Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/85/20240710

Efficiency improvement and application prospects of solar photovoltaic power generation

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Abstract. The background of efficiency improvement and application prospects of solar PV power generation reflects a dynamic and evolving landscape. As technology continues to advance and as society places greater emphasis on sustainability and clean energy, solar PV is expected to play an increasingly significant role in meeting the world's energy needs while mitigating the environmental impact of energy production. This paper is mainly about how to improve the efficiency of solar photovoltaic power generation and the application of solar power generation. We put together an article mainly by looking up technology and summarizing other people's opinions. Among them, we have studied the principle of solar power supply systems in the first part. The author analyzed how to choose monocrystalline silicon and polysilicon and how they can improve the efficiency and the use of HJT batteries and PERC solar cells. Both HJT and PERC applications can greatly improve efficiency

Keywords: Solar, Photovoltaic Power Generation, monocrystalline silicon, polysilicon

1. Introduction

With the continuous development of science and technology, the demand for energy after human beings entered the 20th century also continued to grow. At that time, people also became more and more aware of the importance of protecting the environment. Due to the depletion of fossil fuels, the environment is broken. As a kind of typical generating new energy way, solar power has sustainable development and green environmental protection two advantages

If the bad house causes the greenhouse effect, global warming, and the decline of agriculture, forestry and fishery resources, if it deteriorates further, human beings will be killed. You will receive a warning from nature, and the consequences will be unimaginable. At present, the main energy source in the world's energy mix is still chemistry. Fossil energy includes oil, coal, and natural gas, as well as renewable energy, nuclear energy, hydropower, and other renewable energy sources. It's a tiny fraction. Traditional fossil energy is non-renewable, and the development of renewable energy worldwide is. The only way to solve the energy crisis.

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2. Application of Solar Photovoltaic Power Generation

2.1. PV Generation System

Photovoltaic power generation can be classified according to the way of power supply, solar energy collection and building application, among which grid-connected photovoltaic power generation system is the main application of the current photovoltaic power generation system, with the depletion of fossil energy, in order to achieve sustainable development goals, grid-connected photovoltaic power generation system technology is increasingly perfect. Figure 1 shows a basic grid-connected photovoltaic power generation system. In photovoltaic systems, photovoltaic panels generate direct current by absorbing sunlight, and light intensity, temperature and voltage are essential factors affecting the size of this current (photovoltaic panels have three kinds of arrangement modules 1). Single 2. Series 3. Parallel). The direct current is converted into alternating current in the PV inverter and then connected to the grid, which is the basic grid-connected photovoltaic generation system process. The filter, monitor, and LF transformers in Fig. 1 are used for synchronization, measurement, and islanding detection, respectively.

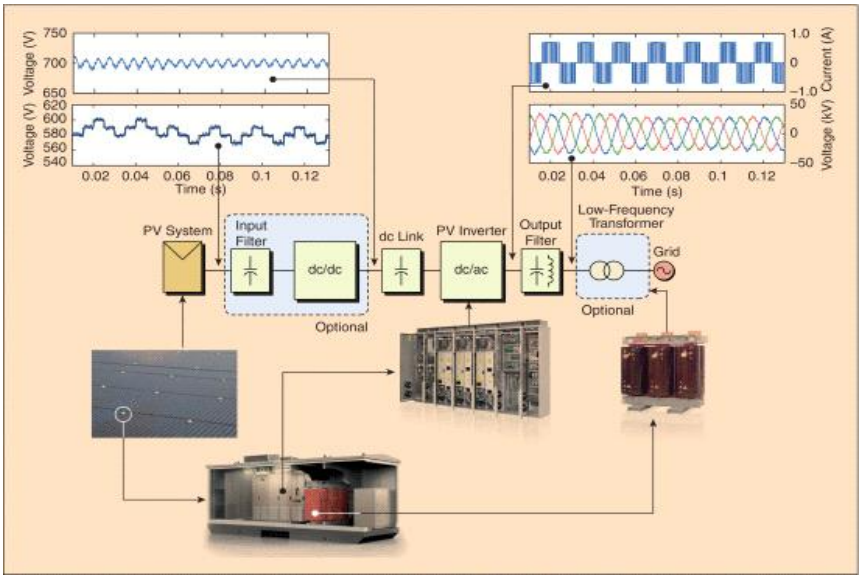

Figure 1. Generic structure of a grid-connected PV system. Source: https://doi.org/10.1109/mie.2014.2376976

2.2. Research

Distributed photovoltaic power generation is a current type of power generation and comprehensive utilization of energy with broad development prospects, advocating four nearby principles (power generation, grid connection, conversion, use), with little pollution, reduce power loss and to a certain extent to alleviate the local power shortage of technical advantages.

Recently, plenty of research into distributed photovoltaic applications to generate electricity with low environmental impact. Pedro et al. has carried out a feasibility study on the widespread use of distributed photovoltaic power in residential buildings in Mexico to support future system design [1]. Abraham et al. has studied the technical economics of a hybrid photovoltaic grid in a village in Nigeria, and it is suitable for areas with insufficient energy industry [2].

Simulation analysis can be used for further system analysis. Vinay and Shishir have proposed an innovative coordinated multi-stage voltage control (CMSVC) for solving the problem of voltage control and reduction of energy loss caused by the gap of distributed generation, which contribute greatly to the optimization and control of the power system. And an improved whale optimization algorithm has been developed [3]. Vinod et al. have developed a novel reconfiguration technique based on recursive addition

DOI: 10.54254/2755-2721/85/20240710

method to immune PSCs (Partial Shading Conditions) problems. Through simulation and experiments, it is found that whether it is a small array (5x5) or a large array(9x9), the more like parameters have been greatly improved [4].

The important findings of these works [1-4] are summarized as:

Replacing the existing electricity consumption subsidies with DPV subsidies will have a positive impact on the popularization of DPV systems and homeowners in both the short and medium term.

The methodology used in the article can be used to evaluate hybrid grid PV systems in villages with inadequate electricity supply.

The CMSVC technology proposed in this paper has greater energy saving potential than the traditional VVC technology, and is the best solution for voltage control and loss minimization.

The reconstruction method based on recursive addition presented in this paper has advantages in theory and practice, but it is not suitable for arrays with unequal numbers of rows and columns.

2.3. Hybrid Solar Power System

Simply replacing fossil fuels with renewable energy sources is not a complete solution to the energy problem, and mixing multiple energy types is an effective solution, which is called a hybrid energy system. Combining photovoltaics with other energy sources is the most common and popular way, such as wind energy, thermal energy, biomass energy, and the following are some recent relevant studies.

2.4. Research

Alphonce et al. [5] have carried out the simulation study for off-gird power supply of hybrid solar-wind-battery-flywheel system in remote areas Makueni County. A multi-objective optimization modeling method was used to obtain the optimal HERS size under local load conditions. In Ref [6] a methodology for the optimal system configuration among PV, biomass, diesel and battery presented is presented by Pankaj et al. They used HOMER analysis to find the hybrid system configuration with the highest yield and the most reliable. Liang et al. [7] have developed and evaluated for Geothermal-solar hybrid power with the double-pressure evaporation arrangement. The have introduce a noval type of hybrid system can improve the annual energy efficiency of the system. Decheng et al. [8] have investigated a PV/T air collector and wind turbine for hybrid drying system. They using carrot as material, the drying efficiency of the mixing system is higher than that of conventional PV/T. Binbin et al. [9] have designed a hybrid system with nuclear power, concentrated solar, and thermal storage using EBSILON. The performance tests were carried out in both design and off-design conditions.

The important findings of these works [5-9] are summarized as:

Hybrid power generation systems (solar and wind) combined with hybrid energy storage systems (hybrid energy storage) can be a highly reliable power supply system in areas with low energy penetration

A self-sufficient renewable hybrid power supply system in remote rural communities is feasible, could solve part of the employment problem, and further eliminate the energy crisis in the East Indies to advance the renewable energy target.

A proper mix of geothermal and photovoltaic systems can improve the overall thermodynamic performance of the system, and in off-design operation, the system cost reduction rate is much less than that of an independent solar power plant.

A new hybrid drying system driven by PV/T air collectors and wind turbines can solve the problem of insufficient solar drying systems and provide all-day supply.

The coupling of the energy storage system can not only reduce the volatility of solar energy, but also make the adjustment of the hybrid system more flexible.

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3. How to Maximize the Efficiency of Solar Cells

3.1. Effects of Radiation Amounts

In general, the amount of solar radiation reaching the ground is mainly affected by factors such as the sun altitude angle, geography, latitude, atmospheric transparency, sunshine hours, and altitude.

3.2. Altitude Angle and Geographical Latitude

The solar altitude angle and the inclination azimuth of the solar photovoltaic array to solar radiation collection, the sun, the greater the altitude angle, the greater the radiation intensity, the change of the solar altitude angle in various places has a relationship with the latitude, the higher the latitude, the smaller the solar altitude angle.

When the solar altitude angle is 90 degrees, the amount of solar radiation is the largest, because the cosine value at this time is 1, so his sunlight receiving area is the largest, and the efficiency of solar photovoltaic power generation is the highest.

3.3. Atmospheric Transparency and Altitude

Atmospheric transparency is a parameter that characterizes the degree of transmission of sunlight by the atmosphere, in clear and cloudless weather, the atmosphere is transparent, the amount of solar radiation reaching the ground is more, the higher the altitude, the thinner the air, the less solar radiation is absorbed, less scattered, and the content of water vapor and dust in the atmosphere is also less, the atmospheric transparency is large, so the altitude is high, the solar radiation energy is also large.

4. Technology

4.1. Monocrystalline

Monocrystalline materials are commonly used in high-performance applications, such as electronic devices and turbine blades, where uniformity and strength are crucial. Czochralski Process: In this method, a seed crystal is dipped into a molten material (usually the substance of interest) and slowly pulled out while rotating. As the seed crystal is pulled up, it collects material from the molten bath and forms a single crystal as it solidifies.

4.2. Polycrystalline

Many polycrystalline materials are initially produced by melting the raw materials and then allowing them to solidify. As the molten material cools and solidifies, it forms grains with various orientations. Or the material is smashed into powders and compacted into a specific shape using pressure. The compacted powder is then heated, which causes the individual powder particles to fuse and form a polycrystalline structure. Polycrystalline materials are generally easier and more cost-effective to produce than monocrystalline materials.

4.3. Difference

(1) A monocrystalline material consists of a single, continuous crystal structure without any grain boundaries.

A polycrystalline material consists of multiple small crystalline structures called grains, each with its own orientation.

(2) All atoms or molecules in a monocrystalline material are aligned in a regular and repeating pattern, resulting in a uniform and consistent structure.

The grains in polycrystalline are separated by grain boundaries, which are regions where the crystal orientations change abruptly. These boundaries can affect the material's mechanical, thermal, and electrical properties [10].

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4.4. P-N Junction

A P-N junction is a boundary or interface between a region of semiconductor material that has been doped with "P-type" impurities (positive charge carriers) and a region that has been doped with "N-type" impurities (negative charge carriers). This type of junction is a fundamental component in semiconductor devices, particularly in diodes and transistors.

To create the P-type region, a small amount of a trivalent element (such as boron) is added to a silicon crystal, which results in the creation of positively charged holes as majority carriers. To form the N-type region, a small amount of a pentavalent element (such as phosphorus) is introduced, leading to the presence of extra electrons as majority carriers.

4.5. PERC

PERC stands for Passivated Emitter and Rear Cell (or Passivated Emitter Rear Contact), and it is a type of solar cell technology that improves the efficiency of photovoltaic cells.

Characteristics:

(1) In a PERC solar cell, the rear surface of the cell is passivated to reduce recombination of charge carriers (electrons and holes) that occurs at the rear surface. This passivation involves applying a thin dielectric layer or other coatings to the rear surface to minimize losses due to recombination. So that PERC cells can capture more of the generated charge carriers, leading to higher efficiency.

(2) The rear surface of the cell is designed to have a conductive contact that collects the charge carriers efficiently. This design allows for a more uniform distribution of the electric field within the cell and reduces shading effects from the front-side contacts, contributing to improved overall efficiency.

(3) By enhancing charge carrier collection and reducing recombination losses, PERC cells tend to exhibit higher voltage output and overall efficiency compared to conventional cells.

4.6. TOPCon.

TOPCon short for Tunnel Oxide Passivated Contact, is an advanced solar cell technology that aims to enhance the efficiency and performance of photovoltaic cells. Similar to PERC (Passivated Emitter and Rear Cell) technology, TOPCon focuses on reducing recombination losses and improving charge carrier collection, leading to higher efficiency solar cells [11,12].

Characteristics:

(1) In a TOPCon solar cell, a thin tunnel oxide layer is deposited on the surface of the silicon wafer. This tunnel oxide layer acts as a passivation layer, reducing the recombination of charge carriers at the surface. It allows electrons and holes to pass through while minimizing losses due to recombination. The thin tunnel oxide layer and possible textured surfaces help reduce the reflectivity of incident light, allowing more light to be absorbed by the cell.

(2) The rear surface of a TOPCon cell features a conductive contact that collects the charge carriers generated by sunlight. This design ensures efficient charge carrier collection and helps maintain a uniform electric field within the cell.

(3) In addition to the rear-side passivation, TOPCon technology also involves passivating the front surface of the solar cell. This enhances the overall efficiency by minimizing recombination losses at both the front and rear surfaces.

4.7. HJT

HJT stands for Heterojunction Technology, which is an advanced solar cell technology designed to improve the efficiency and performance of photovoltaic cells. HJT solar cells are known for their high efficiency, low temperature coefficient, and potential for achieving high open-circuit voltages (Voc) [12].

Characteristic:

(1) HJT cells are often designed to be bifacial, meaning they can absorb sunlight from both the front and back sides. This is achieved by having transparent conductive layers on both sides of the cell, allowing reflected and diffuse sunlight to contribute to the cell's energy generation.

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(2) HJT cells incorporate heterojunctions at the interfaces between different layers of the cell. These heterojunctions involve the joining of different materials, such as amorphous silicon (a-Si) and crystalline silicon (c-Si), which can minimize recombination losses and improve charge carrier collection.

(3) HJT cells use passivation layers to reduce recombination losses at the cell's surfaces. Tese layers prevent charge carriers from recombining before they can be collected and contribute to the cell's overall efficiency.

(4) HJT cells typically have a lower temperature coefficient compared to traditional crystalline silicon cells, making them perform more consistently in varying temperature conditions.

(5) HJT cells are known for their ability to achieve high open-circuit voltage, which is an important factor in determining the efficiency of a solar cell.

5. Conclusion

At present, the development of solar cells based on new principles, new materials and new structures is the main idea to improve efficiency and reduce costs. National adaptation. When the introduction of solar photovoltaic products support policy, increase investment. The research and development of products such as solar cars and solar home appliances as an advantage. The first direction makes the range of solar energy use wider, greater intensity and depth Deeper.

In conclusion, there are two types of material of PV battery. Monocrystalline is a material composed of a continuous crystal structure and has a high degree of crystallinity and uniformity due to the existence of no grain boundaries, single crystal has excellent physical properties and performance. Polycrystalline refers to a material composed of many small crystals or grains and different from single crystal.

Firstly, PERC is passivated Emitter and Rear Cell a solar cell technology that improves the efficiency of photovoltaic cells. Efficient collection of charge carriers while reducing the shadow effect of anterior surface contact contributes to the overall efficiency. Secondly, TOPCon, For Tunnel Oxide Passivated Contact, is an advanced solar cell technology designed to improve the efficiency and performance of photovoltaic cells. Similar to PERC technology, TOPCon technology focuses on reducing compound loss and improving the collection of charge carriers, thus improving the efficiency of solar cells. Thirdly, HJT is short for Heterojunction Technology and aims to improve the efficiency and performance of photovoltaic cells. HJT solar cells are known for their high efficiency, low temperature coefficient, and high open circuit voltage.

To sum up, the biggest issue facing mankind in the 21st century is sustainability. Sustainable development issues and green energy, the full and rational use of existing energy. At the same time, the development of new energy has been attached great importance by governments. Solar power generation is an inexhaustible clean and environmental protection energy. The source will get unprecedented development.

References

[1] Hancevic, P., Nuñez, H. M., & Rosellón, J. (2017). Distributed photovoltaic power generation: Possibilities, benefits, and challenges for a widespread application in the Mexican residential sector. *Energy Policy*, *110*, 478–489. https://doi.org/10.1016/j.enpol.2017.08.046

[2] Amole, A. O., Oladipo, S., Olabode, O. E., Makinde, K. A., & Gbadega, P. (2023). Analysis of grid/solar photovoltaic power generation for improved village energy supply: A case of Ikose in Oyo State Nigeria. *Renewable Energy Focus*, *44*, 186–211. https://doi.org/10.1016/j.ref.2023.01.002

[3] Tatikayala, V. K., & Dixit, S. (2023). Multi-stage voltage control in high photovoltaic based distributed generation penetrated distribution system considering smart inverter reactive power capability. *Ain Shams Engineering Journal*, 102265. https://doi.org/10.1016/j.asej.2023.102265

[4] Mulumba, A. N., & Farzaneh, H. (2023). Techno-economic analysis and dynamic power simulation of a hybrid solar-wind-battery-flywheel system for off-grid power supply in remote

DOI: 10.54254/2755-2721/85/20240710

areas in Kenya. *Energy Conversion and Management: X*, *18*, 100381. https://doi.org/10.1016/j.ecmx.2023.100381

[5] Kumar, P. R., Pal, N., & Sharma, H. (2022). Optimization and techno-economic analysis of a solar photo-voltaic/biomass/diesel/battery hybrid off-grid power generation system for rural remote electrification in eastern India. *Energy*, *247*, 123560. https://doi.org/10.1016/j.energy.2022.123560

[6] Gong, L., Zhang, Y., & Zhang, B. (2021). Geothermal-solar hybrid power with the double-pressure evaporation arrangement and the system off-design evaluation. *Energy Conversion and Management*, *244*, 114501. https://doi.org/10.1016/j.enconman.2021.114501

[7] Kong, D., Wang, Y., Li, M., & Liang, J. (2022). Experimental investigation of a novel hybrid drying system powered by a solar photovoltaic/thermal air collector and wind turbine. Renewable Energy, 194, 705–718. https://doi.org/10.1016/j.renene.2022.05.102

[8] Qiu, B., Li, G., Wei, X., Liu, M., & Yan, J. (2023). System design and operation optimization on the hybrid system with nuclear power, concentrated solar, and thermal storage. *Annals of Nuclear Energy*, *189*, 109862. https://doi.org/10.1016/j.anucene.2023.109862

[9] Wikipedia contributors. (2023, August 23). *Crystalline silicon*. Wikipedia. https://en.wikipedia.org/wiki/Crystalline_silicon

[10] Chan, K. S. (2020, March 25). What is a TOPCON solar cell? -. https://www.kschan.com/what-is-a-topcon-solar-cell/

[11] Yousuf, H., Khokhar, M. Q., Chowdhury, S., Pham, D. P., Kim, Y., Ju, M., Cho, Y., Cho, E., & Yi, J. (2021). A Review on TOPCon Solar Cell Technology. Current Photovoltaic Research, 75–83. https://doi.org/10.21218/cpr.2021.9.3.075

[12] Chan, K. S. (2019, December 23). What is a HJT solar cell? https://www.kschan.com/what-is-a-hjt-solar-cell/