural disasters, and market fluctuations can lead to supply shortages and price spikes, threatening the stability of national economies. By incorporating solar energy into existing electricity grids, countries can reduce their reliance on imported fuels and enhance their energy independence. Solar power, being abundant and widely available, allows nations to harness local resources, thereby stabilizing energy prices and minimizing exposure to external shocks.

Solar energy contributes to grid resilience. Traditional energy systems are often centralized, making them vulnerable to outages caused by extreme weather events or technical failures. By integrating distributed solar generation, which involves deploying solar panels across various locations, the overall resilience of the grid is enhanced. In the event of a disruption in one area, other parts of the grid can continue to function, ensuring a more reliable energy supply. This decentralization is particularly beneficial in regions prone to natural disasters, where conventional energy infrastructure may be severely impacted.

The economic advantages of solar integration also play a significant role in energy security. Investing in solar energy systems can create local jobs in manufacturing, installation, and maintenance, contributing to economic growth and stability. According to a report by the International Renewable Energy Agency (IRENA), the global solar industry employed over 3.8 million people in 2020, highlighting its potential as a significant job creator (IRENA, 2021). This job creation not only supports local economies but also fosters public support for renewable energy initiatives [23].

The integration of solar energy into traditional electricity grids is essential for enhancing energy security. By diversifying energy sources, improving grid resilience, creating economic opportunities, and mitigating environmental risks, solar power presents a viable solution for achieving sustainable and secure energy systems. As nations continue to prioritize energy security in the face of evolving challenges, embracing solar energy will be crucial for building a resilient and sustainable future [24].

2.3.4 Health Improvements

The transition to renewable energy sources is not just an environmental imperative; it is also a crucial factor in improving public health. As the global community increasingly recognizes the detrimental effects of fossil fuel consumption, the shift towards cleaner energy alternatives has emerged as a vital strategy for enhancing health outcomes. The burning of fossil fuels releases a range of harmful pollutants, including particulate matter, nitrogen oxides, and sulfur dioxide, all of which contribute to severe air quality issues. These pollutants are linked to numerous health problems, including respiratory diseases, cardiovascular conditions, and even premature mortality.

DERs are resources connected to the distribution system close to the load, such as DPV, wind, combined heat and power, microgrids, energy storage, microturbines, and diesel generators. Energy efficiency, demand response, and electric vehicles are also sometimes considered DERs [25].

2.4 Renewable Energy Integration with the Grid

The integration of renewable energy into electrical grids is essential for creating a sustainable and resilient energy system. As the world transitions away from fossil fuels, various methods of integrating renewable sources—such as solar, wind, hydro, and biomass—into existing grid infrastructure have emerged. Each method has unique characteristics and benefits, contributing to a diverse energy mix that enhances reliability and flexibility.

One of the most prominent integration methods is grid-tie systems, commonly used in solar energy, as shown in Figure (2.6). In these systems, solar panels generate electricity that is fed directly into the grid. This approach allows for immediate use of solar energy, reducing dependence on fossil fuels and lowering. electricity costs for consumers. Grid-tied systems are often equipped with net metering capabilities, enabling consumers to receive credits for excess energy fed back into the grid, thereby incentivizing solar adoption (U.S. Department of Energy, 2021) [26].

Figure (2.6) integration methods are grid-tie systems

2.4.1 Hybrid Systems

Hybrid systems combine multiple renewable energy sources, such as wind and solar, to optimize energy production. These systems can provide a more stable energy supply by balancing the intermittent nature of individual sources. For example, when solar power generation is low during cloudy days, wind power may be more abundant, ensuring a continuous power supply. Hybrid systems are particularly effective in remote areas where access to the conventional grid is limited, as Figure

(2.7) shows, as they can leverage diverse energy sources to meet local demand.

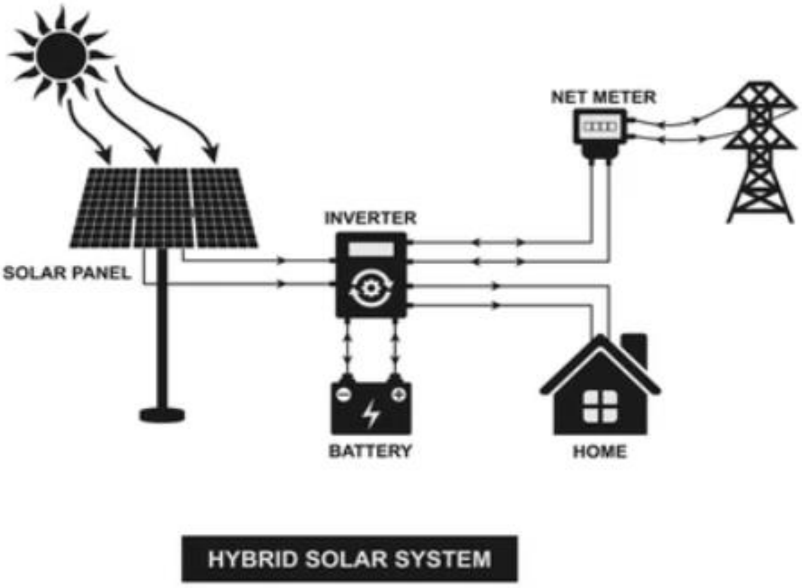


Figure (2.7) Hybrid systems

2.4.2 Grid-Tied Systems

Grid-tied systems are one of the most common methods for integrating renewable energy, particularly solar power. In these systems, solar panels generate electricity that is fed directly into the grid. This allows for the immediate use of solar energy, reducing reliance on fossil fuels and lowering electricity costs for consumers. Grid-tied systems often utilize net metering, which enables consumers to receive credits for excess energy they feed back into the grid. This incentivizes solar adoption and promotes energy efficiency.

2. 4. 3 Energy Storage Systems

The integration of energy storage systems with renewable sources is vital for enhancing grid reliability. Technologies such as batteries allow excess energy generated during peak production times to be stored and used during periods of high demand or low generation. This capability is crucial for balancing supply and demand, making renewable energy more viable as a primary energy source. Energy storage systems can also help mitigate the variability associated with renewable generation, ensuring a stable and reliable power supply.

Battery storage is one of the most prominent energy storage technologies. Batteries can collect excess energy generated during peak times, Types of Battery shown in Figure (2.8).

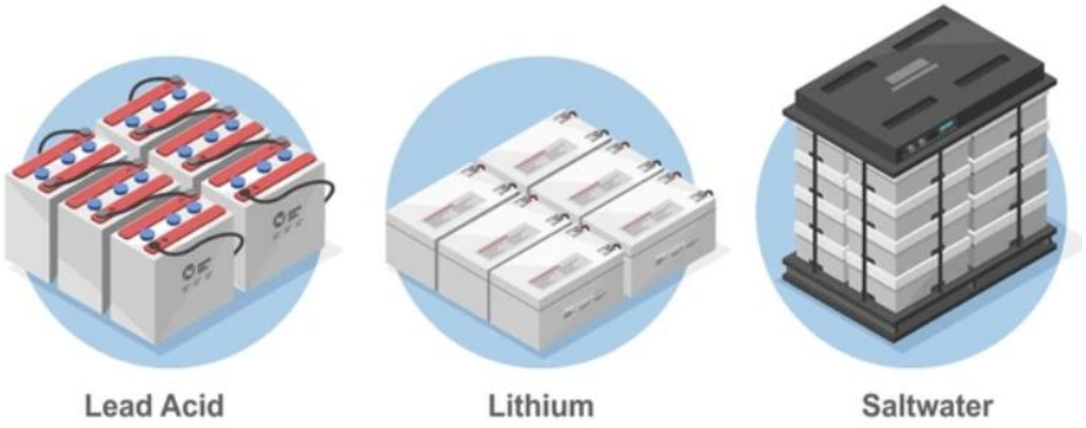


Figure (2.8) Types of Battery

The ability of energy storage systems to balance supply and demand is crucial for the widespread adoption of renewable energy. Without adequate storage solutions, the excess energy produced during favorable weather conditions could go to waste, and utilities might struggle to meet demand during less favorable conditions.

2. 4. 4 Distributed Generation

Distributed generation refers to the deployment of small-scale renewable energy sources close to the point of consumption. This method enhances grid resilience by decentralizing energy production, which reduces transmission losses and can provide backup power during outages.

Community solar projects are a prime example of distributed generation, allowing multiple households to benefit from a shared solar installation. This approach not only promotes local energy independence but also fosters community engagement and investment in renewable technologies.

Distributed generation represents a significant shift in how energy is produced and consumed. By deploying small-scale renewable energy sources close to consumption points, communities can enhance grid resilience, reduce transmission losses, and promote local energy independence. Community solar projects illustrate the myriad benefits of this approach, fostering community engagement and investment in renewable technologies. As society moves toward a more sustainable energy future, the role of distributed generation will continue to grow, making it an essential element of modern energy strategies [27].

2.4.5 Microgrids

Microgrids are localized power systems that operate independently or in conjunction with the main grid. These grids enhance flexibility and adaptability by integrating diverse renewable energy sources and energy storage systems, as shown in the Figure (2.9). Microgrids can manage local energy resources efficiently, making them especially beneficial in regions prone to natural disasters. By allowing localized control over energy generation and consumption, microgrids can improve energy security and reliability.

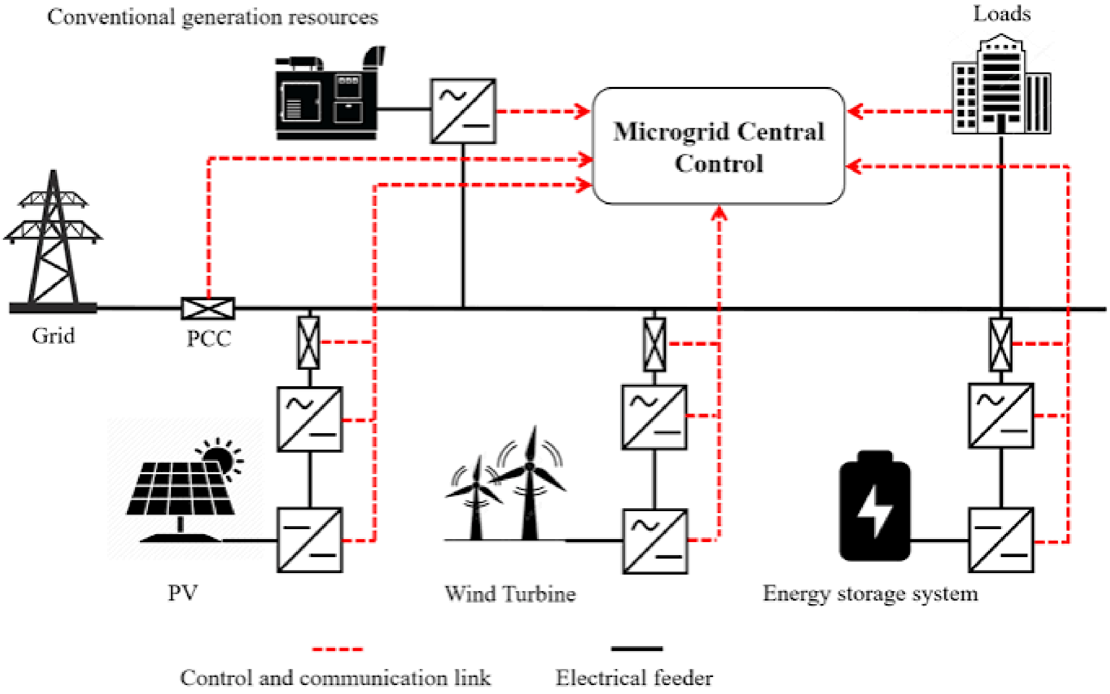


Figure (2.9) Microgrid system

2.4.6 Smart Grids

Smart grids represent an advanced integration method that utilizes digital technology to enhance the efficiency and reliability of electricity distribution. By incorporating smart meters, sensors, and automated controls, smart grids can optimize the flo

w of electricity from renewable sources. They enable real-time monitoring and management of energy resources, facilitating better integration of variable renewable energy sources into the grid. This technology enhances grid stability and allows for more efficient energy use [28].

CHAPTER THREE

Integration of PV System into the distribution system

3-1 Introduction

The methodology of conventional distribution system planning is to meet the load demand growth by adding new substation system and feeders or expanding the existing ones. In the large population, area where the load demand is yearly increased the adding and or expanding the distribution substations start not be easy due to the difficulties in construction inside the city centers and the increase of cost due to inflations.

In this case another way or methodology can be introduced that depend on the new technologies which leads to the idea of future smart grid systems. The penetration of photovoltaic energy system within the electric network seems to be considered as the other way in the re-planning and redesign considerations.

Deregulation of the electric utility industry, environmental concerns associated with traditional fossil fuel generation power plants, volatility of electric energy costs, and world regulatory support of “green” energy, and rapid technological developments all support the proliferation of photovoltaic energy in electric utility systems. The growing rate of photovoltaic energy system deployment also suggests that alternative energy-based solutions will play an increasingly important role in the smart grid and modern utility.

Large-scale implementation of deregulation of the electric utility industry, environmental concerns associated with traditional fossil fuel generation power plants, volatility of electric energy costs, and world regulatory support of “green” energy, and rapid technological developments all support the proliferation of photovoltaic energy system in electric utility systems.

The growing rate of photovoltaic energy system deployment also suggests that alternative energy-based solutions will play an increasingly important

role in the smart grid and modern utility generation pv can lead to the evolution of the distribution network from a “passive” (local/limited automation, monitoring, and control) system to an “active” (global/integrated, self-monitoring, semi-automated) system that automatically responds to the various dynamics of the electric grid, resulting in higher efficiency, better load management, and fewer outages. However, photovoltaic energy system
also poses a challenge for the design, operation, and management of the power grid because the network no longer behaves as it once did.

Consequently, the planning and operation of new systems must be approached differently, with a greater amount of attention paid to the challenges of an automated global system.

New and rapid advances in photovoltaic energy system (PV) technologies have made them as an attractive option for the electric service utilities and the planners for solving the problems of demand growth and get their numerous benefits to the distribution systems.

In this research, the PV will be considered as an option in the re-planning and redesign study of BIR ALGANM (30) KV sub transmission system for next twenty years or more choosing PV to be connected to the sub transmission buses specially the remote ones and/or that suffering the voltage dips due to load increasing, this will compensate for adding feeders or expanding the substations.

The system can be defined by voltage levels for distribution and sub-transmission systems. The distribution system usually considered as a low voltage that ranges between (0.4) kv to (35) kv level, even though in some countries the voltage level of (30) kv and above is not considered as distribution system it’s a sub-transmission system.

In Libya, the (30) kv and (66) kv are considered as medium voltage levels, and then (30) kv system is a sub-transmission system. The voltages under (30) kv are a distribution system or low voltage level systems.

The function of sub-transmission system is to transfer electric energy to the high-density load areas. Usually, high voltage transmission lines transfer power to faraway distance areas which considered long lines that are above (250km), but close to dense population areas in the cities the power transferred by medium line length between (80-250) km. The sub-transmission goes around and inside the cities to distribute power among the loads and to be close to distribution substation to reduce power losses and maximize the power transfer.

3 .2 The Photovoltaic Effect

At the heart of photovoltaic systems lies the photovoltaic effect, a physical phenomenon that allows materials to convert light energy into electrical energy. When photons from sunlight strike a material, typically a semiconductor, they can transfer their energy to electrons within the material. This transfer frees the electrons from their atomic bonds, allowing them to move freely and create an electric current. The efficiency of this conversion process depends on the material's properties, the quality of the solar cells, and the intensity of sunlight Figure (3.1).

Semiconductors, primarily silicon, are the most common materials used in PV cells. Silicon can be found in two forms: monocrystalline and polycrystalline. Monocrystalline silicon cells are made from a single crystal structure, providing higher efficiency but at a higher cost. Polycrystalline silicon cells, on the other hand, are made from multiple crystal structures, resulting in lower efficiency and cost. Emerging technologies, including thin-film solar cells and organic photovoltaics, are also being developed to enhance efficiency and reduce production costs.

Figure (3.1) photovoltaic systems

3 .2.1 Key Components of a Photovoltaic Energy System

A typical photovoltaic energy system consists of several essential components, each playing a critical role in converting sunlight into usable electricity:

-Solar Panels: Solar panels, or photovoltaic modules, as shown in Figure (3.2) are the most recognizable components of a PV system. They contain multiple solar cells that convert sunlight into direct current (DC) electricity. The efficiency of solar panels can vary significantly based on the technology used, the angle of installation, and environmental factors.

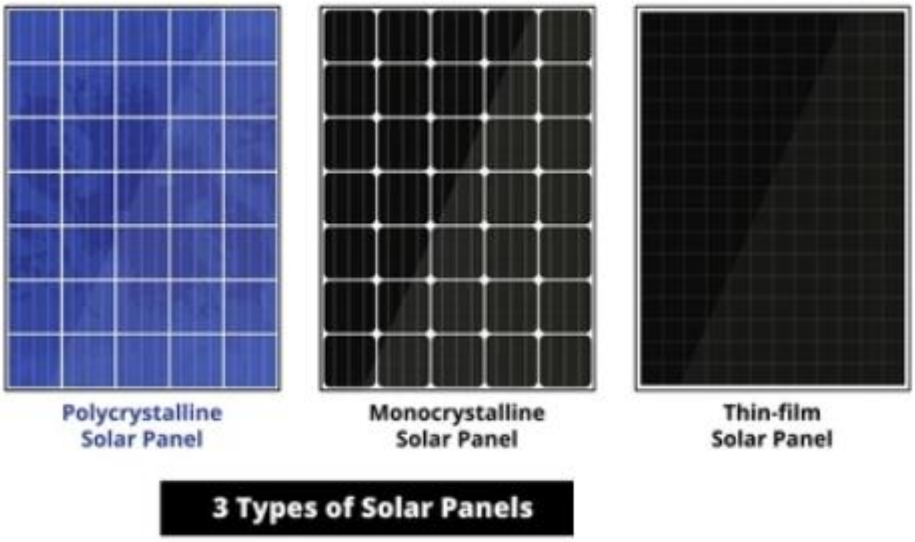


Figure (3.2) Types of solar panels

-Inverters: Inverters are necessary to convert the direct current electricity produced by solar panels into alternating current (AC), which is the standard form of electricity used in homes and businesses as shown in Figure (3.3).

In addition to conversion, modern inverters often include features like Maximum Power Point Tracking (MPPT), which optimizes the energy output from the solar panels based on varying sunlight conditions.

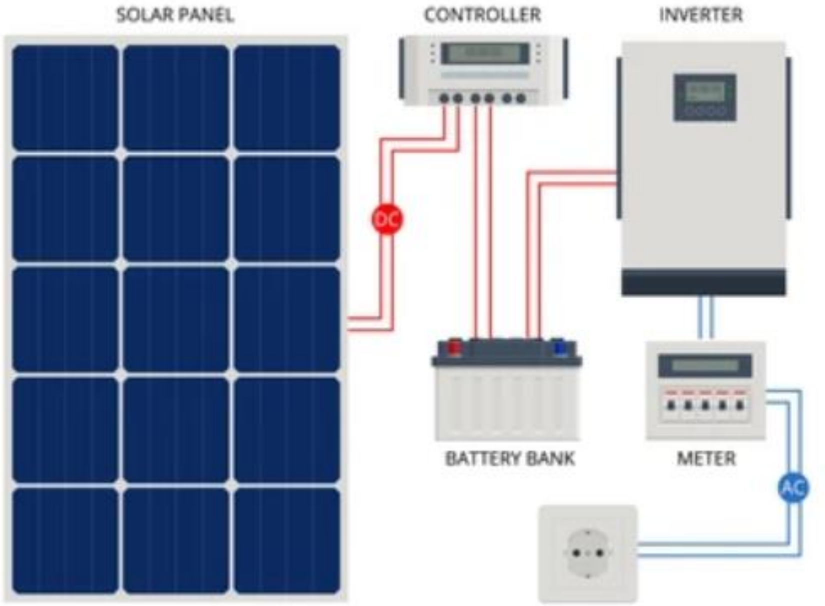


Figure (3.3) Inverters electrical

-Mounting Systems: These structures secure solar panels in place, ensuring they are positioned to capture maximum sunlight. Mounting systems can be fixed or adjustable, with adjustable systems allowing for changes in angle to better follow the sun's path throughout the day.

-Battery Storage: In many photovoltaic systems, especially off-grid installations, battery storage is used to store excess energy generated during sunny periods for use during cloudy days or at night. This capability enhances the reliability of solar energy systems, allowing them to provide consistent power irrespective of sunlight availability.

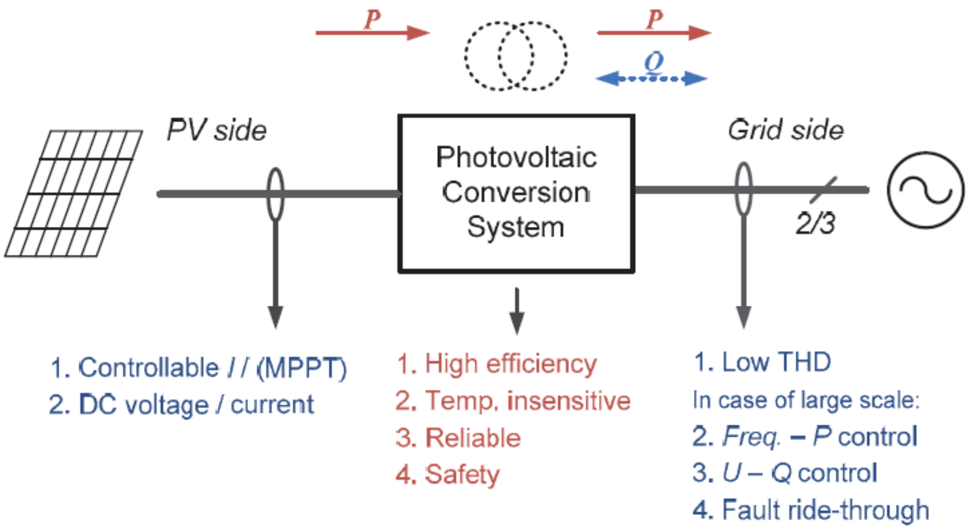
-Charge Controllers: These devices manage the flow of electricity to and from the batteries, preventing overcharging and optimizing performance. Charge controllers are critical in ensuring the longevity of the battery storage system.

-Wiring and Electrical Components: Proper wiring and electrical components are necessary to connect all parts of the photovoltaic system safely and efficiently. This includes fuses, circuit breakers, and connectors that ensure safe operation and facilitate maintenance.

3.2. 2 Types of Photovoltaic Systems

Photovoltaic systems can be categorized based on their configuration and application. The main types include:

-Grid-Tied Systems: These systems are connected to the local utility grid. They allow homeowners and businesses to sell excess electricity back to the grid, often through net metering agreements. This arrangement not only reduces electricity bills but also provides a financial incentive for investing in solar technology Figure (3.4).



Demands for PV power conversion system.

Figure (3.4) Demands for PV power conversion system

-Off-Grid Systems: Off-grid systems operate independently of the utility grid and are typically used in remote areas where grid access is limited or nonexistent. These systems rely heavily on battery storage to provide a reliable power supply. Off-grid installations are popular in rural communities, cabins, and emergency backup systems.

-Hybrid Systems: Hybrid systems combine photovoltaic energy with other energy sources, such as wind turbines or diesel generators. This configuration enhances reliability by providing multiple sources of energy, ensuring that power generation can continue even when one source is not available.

3 .2.3 Applications of Photovoltaic Energy Systems

The versatility of photovoltaic energy systems allows for a wide range of applications, including:

-Residential Use: Homeowners can install solar panels on rooftops to generate electricity for their households. This not only reduces electricity bills but also contributes to a more sustainable lifestyle.

-Commercial and Industrial Use: Businesses are increasingly adopting PV systems to reduce energy costs and enhance their sustainability credentials. Large commercial installations can significantly lower operating expenses and provide a competitive advantage.

-Utility-Scale Solar Farms: Utility-scale solar farms are massive installations that generate electricity for distribution to the grid. These projects can produce significant amounts of energy, helping to meet growing electricity demands while reducing reliance on fossil fuels.

-Remote and Off-Grid Applications: Photovoltaic systems are ideal for powering remote locations, such as telecommunications towers, weather stations, and rural electrification projects. They provide reliable energy in areas without access to traditional power sources.

-Agricultural Applications: PV technology can be integrated into agricultural practices, providing power for irrigation systems, water pumps, and greenhouses. This integration supports sustainable farming and enhances food production efficiency.

3 .2. 4 Advantages of Photovoltaic Energy Systems

-Environmental Impact: Solar energy is a clean and renewable resource that significantly reduces greenhouse gas emissions. By transitioning to PV systems, we can mitigate climate change and protect natural ecosystems.

-Economic Growth: The solar industry has created millions of jobs worldwide, from manufacturing to installation and maintenance. As demand for renewable energy grows, so do opportunities for economic development.

-Energy Independence: By harnessing local solar resources, countries can reduce their reliance on imported fossil fuels, enhancing energy security and stability. This independence can lead to more stable energy prices and reduced vulnerability to geopolitical tensions.

-Health Benefits: The reduction in air pollution from decreased fossil fuel use has direct health benefits. Improved air quality translates to fewer respiratory and cardiovascular diseases, leading to healthier communities.

3 .2 .5. Future Trends in Photovoltaic Energy Systems

The future of photovoltaic energy systems is promising, with several trends emerging in the industry:

-Technological Advancements: Ongoing research is focused on improving the efficiency and affordability of solar technologies. Innovations in materials, such as perovskite solar cells, hold the potential for higher efficiency at lower costs.

-Energy Storage Solutions: As battery technology continues to advance, energy storage solutions are becoming more effective and affordable. This will enhance the viability of solar energy, allowing for greater grid stability and independence.

-Smart Grid Integration: The integration of PV systems into smart grids will enable more efficient energy management, allowing for better demand response and load balancing. This approach can optimize the use of renewable energy sources and reduce waste.

-Policy and Incentives: Governments around the world are increasingly implementing policies and incentives to promote the adoption of renewable energy. These include tax credits, grants, and feed-in tariffs that make solar energy more accessible.

photovoltaic energy systems are a critical component of the global shift towards renewable energy. Understanding their definitions, components, types, applications, benefits, and future trends is essential for recognizing their potential to address the pressing challenges of climate change, energy security, and economic sustainability. As technology advances and awareness increases, photovoltaic systems will continue to play a pivotal role in shaping our energy landscape, paving the way for a cleaner, more sustainable future [32].

3.3 PV technologies

Photovoltaic (PV) technologies are essential for harnessing solar energy and converting it into electricity. These technologies have evolved significantly over the years, driven by advancements in materials science, engineering, and manufacturing processes. This evolution has led to various types of PV systems, each with distinct characteristics and applications as shown in the Figure (3.5) .

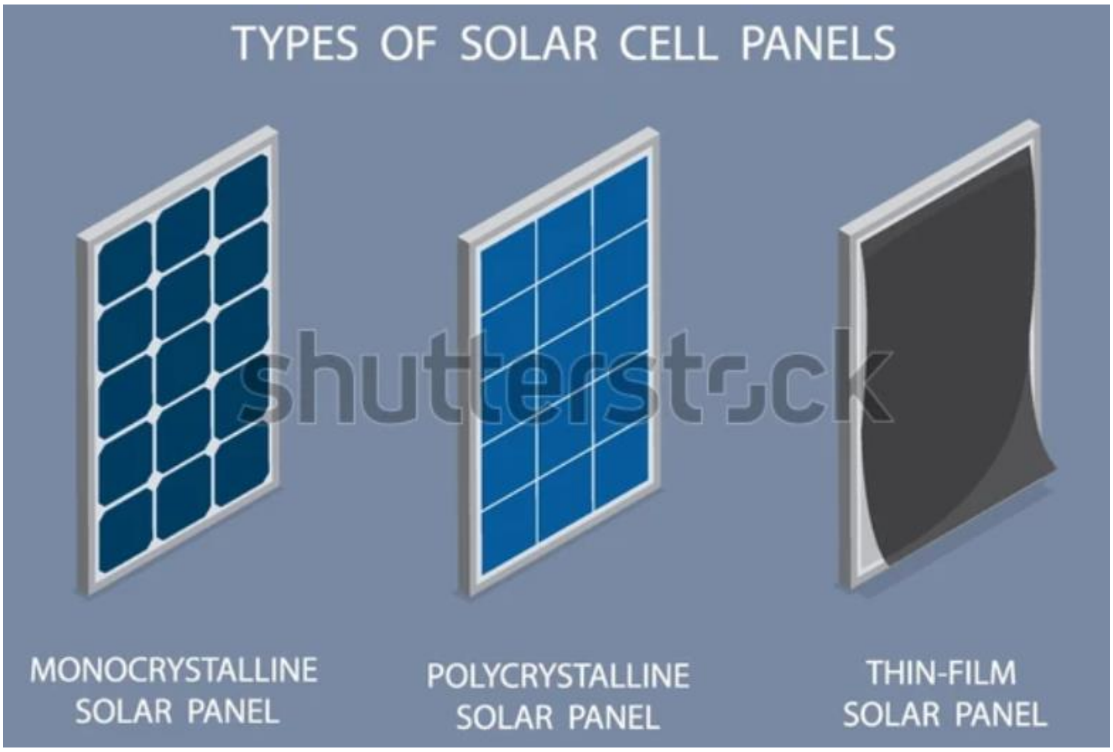


Figure (3.5) Types of solar cell panels

-Crystalline Silicon Solar Cells

Crystalline silicon solar cells are the most widely used PV technology, accounting for about 90% of the global market. They come in two main types: monocrystalline and polycrystalline.

-Monocrystalline Silicon: Made from a single crystal structure, these cells are known for their high efficiency and longevity. They typically have efficiencies ranging from 15% to over 22%, making them ideal for residential and commercial applications where space is limited. Their uniform appearance and sleek design contribute to their popularity.

-Polycrystalline Silicon: These cells are made from multiple silicon crystals and are typically less expensive to produce than monocrystalline cells. As shown in the Figure (3.6), although their efficiency is slightly lower, typically ranging from 13% to 17%, they are a practical option for large-scale installations, especially when budgets are limited.

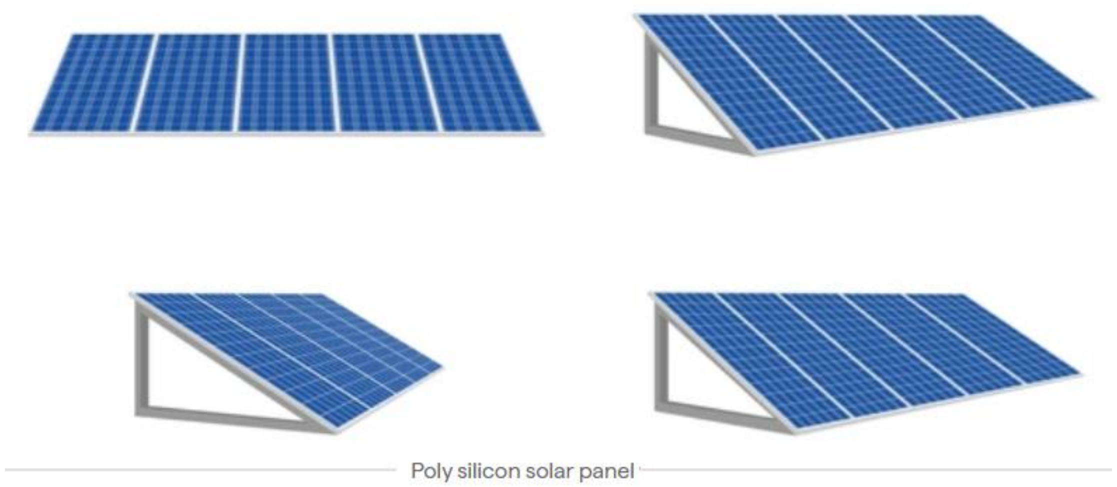


Figure (3.6) poly silicon solar panel

-Thin-Film Solar Cells

Thin-film solar cells are another significant category of PV technology. These cells are made by depositing one or more thin layers of photovoltaic material onto a substrate. There are several types of thin-film technologies:

-Cadmium Telluride (CdTe): CdTe cells are among the most cost-effective thin-film technologies. They have lower efficiency compared to crystalline silicon cells, typically ranging from 9% to 12%, but their lower production costs make them suitable for large-scale solar farms.

-Copper Indium Gallium Selenide (CIGS): CIGS cells are known for their high efficiency within the thin-film category, reaching up to 22%. They can be manufactured on flexible substrates, making them versatile for various applications, including building-integrated photovoltaics (BIPV).

-Amorphous Silicon (a-Si): This technology uses non-crystalline silicon and is often found in small-scale applications, such as calculators and small electronic devices. While its efficiency is lower (around 6% to 10%), it is lightweight and flexible, making it suitable for niche applications.

Emerging PV Technologies

Research is ongoing to develop innovative PV technologies that enhance efficiency and reduce costs. Notable advancements include:

-Perovskite Solar Cells: Perovskite materials have shown remarkable efficiency improvements, reaching over 25% in laboratory settings. Their potential for low-cost manufacturing and flexibility makes them a promising candidate for future solar applications.

-Bifacial Solar Panels: These panels can capture sunlight from both the front and back sides, increasing overall energy production. This technology is particularly effective in environments with reflective surfaces, such as snow or sand.

-Building-Integrated PhotoVoltaics (BIPV): BIPV integrates solar cells into building materials, such as windows and facades, allowing buildings to generate their own electricity without compromising aesthetics.

PV technologies are at the forefront of the renewable energy revolution, providing sustainable solutions to meet the growing global energy demand. As advancements continue in efficiency, cost-effectiveness, and integration, PV technologies will play a crucial role in shaping a cleaner and more sustainable energy future [33].

3.4 The Plan assumptions

The GECOL operating limits will be the main assumption for system master plan:

- The bus voltage should remain between the ranges (95% to 105 %) of the rated voltage at normal operation out of this range considered as a violation.
- For contingency operation condition the voltage will be within the range of (90% to 110%) of the rated voltage.
- Line loaded to (100%) capacity if more it will be considered over loaded.
- 20% over loading can be accepted for short period of time [2 hours -only].
- All loads are uniformly distributed among the area re-planned.
- Load density is constant among the area re-planned.

- GECOL standards are considered in this study.
- The annual demand growth for next twenty years.
- Exponential forecast is considered in the research that results a high growth, which is considered safe.

3.4.1 Methodology and Master plan for PV penetration method.

The PV penetration method is a systematic approach to integrating photovoltaic systems into existing electrical grids. This methodology enhances system resilience and efficiency, particularly under the guidelines of GECOL standards.

The process begins at step 6 of the conventional planning methodology, as outlined in the flowchart Figure (3.7).

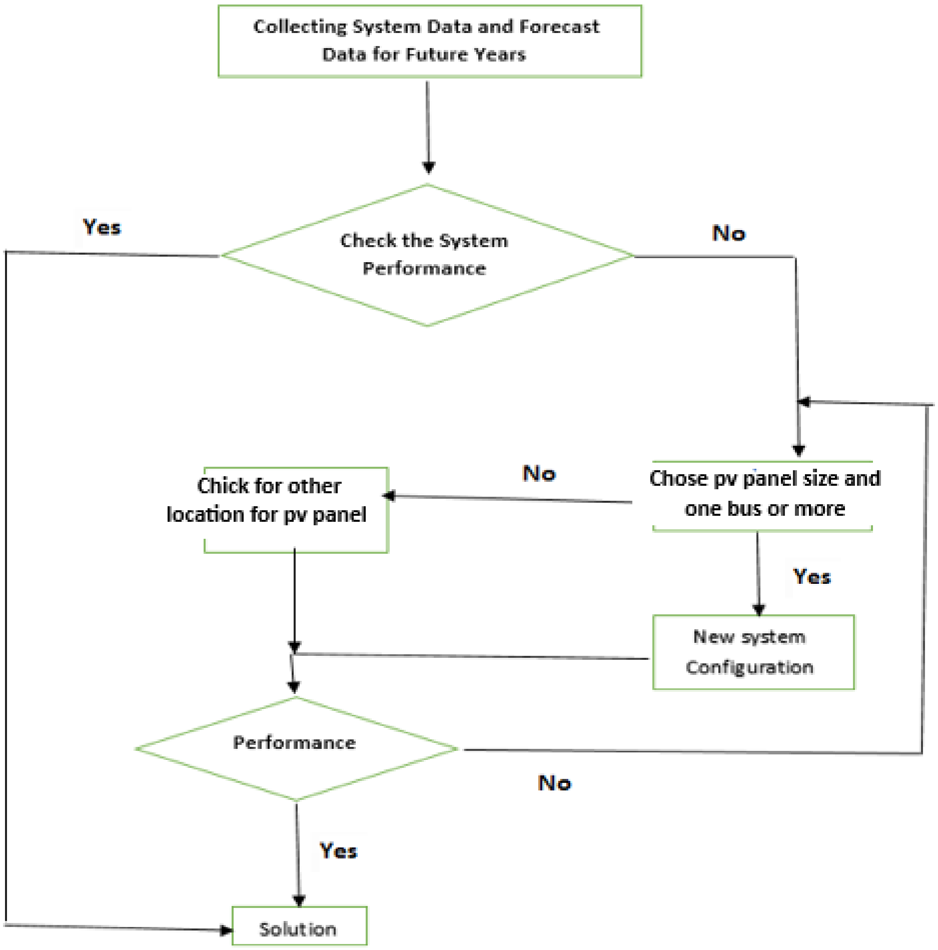


Figure (3.7) master plan using PV perforation

1. System Performance Evaluation

The first step involves assessing the current system performance using load flow software, specifically applying the Newton-Raphson method. This analytical approach allows for accurate modeling of voltage levels and power flows throughout the network.

2. Satisfaction of Standards

If the system performance meets GECOL standards, the current configuration is deemed satisfactory. If the performance is inadequate, further analysis is required.

3. Identifying Weaknesses

The next step involves diagnosing the system's weaknesses, particularly focusing on components experiencing voltage violations or overloads. Solutions may involve expanding existing system components to enhance capacity and stability.

4. Iterative Performance Checks

After implementing any adjustments, the system's performance is re-evaluated. If it meets the required standards, the solution is confirmed. If not, the analysis is repeated to identify further enhancements.

5. Expansion Limitations

If expanding existing components is not feasible, the methodology suggests adding new feeders or substations. This step includes selecting optimal locations and sizing them to accommodate anticipated system growth.

6. Forecasting Weakness

Evaluating future system performance is crucial. The methodology includes forecasting when weaknesses may arise based on projected load growth.

7. PV Integration

The next critical step is adding photovoltaic systems at identified buses where voltage violations occur. This strategic placement aims to mitigate issues effectively.

8. Optimization of PV Configurations

The methodology encourages experimenting with different PV locations and sizes to minimize power losses and enhance system performance.

9. Long-term Planning

The procedure is repeated to account for growth over the next five years, adjusting configurations as necessary.

10. Continuous Assessment

This iterative process continues for a twenty-year horizon, ensuring that the system adapts to load growth while maintaining reliability and efficiency.

This comprehensive methodology allows for proactive planning and effective integration of renewable energy sources into the grid.

CHAPTER FOUR

Optimization and redesign of the 30 KV Bir Al-Ghanam network and analysis of the results.

4.1 Introduction

The electricity network of Bir Al-Ghanam village serves as a crucial infrastructure component that significantly influences both the local economy and urban development. The establishment of a 30 kV electrical ring in the region has enhanced the reliability and efficiency of power supply, enabling the village to meet growing energy demands. This infrastructure not only supports existing residential and commercial activities but also lays the groundwork for future urban expansion.

The 30 kV ring provides a robust electricity distribution system that ensures stable voltage levels and reduces the likelihood of outages, which can severely hinder economic activities. With a reliable power supply, local businesses can operate more efficiently, and residents enjoy improved quality of life. Furthermore, this enhanced electrical infrastructure attracts potential investors and developers, fostering an environment conducive to urban growth.

As Bir Al-Ghanam continues to grow, integrating renewable energy sources into the electricity network becomes imperative. One of the most promising solutions is the incorporation of photovoltaic (PV) solar panels. The region's climatic conditions are favorable for solar energy production, making it an ideal candidate for PV integration. By installing PV panels, the village can harness solar energy, reducing reliance on conventional power sources and promoting sustainability.

The integration of PV systems into the existing 30 kV ring can be achieved through a strategic approach. First, an assessment of the current energy consumption patterns in the village is essential. This analysis helps in determining the optimal size and placement of PV installations to maximize energy output and minimize losses. Areas with higher energy demands, such as schools, clinics, and commercial centers, are prime candidates for PV integration.

Once the assessment is complete, the next step involves designing a connection strategy between the PV systems and the 30 kV ring. This includes ensuring that the infrastructure can handle the additional load from the PV installations without compromising the stability of the network. The integration process may require upgrading existing transformers and protective devices to accommodate the influx of renewable energy.

4.2 Bir alghanm (30kv) network case study.

As shown in Figure (4.1) the 30kv line diagram is shown with all system data and loading of year 2024.

The following assumptions are considered through this study:

- The system loads taken from GECOL are during august 2024 and considered as the yearly highest loads.

-The (30/11kv) transformers MVA rating are considered as the rated loads of (30kv) system.

-The buses voltage limits in normal operating condition are ranged between (95% to 105%).

-The loading limits of the lines are (100%) loading according the line ampacity (current carrying capacity).

-The load is uniformly distributed among Bir alghanm area which means that the load density MVA/km is uniformly among the area.

- If a contingency is up normal conditions is considered the voltage limits range will be (90% to 110%) and the load ability is (120%).

For the optimizing and re-planning the following procedure steps are considered:

- Study the circuit performance at rated loading condition by using load flow analysis program (ETAB).

- Considering annual load growth of 8% and using exponential load growth procedure to find how many years, this rated load will be reached.
- Considering the peak load of year 2024, that is the actual loads and run the program for performance analysis to check for system weakness.
- Consider the short-range period of five years and check the system performance considering the changes needed in the past annual analysis and make remedy needed.
- Consider also the longer period of ten year and twenty years planning and, repeat the same procedure, and find the new plan and design.
- In this step, all past steps will be repeated but considering the photovoltaic energy system, as the solution for the system deregulation by adding a certain size of PV to the buses suffering voltage violation and /or close to loaded feeders.
- According to GECOL the annual load growth is given to be (8%) annually.
- For safety optimizing and re-planning the exponential load growth is considered.

In all cases, total power losses are counted and compare the redesigned cases for analysis.

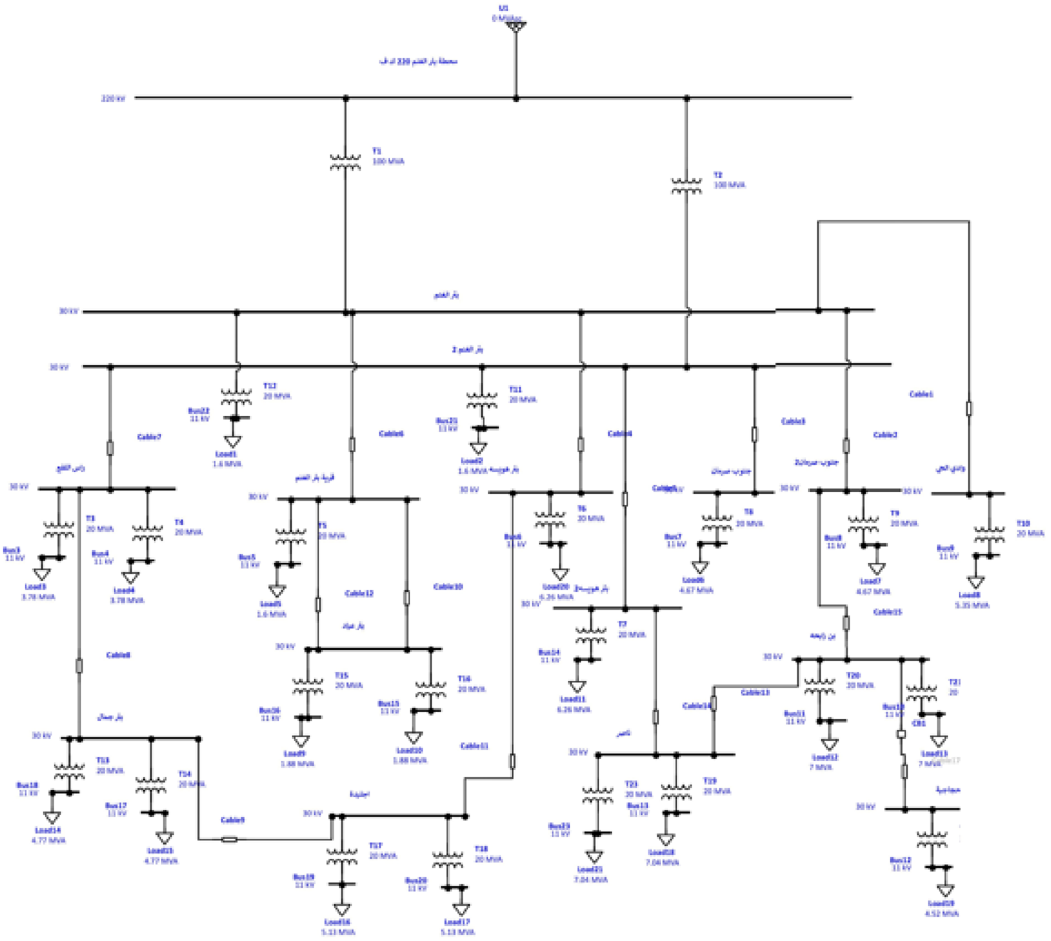


Figure (4.1) the current state of the ring network2024

4.3 Case studies on improving and redesigning the electrical network of Bir Al-Ghanam (30kv) circuit.

considering the rated loads

In this case, the analysis shows that the network suffering of feeders overloading, that should be considered for redesign.

This rated load will be reached according to annual load growth of 8% and using exponential load growth procedure after (n) years that can be calculated as follows.

$$Sn = So(1+g)^n \tag{4.1}$$

Assuming annual load growth $g = 0.08$

To find the number of years for the transformers to start reaching rated loading, consider the highest actual load on one of the buses at year 2024.

Use the exponential load growth given equation (4.1) to find the number of year **n** considered the actual present load of (2024) at bus number **9** in the network, fed by (30/11) transformer of 20 MVA rated, this is the highest load.

Use equation (4.1) to find number of year **n**

$\mathbf{20 = 10(1 + 0.08)^{n}}$,

Solving for **n** ⇒ **n**=9 years.

Then the rated loading will be reached after 9 years that means 2033 is the year for the circuit to start rated loading though it is buses.

To check for system weakness the year 2024 will checked.

4.3.1 Current Situation in 2024

In 2024, upon operating the electrical network, we identified significant voltage drops across several key lines. These include the Ras Al-Fa’a line, the Al-Qarya Bir Al-Ghanam line, the Bir Hoisa 1 line, the Jalda line, the Nasser line, the Ben Rabha line, as well as the main distribution buses for the 220 kV station (1 and 2).

The voltage drops observed in these lines raise serious concerns about the reliability and efficiency of the power supply. Such fluctuations can lead to operational disruptions, affecting various facilities and services dependent on stable electricity. Additionally, these voltage issues may cause long-term damage to electrical equipment and systems.

To address these challenges, a thorough investigation into the causes of the voltage drops is essential.

The following figure shows the current state of the ring network when running.

•Case i: Considering actual peak loads of 2024.

The current status of the Bir al-Ghanam ring network in operational condition. We see problems occurring in the network as shown in Figure (4.2).

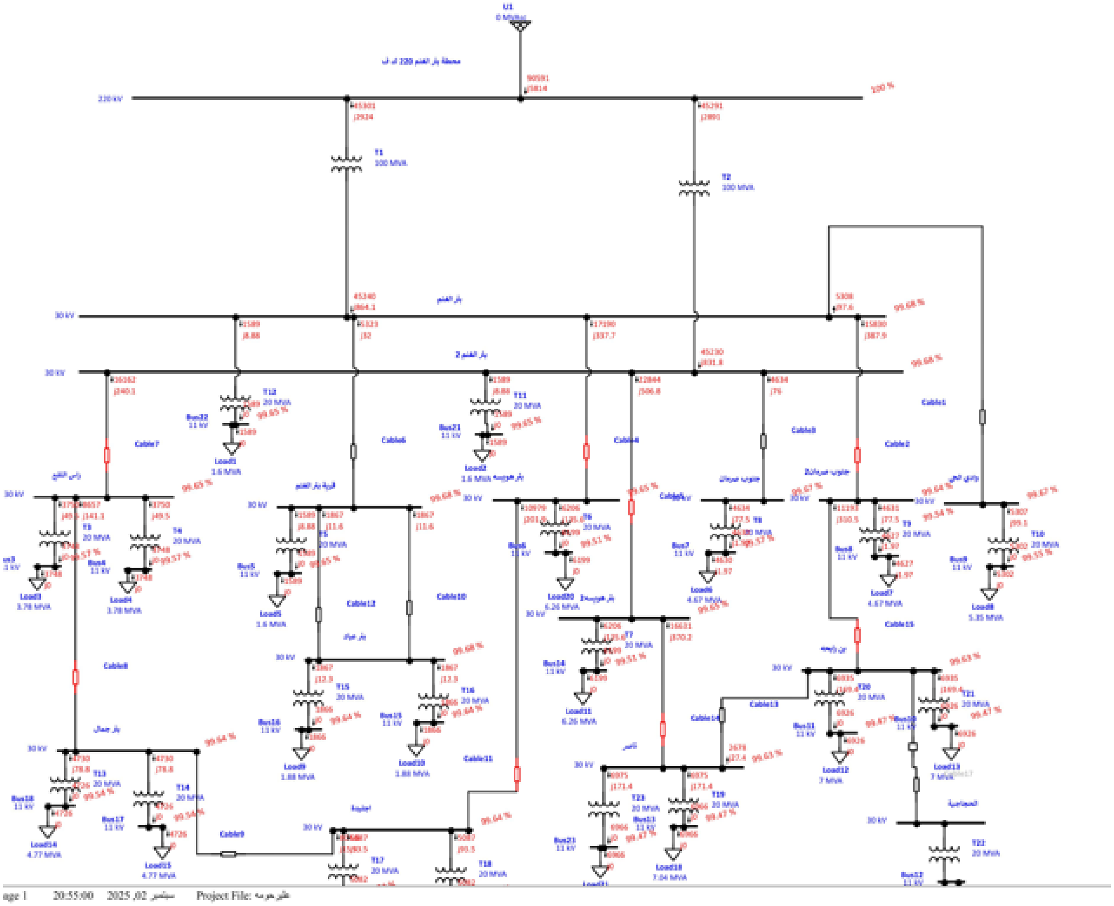


Figure (4.2) Current status of the Bir al-Ghanam ring network with problems occurring

The Problem in the network

1. Line Rasalafa
2. Line Bir gmal
3. Line Birhawisa1 &2
4.Line Aglda
5. Line Binrabha
6. Line South sorman 2
7. LineNaser

•Case ii: Consider the actual maximum loads for the year 2024 after the network improvement.

As observed in the diagram, the integration of photovoltaic panels effectively addresses various issues within the electrical network. By harnessing solar energy, these panels enhance system reliability and reduce voltage fluctuations, ensuring a stable power supply. The addition of PV systems mitigates overloads in critical areas, allowing for better distribution of electricity across the network. Furthermore, the use of renewable energy sources decreases dependence on conventional power grids, promoting sustainability. Overall, the implementation of photovoltaic panels not only resolves existing problems but also contributes to a more resilient and efficient energy infrastructure for the community as shown in the Figure (4.3).

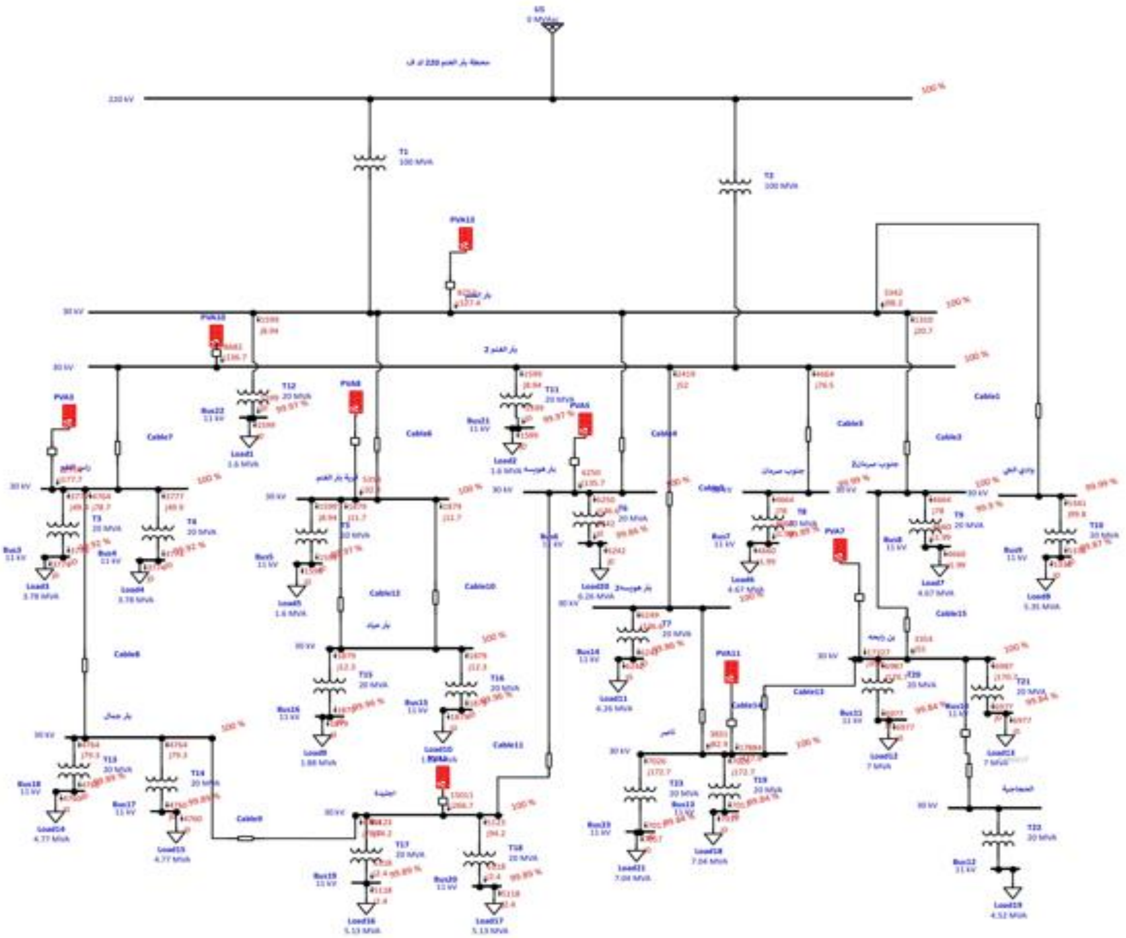


Figure (4.3) showing the network status after optimization for year 2024.

•Case iii five years load growth (the year (2029) is considered.

In 2029, we conducted a comprehensive study of the current electrical network, analyzing its performance over the past five years. This assessment was crucial due to the anticipated increase in load driven by population growth, which was calculated using the established proportional growth lawas shown in the Figure (4.4).

According to this law, the population growth rate is projected at 0.08%. By applying this percentage to the existing load data from our records, we observed a corresponding increase in the load across all lines. This growth necessitated a thorough reevaluation of our capacity and resources.

To effectively manage the new load demands, we incorporated these updated figures into our load management software, ETAP. This program allowed us to simulate the effects of the increased loads on the network, facilitating accurate forecasting and planning.

The findings indicated that the current infrastructure would require enhancements to accommodate the projected increases. By identifying potential bottlenecks and weaknesses, we can implement targeted upgrades to ensure the network remains stable and reliable.

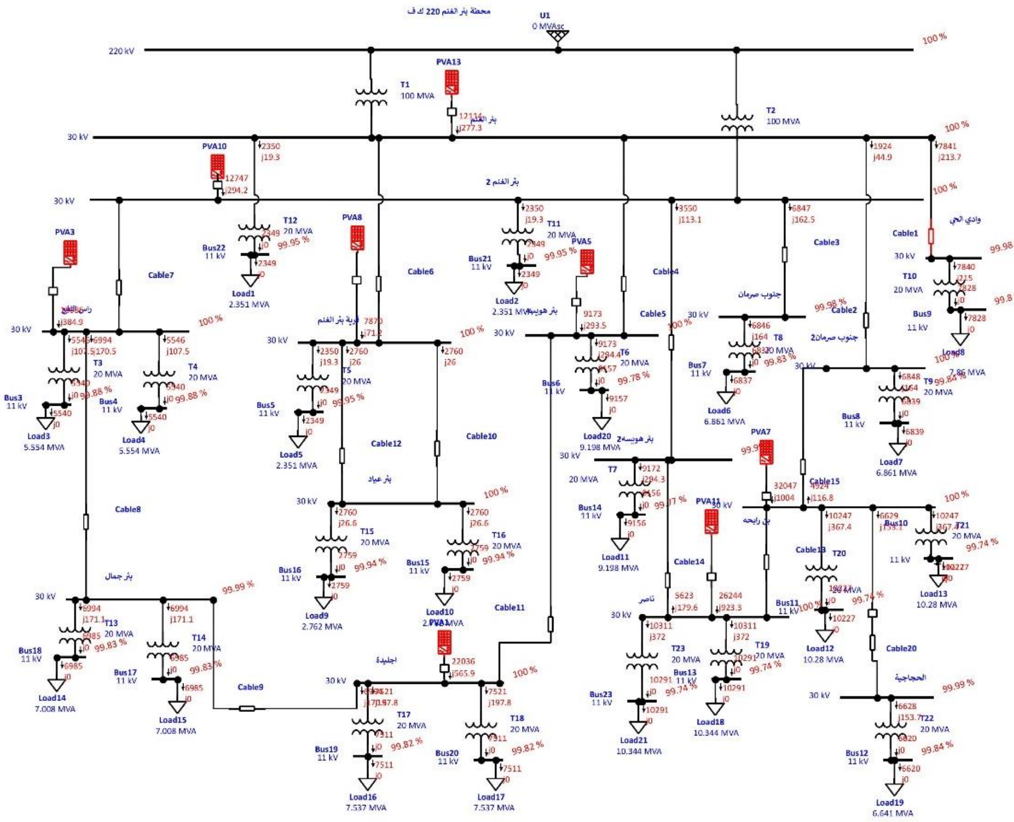


Figure (4.4) showing the network status before optimization in 2029

The Problem in the network

1. Line Wadialhi .

•Case iv: Consider the actual maximum loads for the year 2029 after the network improvement

After incorporating the new loads into our system, we ran the ETAP software on the network to assess its performance. Upon evaluating the network with these updated loads, we identified a single issue: a problem on the Wadi Al-Hay line. This was a critical finding, as it indicated that most of the network was performing well under the new conditions.

To address the issue on the Wadi Al-Hay line, we strategically installed solar panels on the existing substation associated with this line. This addition aimed to enhance the energy supply and improve voltage stability. Following the installation, we re-ran the network simulation using the same software.

The results were encouraging. The voltage levels on the Wadi Al-Hay line showed a significant improvement, with stability reaching 100%. This marked a drastic change from previous years, where voltage drops had been a persistent issue across various lines.

This successful adjustment not only resolved the existing problem but also highlighted the effectiveness of integrating renewable energy sources into our infrastructure. The study for 2029 concluded positively.

The results shown in Figure (4.5), no weakness are shown in the system performance.

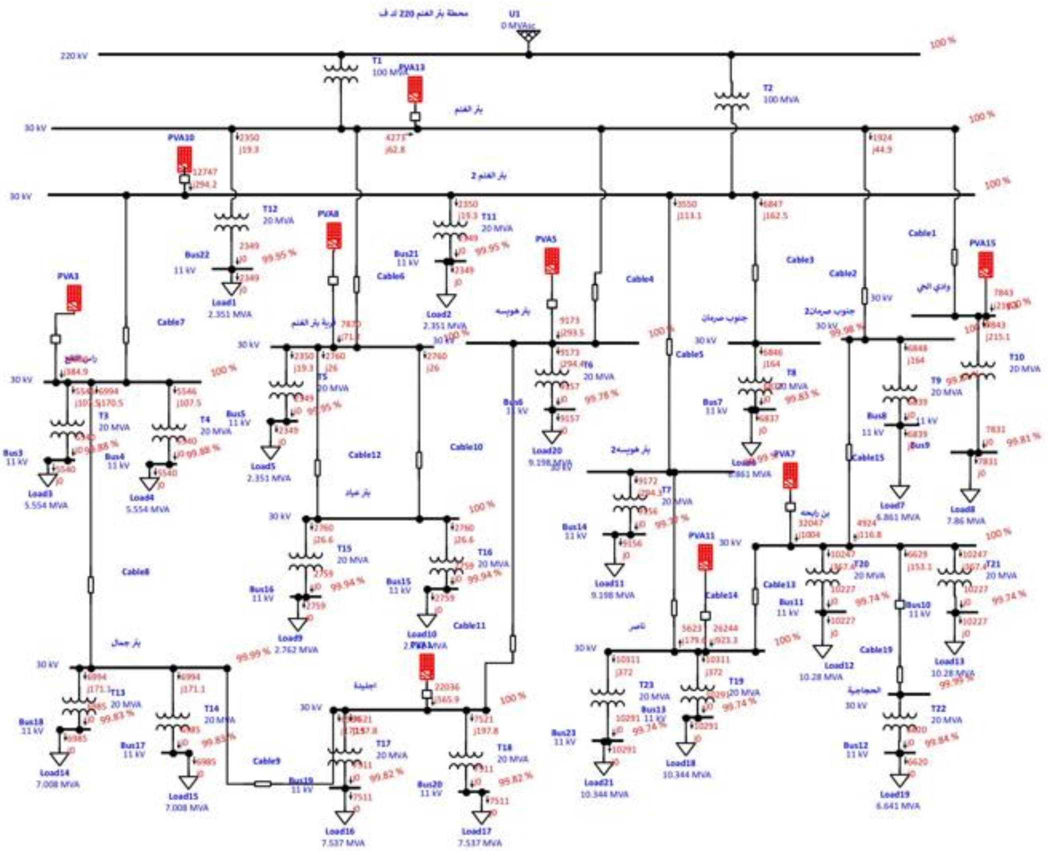


Figure (4.5) showing the network status after optimization in 2029

•Case v: Circuit performance after ten years (2034)

In 2034, we conducted another comprehensive study focused on load assessment, similar to our previous analysis in 2029. We applied the proportional growth law to the existing load data from 2029, taking into account the anticipated increases in demand.

After integrating the new loads for 2034 into our system, we ran the ETAP software to evaluate the network's performance. The results revealed several significant issues, primarily voltage drops affecting multiple lines, including South Sorman 1 and 2, Bir Hoisa 2, and Bir Jamal as shown in the Figure (4.6).

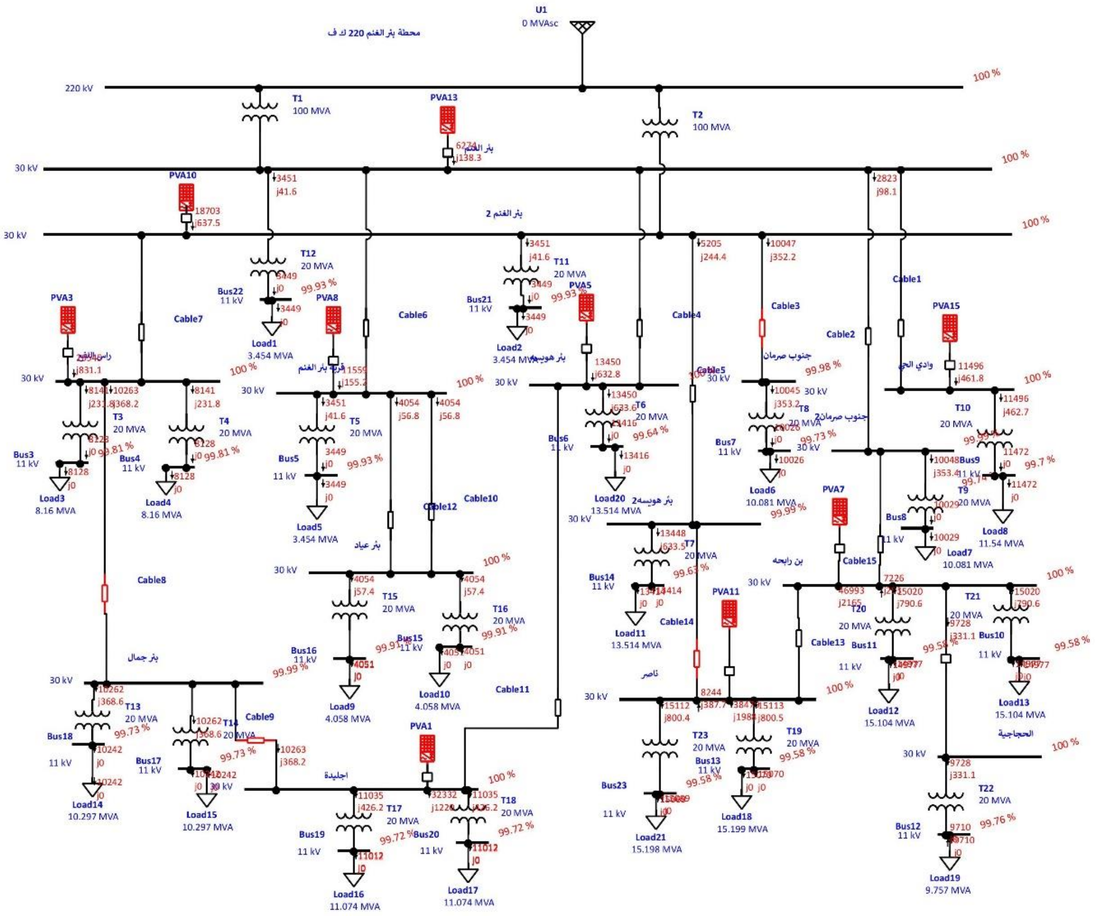


Figure (4.6) showing the network status before optimization in 2034

The Problem in the network

1. Line south sorman
2. Line Bir gmal
3. Line Naser
4.Line Aglda

•Case vi: Consider the actual maximum loads for the year 2034 after the network improvement.

The installation of solar panels is expected to provide supplemental energy, mitigating the voltage drops and ensuring a more reliable power supply. This proactive approach not only addresses the immediate concerns but also aligns with our commitment to integrating renewable energy sources into our grid shown in the Figure (4.7).

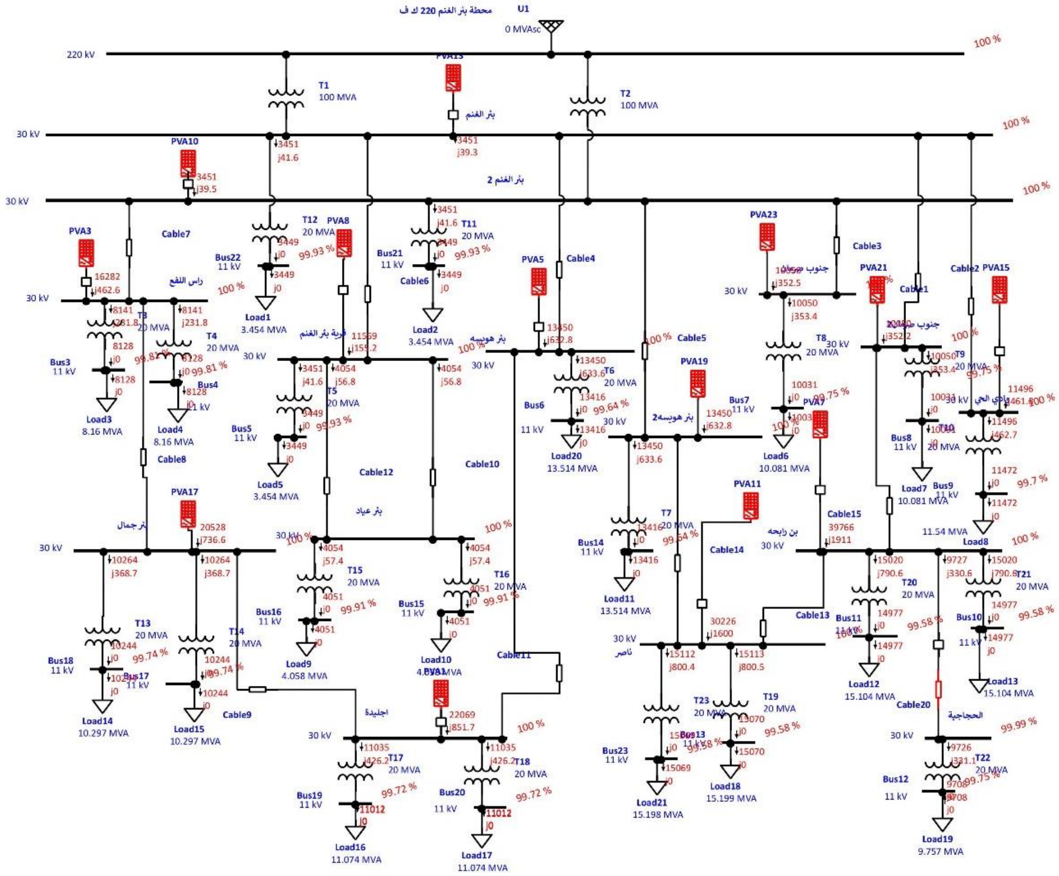


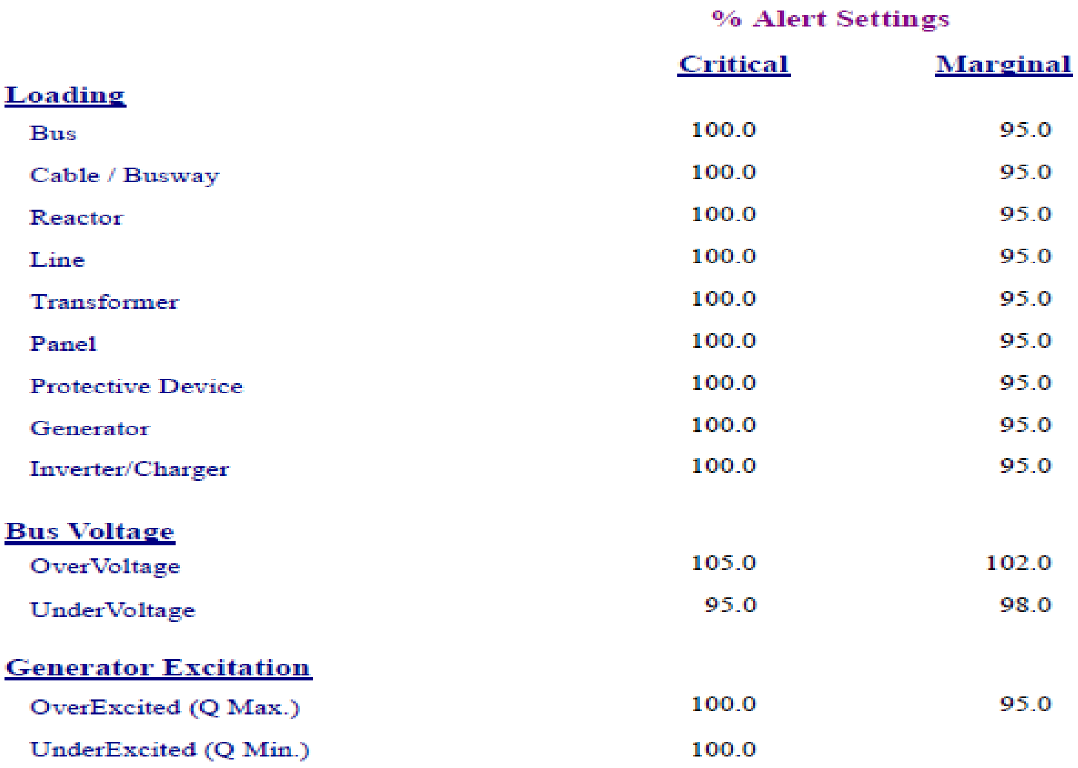
Figure (4.7) showing the network status after optimization in 2034

The successful addition of solar panels effectively resolved all previous voltage drop issues, ensuring a stable and reliable power supply across the network. This improvement not only enhanced the performance of the affected lines but also reinforced our commitment to integrating renewable energy solutions into our infrastructure.

This adjustment laid the groundwork for future load assessments. We conducted predictive studies for the network, projecting load demands over the next ten years, from 2024 to 2034. This forward-looking approach allows us to anticipate potential challenges and implement proactive measures to maintain stability and efficiency.

Here we notice in Table (4.1) data showing the loads, load data and their status on the network.

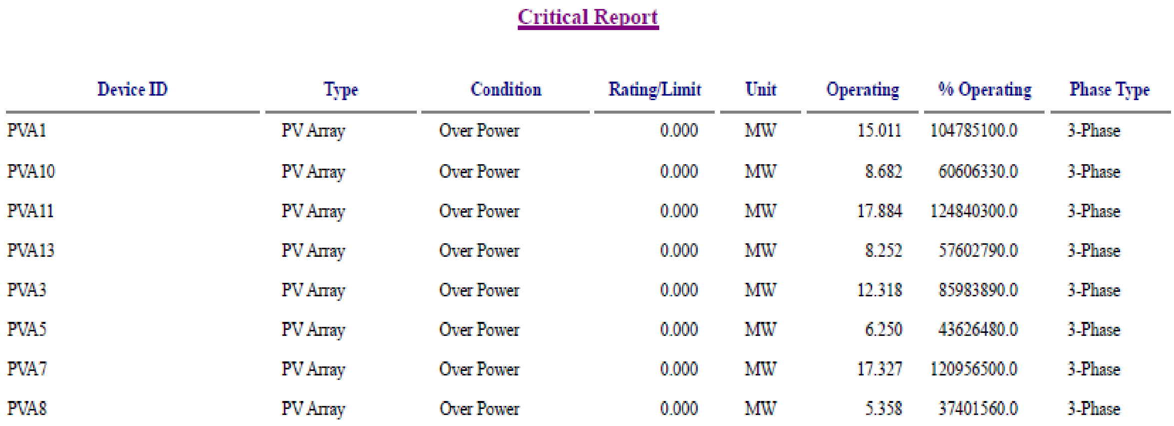
Table (4.1) load data



	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable / Busway	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

As we see in Table (4.2) the data here shows the loads, data on the photovoltaic panels, and their condition on the network.

Table (4.2) data on the photovoltaic panels



Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
PVA1	PV Array	Over Power	0.000	MW	15.011	104785100.0	3-Phase
PVA10	PV Array	Over Power	0.000	MW	8.682	60606330.0	3-Phase
PVA11	PV Array	Over Power	0.000	MW	17.884	124840300.0	3-Phase
PVA13	PV Array	Over Power	0.000	MW	8.252	57602790.0	3-Phase
PVA3	PV Array	Over Power	0.000	MW	12.318	85983890.0	3-Phase
PVA5	PV Array	Over Power	0.000	MW	6.250	43626480.0	3-Phase
PVA7	PV Array	Over Power	0.000	MW	17.327	120956500.0	3-Phase
PVA8	PV Array	Over Power	0.000	MW	5.358	37401560.0	3-Phase

4.4 Summary of results

In this case, the proposed optimization method is shown on the local electricity grid with the addition shows the following:

-The lines are suffering overloading as load increased through load forecast with growth rate of 8%.

-The integration of photovoltaic (PV) panels can significantly enhance network performance. By installing PV systems, the reliance on conventional power sources can be reduced, thereby alleviating some of the load on the network. This sustainable approach not only improves voltage stability but also contributes to energy independence.

-The system is reconfigured every five years by recon ducting and for doubling the system lines to handle the load growth.

This procedure will affect the commercial and industrial as well the social activity cost calculations.

4.5 Discussion of results

Using this system, load growth can be effectively managed by integrating photovoltaic (PV) modules into transmission lines experiencing voltage drops or overburdened power lines. This Raasch demonstrates that adding renewable energy generation units can offset the need for expanding system cables and distribution substations, providing a more efficient solution.

Using this grid-penetrating PV method offers several notable advantages:

-Voltage stability: PV modules help maintain voltage levels across the grid, reducing fluctuations and improving reliability.

-Reducing overloads: By distributing power generation closer to the point of consumption, the burden on existing infrastructure is reduced.

-Sustainability: Integrating renewable energy sources, such as solar, reduces reliance on fossil fuels, promoting a more environmentally friendly mix.

-Cost-effective: Adding photovoltaic systems can be more cost-effective than comprehensive upgrades to traditional infrastructure, saving time and resources.

4.6 Operations of Solar PV Systems

The most practical indicator of the performance of the solar PV systems can be obtained from the remote monitoring and data logging software supplied by most inverter manufacturers.

The data logging software will record daily, monthly, and annual output for comparison of the actual system performance against the expected system performance. See Figure (4.8) for typical performance monitoring displays.

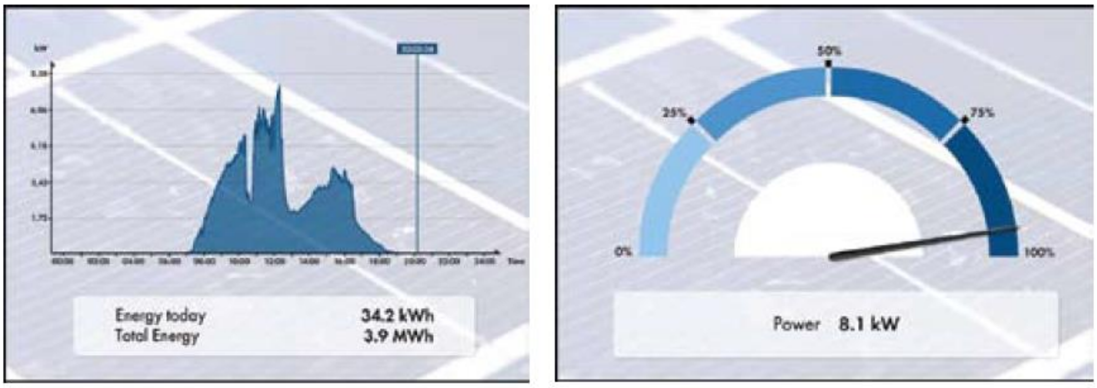


Figure (4.8) Examples of performance monitoring displays (Courtesy of Phoenix Solar)

Solar PV systems require minimal maintenance, as they do not usually have moving parts. However, routine maintenance is required to ensure the solar PV system will continue to perform properly.

It is a good practice for contractors of solar PV systems to provide an operation maintenance ("O&M") manual for the client.&

The manual should include basic system data, test and commissioning data, O&M data, and warranty information.

4.7 Designing grid-connected PV system

Now we can use all the things learned in this and the other chapters for actually designing a PV system. For designing the PV system we use the energy balance approach, meaning that we design the system such that the generated energy and the consumed energy during one year match. Of course, there are also other ways of designing systems for example based on economic arguments.

For the energy balance we first need to calculate the annual load. The energy yield at the DC side is given by

$$E_{DC}^{Y} = A_{tot} \int_{year} G_M(t)\eta(t)dt, \tag{4.2}$$

where **A_{tot}** is the total module area. It is related to the area of one module **A_M via**

$$A_{tot} = N_T . A_{M,} \tag{4.3}$$

where **N_T** is the number of modules. The energy balance now writes as

$$E_{DC}^{Y} = E_L^Y . SF, \tag{4.4}$$

where **SF** is a sizing factor that usually is assumed to be1.1. We therefore can calculate the required number of modules,

$$N_T = \left\lceil \frac{E_L^Y .SF}{A_M . \int_{year} G_M(t)\eta(t)dt,} \right\rceil \tag{4.5}$$

where [**x**] denotes the ceiling function, i.e. the lowest integer that is greater or equal than **x**.

Now it is important to decide how many modules are to be connected in series (**NS**) and in parallel (**NP**). Of course,

$$N_T = N_S . N_P \tag{4.6}$$

Such a PV array hence consists of P strings of S modules each. The **NT** determined in Eq. not necessarily needs to be an even number. For example, if

NT = 11, you might want to choose for **N**T = 12 panels,

because you can install them as **S** X **P**= 12 X 1, 6 X 2, 4 X 3, 3 X 4, 2 X 6 or 1 X 12 strings.

In principle, it is preferable to connect as many modules as possible in series since then the currents on the DC side and hence the cable losses stay low. Further, thinner cables can be chosen. However, many modern inverters can connect two or even more individual strings, which can be important if the installation contains two or more areas with different shading, for example on two different sides of a roof. Further, it can be chosen to connect different strings to different inverters as well, such that the system uses several string inverters.

NS and hence the voltage at the inverter is also restricted by the chosen inverter typ — or, if seen the other way round, the inverter has to be chosen such that its operating voltage fits well to the string voltage.

In a conservative assumption, the power on the DC side at STC now is given as:

$$\boldsymbol{P_{STC_{DC}}} = \boldsymbol{N_T} \times \boldsymbol{P_{MPP}} \tag{4.7}$$

The inverter must be chosen such that its maximal power $\boldsymbol{P_{inv_{DC,max}}}$ is above the maximal PV output, i.e.,

$$\boldsymbol{P_{inv_{DC,max}}} > \boldsymbol{P_{STC_{DC}}}$$

Further, the nominal DC power of the inverter should be approximately equal to the PV power:

$$P_{DC} \approx P_{PV}$$

Usually,

for $P_{DC} < 5\ kW_p$, single-phase inverters are used, while for

$P_{DC} > 5\ kW_p$,

three-phase inverters are advised.

It's challenging to provide exact figures for the cost of photovoltaic (PV) panels for a 30kV grid in Bair Al-Ghanem, Libya, due to variations based on location, system size, panel type, and market conditions.

4.8 General Cost Estimates (Commercial Solar in 2025)

- **Cost per Watt:** Commercial solar panel systems are averaging around \$2.00 per watt in the U.S. Other sources suggest a range of \$1.80 to \$2.60 per watt for commercial systems.
- More costly installations can range from \$1.83 to \$3.50 per watt before incentives.
- **30kW System Cost:** For an on-grid installation, a 30kW solar power system may cost anywhere from \$15,000 to \$18,000.
- **50kW System Cost:** A 50kW system might cost around \$60,000 or between \$125,000 and \$175,000.
- **200kW System Cost:** A 200kW solar rooftop system could range from \$360,000 to \$520,000.

Approximate Costs by Panel Type:

- **Monocrystalline Panels:** \$1.00 to \$1.50 per watt or \$0.30 to \$0.50 per watt.
- **Polycrystalline Panels:** \$0.90 to \$1.00 per watt or \$0.25 per watt.

Important Considerations:

- **Incentives:** Government incentives, such as the federal solar tax credit (ITC), can significantly reduce the net cost.
- **Installation Costs:** Installation can be a substantial portion of the total cost.
- **Soft Costs:** These include labor, permitting, and administrative overhead.
- **Maintenance:** Ongoing maintenance expenses should be factored in [29].

CHAPTER FIVE

Conclusion and Future network

5.1 Conclusion.

This research addresses the application of modern methods to improve the 30 kV power system in the Bir Al-Ghanim grid, and presents the results. It also addresses a new approach to power distribution for system optimization and redesign, along with the results. A comprehensive analysis and cost comparison are also conducted based on global markets and local electric utility companies, based on 2024 costs.

The research concludes the following:

1.The 30 kV power grid is a key component of the electricity grid and should be improved and redesigned to reduce energy loss and increase its flexibility.

2.The use of the photovoltaic (PV) penetration method shows better results and a significant reduction in energy loss, leading to cost savings. Additionally, it provides additional centralized power generation capacity, achieving significant cost savings compared to the traditional method.

3. The PV penetration technology is environmentally friendly, which is an additional advantage.

5.2 Recommendations for Future Work

The following recommendations were considered:

1.The General Electricity Company (GCOLE) should initiate programs for the re-planning and redesign of the Libyan electricity systems.

2.The General Electricity Company of Libya (GECOL) should consider a photovoltaic (PV) energy generation strategy, given that Libya has vast amounts of solar energy that should be harnessed, as these technologies are now available for implementation with significant benefits.

The following future work is proposed:

1. A comprehensive plan for the Libyan grid should be developed, taking into account other renewable energy technologies.
2. The Libyan grid can be re-planned and redesigned using neural networks and fuzzy logic, contributing to transforming the Libyan electricity network into a smart grid.

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