DESIGN OF GRID CONNECTED PHOTOVOLTAIC POWER PLANT FOR Al-AHLIYYA AMMAN UNIVERSITY IN JORDAN

AHMAD HELMI DAWOOD HAJ DAWOOD

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To my beloved parents, thank you.

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ABSTRACT

The Photovoltaic power plant is considered one of the most important renewable energy resources economically and environmentally. This project proposes the production and performance analysis for a GCPV power plant. The high irradiance and high tariff rate for the private sectors in Jordan are the main factors that encourage the usage of a renewable energy source to reduce the annual electricity bill. The tariff rate for Al-Ahliyya Amman University is 0.36 $/kWh and annual energy consumption is 4 GWh. The proposed power plant size is set to be 985 kWp on a 7,550 m^2 available area designed using three methods which are mathematical equations, PVsyst software and Helioscope. Different methods are used to identify the power plant annual production and performance considering orientation, arrangement and irradiance losses. The mathematical equations annual production is 1616.041 MWh, performance ratio of 80%, payback period of 1 year and 11 months and CO_2 emission of 24240.615 tCO_2. The PVsyst software method annual production is 1704.4 MWh, average performance ratio 83.4%, payback period of 2 years and CO_2 emission of 24628.6 tCO_2. Lastly the Helioscope software annual production is 1,343.4 MWh, performance ratio of 80.8% and payback period of 2 years and 5 months CO_2 emission of 19406.35 tCO_2. It's found that mathematical equations and PVsyst software obtained similar results of annual production and payback period comparing to the Helioscope due to the consideration of the location irradiance. For this study it's found that the PVsyst achieved the highest energy generation, annual electricity saving and CO_2 emission due to the consideration of orientation, irradiance changes, detailed losses factors and sizing.

ABSTRAK

Janakuasa fotovoltaik dianggap sebagai salah satu sumber tenaga boleh diperbaharui yang paling penting dari segi ekonomi dan alam sekitar. Projek ini mencadangkan analisis pengeluaran dan prestasi untuk janakuasa GCPV. Sinaran yang tinggi dan kadar tarif yang tinggi untuk sektor swasta di Jordan adalah faktor utama yang menggalakkan penggunaan sumber tenaga boleh diperbaharui untuk mengurangkan bil elektrik tahunan. Kadar tarif untuk Universiti Al-Ahliyya Amman ialah 0.36 $/kWj dan penggunaan tenaga tahunan ialah 4 GWj. Saiz janakuasa yang dicadangkan telah ditetapkan kepada 985 kWp pada kawasan tersedia seluas 7,550 m^2 yang direka menggunakan tiga kaedah iaitu persamaan matematik, perisian PVsyst dan Helioscope. Kaedah yang berbeza digunakan untuk mengenal pasti pengeluaran dan prestasi tahunan janakuasa dengan mengambil kira orientasi, susunan dan kehilangan sinaran. Persamaan matematik untuk pengeluaran tahunan ialah 1616.041 MWj, nisbah prestasi 80%, tempoh bayaran balik 1 tahun dan 11 bulan dan pelepasan CO_2 sebanyak 24240.615 tCO_2. Kaedah perisian PVsyst untuk pengeluaran tahunan ialah 1704.4 MWj, nisbah prestasi purata 83.4%, tempoh bayaran balik selama 2 tahun dan pelepasan CO_2 sebanyak 24628.6 tCO_2. Akhir sekali, perisian Helioscope untuk pengeluaran tahunan ialah 1,343.4 MWj, nisbah prestasi 80.8% dan tempoh bayaran balik 2 tahun dan 5 bulan pelepasan CO_2 sebanyak 19406.35 tCO_2. Hal ini didapati bahawa persamaan matematik dan perisian PVsyst memperoleh hasil pengeluaran tahunan dan tempoh bayaran balik yang serupa berbanding dengan Helioscope kerana pertimbangan sinaran lokasi. Kajian ini mendapati bahawa PVsyst mencapai penjanaan tenaga tertinggi, penjimatan elektrik tahunan dan pelepasan CO_2 disebabkan oleh pertimbangan orientasi, perubahan sinaran, faktor kehilangan terperinci dan saiz.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	–	Carbon dioxide
CIS	–	Copper indium selenide
CIGS	–	Indium gallium diesel
SiC	–	Silicon Carbide
a-Si	–	Amorphous silicon
a-Si, μc-Si	–	Small amorphous silicon
c-Si	–	Crystalline silicon
CdTe	–	Cadmium telluride
EPA	–	High temperatures
mono-Si	–	Monocrystalline solar cell
mc-Si	–	Polycrystalline solar cell
PV	–	Photovoltaic
SF_6	–	Sulfur hexafluoride
TFSC	–	Thin-film solar cell
AAU	–	Al-Ahliyya Amman University
m	–	Meter
W	–	Watt
Wp	–	Watt Peak
kW	–	Kilo Watt
MW	–	Mega Watt
GW	–	Giga Watt
kWh	–	Kilo Watt Hour
MWh	–	Mega Watt Hour
GWh	–	Giga Watt Hour
GHG	–	Green House Gas
GCPV	–	Grid Connected Photovoltaic
RES	–	Renewable Energy Source
BOS	–	Balance Of System
DC	–	Direct Current
AC	–	Alternate Current
AGM	–	Absorbed Glass Mat
EMC	–	Electro Magnetic Compatibility
LED	–	Light Emitting Diode
PSH	–	Peak Sun Hours
STC	–	Standard Test Condition
SC	–	Short-circuit
OC	–	Open-circuit

Min	–	Minimum
Max	–	Maximum
°C	–	Celsius
V	–	Voltage
I	–	Current
MPP	–	Maximum Power Point
MPPT	–	Maximum Power Point Tracker
$	–	United States Dollars
LID	–	Light Induced Degradation
tCO_2	–	Tons of Carbon Dioxide

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Energy plays a critical role in the evolution and modernization of various civilizations. It is one of the most essential requirements of the economic and social sectors, and it is widely regarded as the most crucial component in raising the public's standard of living. The relationship between energy and diverse industries is complementary, and it has a favorable impact on levels of development in all fields when high standards are met, and a negative impact when not.

In recent decades, there has been a lot of research and development on renewable energy sources, with a focus on hybrid systems. Renewable energy sources have the potential to provide cost-effective and long-term energy solutions. These systems are environmentally favorable for a variety of reasons, including rising global energy demand and the resulting pollution, significant increases in the pricing of petroleum supplies, and their fluctuating prices and quantities.

With the ongoing change in oil costs, renewable energy sources are becoming increasingly appealing. Solar has a lot of potential and direct conversion solar photovoltaic technology provides a lot of advantages, especially in remote areas. In this approach, the photovoltaic (PV) system is acknowledged as one of the most important alternative sources. PV energy generation is a particularly attractive power source for many applications since it is clean, infinitely available, and very reliable, especially in rural and remote areas of Mediterranean nations that receive a lot of solar radiation all year.

Solar photovoltaic energy is now being used in the production of electrical energy to meet the rapidly increasing demand for energy. Grid-connected photovoltaic (PV) systems with 6 kW PV modules may power a 120–180 m^2 residential structure. Large-scale PV power plants, on the other hand, present significant hurdles in terms of cost, reliability, and efficiency due to the use of a large number of components, necessitating a PV power plant design that is optimal [1].

Jordan is still one of the Middle East's most rapidly developing countries. Jordan, according to the Jordanian Department of Statistics, is still one of the Middle East's fastest developing countries. According to the Jordanian Department of Statistics, the current overall population of the country is roughly 9,864,336 people. Jordan has become one of the most energy-demanding countries in the area due to its rapid population growth and infrastructure demands. As a result of the high demand for energy, there is a higher amount of GHG emissions in comparison to the region's bordering countries. Jordan is now attempting to reduce GHG emissions by pursuing more cost-effective, reliable, environmentally friendly, and cost-effective energy sources. Jordan has the potential to become one of the world's finest renewable energy suppliers due to its location and environment [2].

The necessity of employing more renewable energy systems would have a significant influence on lowering Jordan's GHG emissions, given that electricity generation accounts for the majority of Jordan's GHG emissions. Jordan has an abundance of renewable energy resources. Jordan will be able to generate 100 percent of the country's electricity needs utilizing renewable energy resources in the future, saving the government $12 billion a year. Furthermore, by 2050, Jordan's wind and solar energy resources might provide up to 50 times more electricity than the country's predicted need. Jordan's overall GHG emissions by the end of 2015 accounted for 7% of the country's total energy generation. Figure 1.1 shows the contribution of renewable energy to the country's total energy mix, which is divided into three categories: wind energy, solar energy, and biomass, which account for 65 percent, 32 percent, and 3 percent, respectively, with 15 renewable energy power plants installed by the end of 2015, with a total installed capacity of 500 MW. Furthermore, by 2025, Jordan's government intends to increase renewable energy's contribution to 10% of overall energy mix, which will include the installation of 30-50 MW of biomass energy generation [2][3].

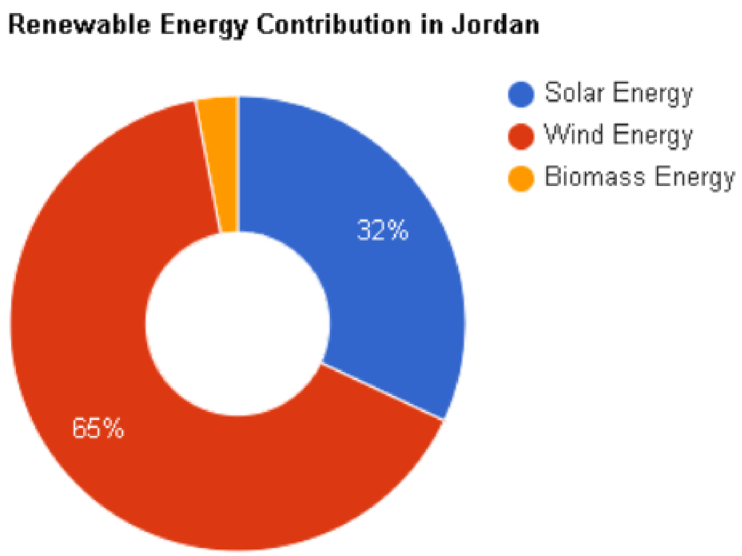

Figure 1.1: Jordan Renewable Energy Share in 2015 [2].

In this project, a grid-connected power plant will be designed for Al-Ahliyya Amman University using three designing methods which are Mathematical equations, PVsyst software and Helioscope. The outputs of the power plant from the three methods will measure the annual energy production of the proposed power plant, performance rate, annual savings, payback period and carbon dioxide emission. The findings are compared to the university energy consumption without renewable energy source. This will help reducing the annual electricity bill of the university and reduce the carbon dioxide emission.

1.2 Problem Statement

Al-Ahliyya Amman University (AAU) consists mainly of 7 Buildings, 5 Female Dormitories and the Cultural Foundation Forums (ARENA); The total annual electricity consumption is about 4 GWh with a high tariff rate for the private sector which is 0.36 $/kWh and the annual cost of energy of 1,400,000 USD. The main source of the university energy consumption is from the utility that uses non-renewable energy resources which leads to a high annual electricity bill and high carbon dioxide emission.

Every power plant designing method has it’s own limitations in terms of factors consideration such as radiance losses, orientation, arrangement and sizing therefore designing a grid-connected photovoltaic (GCPV) power plant for AAU using three different methods which are mathematical equations, PVsyst software and Helioscope, can help measure the annual energy productivity, power plant performance, economic and environmental analysis with the consideration of multiple factors.

1.3 Aim and Objectives

This research work embarks on the following objectives:

a) To design a GCPV power plant for Al-Ahliyya Amman University (AAU) using mathematical equation, PVsyst and Helioscope.

b) To perform economic and environmental analysis to the proposed GCPV power plant for the three methods.

c) To compare the results obtained from the three methods in term of annual power plant production, performance, economic and environmental analysis.

1.4 Scopes of Study

The scopes of the research are:

a) Analyze the University's energy demand and available space for the installation of the power plant.

b) Calculate the number of components required, sizing and arrangement using mathematical equations, PVsyst software and Helioscope.

c) Perform economic and environmental analysis to obtain the payback period of the project and CO_2 emission.

d) Compare the university annual electricity bill with the results obtained from the three different designing methods.

1.5 Outline of the Report

Chapter 2 covers the literature review that explained the important parameters for designing solar panels and shows the related work with this project.

Chapter 3 presents the methodology of the project that will explain all methods to complete the project using mathematical equations and software chosen. It includes a flow charts and its detailed explanation.

Chapter 4 presents the initial result of the proposed grid-connected power plant from available area, energy consumption, electricity bill and basic PVsyst input data.

Chapter 5 presents the initial conclusion of this project along with future work and recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter the importance of the solar energy is discussed and the relation to the title of the project. The PV power plant principle is explained in terms of energy production and the components required for the power plant. The different types of solar panel technologies and the general configurations of PV power plants. The solar renewable energy potential in Jordan and previous researches are explained as a reference for the study of the proposed GCPV power plant.

2.2 Solar Energy

When fossil fuels are integrated with renewable energy sources, a hybrid electrical system is created that can overcome the RES' constraints, such as intermittency and energy quantity. Such hybrid designs can provide a system that is more dependable, long-lasting, and environmentally friendly. Solar energy technologies are one of the RES technologies that have made substantial progress and maturity in terms of electricity generation. Solar PV technology, which transforms sunlight directly into electricity, is one of the most rapidly increasing renewable energy technologies in the world [4]. This is primarily due to intensive cost-cutting and incentive strategies. Solar PV module prices have recently plummeted by 80% and are expected to continue to fall. Over the last few years, solar PV technologies have advanced in efficiency while their production price have decreased. PV panels, in contrast to concentrated solar thermal technology, work under both direct and diffuse sun irradiation [5].

As demonstrated in Figure 2.1, the implementation of grid-connected PV has outpaced off-grid PV adoption for the past 15 years. The use of utility-scale grid-connected solar PV has demonstrated its benefits and gained popularity in locations where large areas are available and a sufficient amount of sun irradiation is obtainable. Solar PV is expected to be the primary source of annual renewable capacity increases over the next five years (2020-2025), surpassing wind and hydro [6].

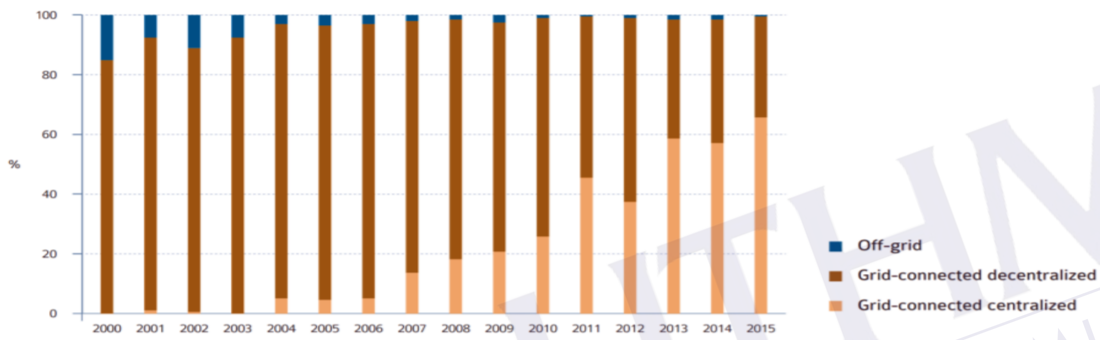

Figure 2.1: Worldwide Share of On and Off-grid Installations 2000-2015 [4].

2.3 Photovoltaic System Principle

The photovoltaic effect, which was discovered in the early nineteenth century when scientists noticed that some materials produced an electric current when exposed to light, is how a solar panel generates power. This effect is created by combining two layers of a semi-conducting substance. A depleted number of electrons must be present in one layer. The photons are absorbed by the layers of material when they are exposed to sunlight. This activates the electrons leading some of them to ‘jump' from one layer to the next, causing an electrical charge to be generated. Silicon, sliced into very thin wafers, is the semi-conducting material used to make solar cells. Several of these wafers are then contaminated by being ‘doped,' which causes an electron imbalance in the wafers. After that, the wafers are positioned to form a solar cell. The electrical current is carried by conductive metal strips attached to the cells. When a photon strikes a solar cell, it has multiple methods it can be consumed by the cell, reflected off the cell, or sent right through it. An electrical current is generated when a photon is absorbed by the silicon. The current created by the solar cell increases as the number of photons (i.e. the intensity of light) absorbed by the solar cell increases. The majority of the electricity produced by solar cells comes from direct sunlight. On cloudy days, they create electricity, and some systems may even generate limited amounts of electricity on clear moonlight nights. Individual solar cells typically produce only a few watts of electricity. These cells are linked together to create a solar module, also known as a solar panel or, to be more accurate, a photovoltaic module, to generate useful amounts of power [6].

2.4 Photovoltaic System Components

Because of the solar cell's small size, it can only supply a limited amount of power within constant current voltage settings, which are inconvenient for most purposes. A number of solar cells must be joined together to form a solar module, also known as a PV module, in order to use solar electricity for practical devices that require a specific voltage and/or current for operation. Solar panels are joined together to form a PV array for large-scale solar electricity generation. Although solar panels are the mains of a PV system, it requires several other components to function properly. as briefly discussed above. The balance of system (BOS) refers to all of these elements working together. Whether the system is connected to the energy grid or is intended as a stand-alone system determines which components are required. The BOS's most critical components are:

- **Mounting structure** to hold the modules in place and orient them towards the sun light.
- **Batteries,** because it ensures that the system can deliver electricity at night and during severe weather, it is an essential component of stand-alone systems. Batteries are commonly used to store energy.
- **Inverters** have been used in grid-connected systems to transform DC electricity generated by PV modules into AC electricity that may be supplied into the grid. Usually inverters contain a DC-DC converter that converts the PV array's changing voltage to a fixed voltage that serves as the input to the real DC-AC converter. An inverter may also be connected to the batteries in

stand-alone systems. In comparison to a grid-connected system, the architecture of such an inverter is rather different.

- **Charge controllers** are implemented in stand-alone systems to control battery charging and, in some cases, discharging. They keep the batteries from being overcharged as well as being discharged at night by the PV array. In order to make the PV voltage and current independent of the battery voltage and current, high-end charge controllers also include DC-DC converters and a maximum power point tracker.
- **Cables** are used to connect the PV system's separate components to one other and to the application to reduce contact resistance, it's essential to use cables that are thick enough.

The electric load, which includes all linked electric appliances, must be included during the planning process, even though it is not part of the PV system. It's also important to properly determine whether the loads are AC or DC. Figure 2.2 illustrates the various components of a PV system schematically [6].

Figure 2.2: Different Components of a PV System [6].

2.4.1 Batteries

Energy storage is considered essential in almost all off-grid applications. Usually this means storing solar-generated electricity in a battery, although pumped water storage

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