



Analysis of Solar Energy Efficiency and its Applications in Sustainable Electricity Production"

Rabeah Ali Ahmed Abuitayma

College of Engineering Technology – Janzur

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1- Abstract

Solar energy is witnessing a major expansion as it is considered one of the most important renewable energy sources that contribute to reducing carbon emissions and providing sustainable electricity solutions. This study aims to analyze the efficiency of solar energy systems and the factors affecting their performance, while presenting a comparison between different types of solar cells (see Table 1) and analytical figures illustrating the study results (see Figure 1). The paper summarizes a set of recommendations that contribute to raising the efficiency of electricity generation based on solar energy. It also relies on a scientific review of the latest technologies used to increase efficiency, such as high-performance cells and Maximum Power Point Tracking (MPPT) algorithms.

Keywords: Solar Energy, Efficiency, Photovoltaic (PV) cells, Sustainable Electricity, Renewable Energy.

2- Introduction

Environmental challenges associated with fossil fuels have necessitated the search for clean alternatives. Solar energy stands out as an ideal choice due to its wide availability and the possibility of converting it into electrical energy through effective methods. Several scientific studies have addressed the development of materials used to increase efficiency and reduce losses. Technical innovations have also contributed to improving solar tracking systems and limiting the power loss resulting from environmental conditions. This paper aims to analyze the efficiency of solar energy systems and identify the most prominent factors affecting them, in addition to reviewing their applications in sustainable electricity production based on the latest technologies used in this field.

3- Theoretical Framework and Previous Studies

The research focuses on three main pillars:

1. **Improving Materials in Solar Cell Manufacturing:** Sources indicate that silicon cell efficiency has evolved from 12-15% to exceeding 25% for monocrystalline cells, while multi-junction cells reached efficiencies exceeding 40% in some research models.
2. **Light Absorption Enhancement Techniques:** Several methods for surface treatment and reflection reduction have been developed to increase the amount of absorbed light, leading to a significant improvement in performance.
3. **Solar Tracking Systems and MPPT Algorithms:** Studies indicate that tracking systems can increase productivity by 15-30%, while the use of MPPT algorithms leads to improved utilization of radiation and achieving higher output power.

4- Research Methodology

The study adopts a theoretical analytical approach based on:

1. Analyzing the relationship between temperature and solar cell efficiency using a mathematical model (see Equations 1-2).
2. Conducting a comparison between fixed systems and solar tracking systems.
3. Preparing a comparative table for the most common types of solar cells (see Table 1).
4. Comparing performance results under different operating conditions.

5- Theoretical Framework

5.1 Solar Cell Efficiency

Solar cell efficiency is defined as the ratio of output electrical power to the incident solar power falling upon it:

$$\eta = P_{out}/P_{in} \longrightarrow (1)$$

$$P_{in} = G \times A \longrightarrow (2)$$

This efficiency reflects the system's effectiveness in utilizing available solar radiation.

5.2 Types of Solar Energy Systems

Solar energy systems used in electricity production are divided into:

- **Photovoltaic (PV) Systems:** Focus on the photovoltaic effect to convert radiation directly into electricity.
- **Concentrated Solar Power (CSP):** Rely on concentrating radiation to produce thermal energy, which is later converted into electricity.

6- Results and Analysis

6.1 Effect of Temperature on Efficiency

Results indicate an inverse relationship between temperature and solar cell efficiency, leading to a decrease in efficiency. Temperature negatively impacts photovoltaic cell efficiency because rising temperatures lead to a decrease in electrical voltage. This can be expressed by the following relationship:



Figure (1): The effect of temperature on solar cell efficiency. The graph shows a gradual decrease in efficiency as temperature rises

((e.g., efficiency drops from 100% at 25°C to 89% at 45° C).

6.2 Solar Radiation

Electricity production increases with increased solar radiation, but the relationship between them is not linear due to internal losses within the cells.

6.3 Comparison Between Solar Cell Types

Efficiency varies according to the type of cells, such as:

- Monocrystalline Silicon.
- Polycrystalline Silicon.
- Thin Film Cells.

Solar cell technologies vary in terms of efficiency, cost, and operational lifespan, as shown in Table (1): Comparison between types of solar cells.

Relative Cost	Average Efficiency (%)	Cell Type
High	25-20	Monocrystalline Silicon
Medium	20-15	Polycrystalline Silicon
Medium	24-22	PERC Cells
Low	28-18	Perovskite Cells
Very High	45-35	Multi-Junction Cells

6.4 Annual Performance Analysis

Table (2) shows the variation in a photovoltaic system's efficiency for a model over the months of the year.

Table (2): Monthly Performance Data

Efficiency Level	Produced Energy (kWh)	Temperature (°C)	Radiation (W/m²)	Month
19.3	480	12	420	January
17.6	670	21	610	April
15.3	880	29	720	July
16.8	610	30	560	October

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7- Discussion of Results

Results indicate that the best system performance is achieved at high radiation levels combined with moderate temperatures, while rising temperatures lead to decreased efficiency despite increased radiation.

8- Practical Applications for Sustainable Electricity Production

8.1 Residential Applications

Small solar systems are used to cover residential loads, reducing reliance on traditional grids.

8.2 Industrial Applications and Power Plants

Large-scale systems are used in power plants to feed national electrical grids, with the possibility of integration with storage systems.

9- Conclusion

The study proves that solar system efficiency primarily depends on temperature, cell type, and tracking systems. Single and dual-axis tracking systems significantly increase production compared to fixed systems. The paper recommends the necessity of cooling solutions and material improvements in cell manufacturing, while increasing reliance on MPPT technologies to enhance performance. Improving engineering design and selecting appropriate cells for thermal conditions can raise efficiency and enhance the role of solar energy in the future energy mix.

10- Recommendations

- Improve ventilation and cooling for cells in hot regions.
- Adopt accurate site-specific studies before installing systems.
- Support research related to high-efficiency cell technologies.

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