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التحديات وتحسين أنظمة الطاقة الشمسية الكهروضوئية: مراجعة

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The Challenges and Optimization of Solar PV Systems: Review

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Abstract

The methods for optimizing solar energy are the topic of this research, along with the associated challenges and worries. To serve as a resource for decision-makers involved in solar plant construction around the world, this report examines the latest innovations in solar power-producing technologies. Photovoltaic, thermal, and hybrid (thermal/photovoltaic) systems are the three main categories of these technologies. Sub-categories of solar energy production systems are then specified, and their resource requirements and distinguishing characteristics are established through research. After that, a lengthy discussion takes place. To further emphasize the efficiency and performance of each solar technology and to determine their global rankings in terms of power output, a statistical analysis is also performed. Finally, current directions in solar power plant development research are discussed. The system uses the sun's energy to generate electricity with the use of several procedural systems; stand-alone, hybrid, or grid-charged; reliability, types, and limitations of which are discussed. Several problems and issues associated with solar energy optimization are briefly discussed in this article.

Keywords: PV System, Hybrid system, Renewable, Clean energy, Optimization methods

الملخص

إن طرق تحسين الطاقة الشمسية هي موضوع هذا البحث، إلى جانب التحديات والمخاوف المرتبطة بها. ليكون بمثابة مورد لصانعي القرار المشاركين في بناء محطات الطاقة الشمسية في جميع أنحاء العالم، يدرس هذا التقرير أحدث الابتكارات في مجال تقنيات إنتاج الطاقة الشمسية. الأنظمة الكهروضوئية والحرارية والهجينة (الحرارية / الكهروضوئية) هي الفئات الثلاث الرئيسية لهذه التقنيات. يتم بعد ذلك تحديد الفئات الفرعية لأنظمة إنتاج الطاقة الشمسية، ويتم تحديد متطلباتها من الموارد وخصائصها المميزة من خلال البحث. وبعد ذلك، يتم إجراء مناقشة مطولة. وللتأكيد بشكل أكبر على كفاءة وأداء كل تكنولوجيا للطاقة الشمسية وتحديد تصنيفاتها العالمية من حيث إنتاج الطاقة، يتم أيضًا إجراء تحليل إحصائي. وأخيرا، تتم مناقشة الاتجاهات الحالية في أبحاث تطوير محطات الطاقة الشمسية. يستخدم النظام طاقة الشمس لتوليد الكهرباء باستخدام عدة أنظمة إجرائية؛ مستقلة أو هجينة أو مشحونة بالشبكة؛ تمت مناقشة الموثوقية وأنواعها وقيودها. تمت مناقشة العديد من المشكلات والقضايا المرتبطة بتحسين الطاقة الشمسية بإيجاز في هذه المقالة.

الكلمات المفتاحية: النظام الكهروضوئي، النظام الهجين، الطاقة المتجددة، الطاقة النظيفة، طرق التحسين.

1. Introduction

The term "global warming" is commonly used to describe the effect that greenhouse gases have on the average global surface temperature. The term "global warming" is suitable when referring to extreme weather occurrences brought on by greenhouse gases. However, "climate change" is the most accurate phrase when describing other long-term shifts in the planet's weather patterns. Sceptics of human-caused global warming and environmental degradation point to the long-term variability of Earth's temperature patterns as evidence that the current climatic changes are neither as severe nor the result of human activity alone [1]. As a layer, the gases that makeup Earth's atmosphere prevent the planet's internal heat from escaping into space. Ninety-seven percent of working climate specialists around the world agree that human activity is a contributing factor to rising global temperatures. Experts on the climate say that this pessimism stems from people being unwilling to face the full scope of the damage that humans have wreaked on the planet. The ice sheets grow and shrink due to tiny changes in Earth's orbit around the Sun. The sun's radiation changes throughout time. Such shifts have far-reaching effects on the cosmos, the atmosphere, and the surface of the planet [2].

Recent scientific consensus holds that variations in solar activity have a negligible impact on global average temperatures. Increasing amounts of man-made greenhouse gas emissions are responsible for far more warming than any other sources combined. Solar activity has been fluctuating recently. Solar energy has far more positive effects on human health. New versions of current technology are always being released [3].This paper [4] provides a comprehensive literature overview of the history, evolution, and refinement of particle swarm optimization (PSO). The study is structured so that the essentials of PSO and its history are covered first, followed by its adaptations using inertia weight and the constriction parameter. PSO is reviewed in detail before being applied to solar PV, where problems including parameter tuning, changing surroundings, getting stuck, and hybridization are addressed. Moreover, another research paper concentrates on solar power optimization methods, as well as the barriers and relates that come with them.

Solar photovoltaic (PV) systems have become a cornerstone of sustainable energy generation, offering a clean and renewable source of electricity. As the world grapples with the challenges of climate change and the need to reduce greenhouse gas emissions, PV technology has gained prominence. However, alongside its remarkable benefits, the deployment of solar PV systems is associated with a set of challenges that necessitate ongoing research and optimization efforts. One of the primary challenges in the solar PV domain is efficiency. While PV systems have witnessed considerable advancements in recent years, there remains room for improvement. Enhancing the efficiency of PV panels, inverters, and balance of system components is a key research area. Increasing the conversion efficiency of solar cells and mitigating losses during electricity conversion and transmission is paramount to optimizing the overall system.

Intermittency and variability pose another formidable challenge. Solar energy production is dependent on weather conditions, daylight hours, and geographical location. As a result, the output of PV systems can be intermittent and variable, making it essential to develop effective energy storage solutions and grid integration techniques to ensure a continuous and reliable power supply. The durability and reliability of PV systems are also critical concerns. Solar panels are exposed to various environmental stresses, such as temperature fluctuations, humidity, and UV radiation. Over time, these factors can degrade the performance of PV modules. Ensuring the longevity and reliability of solar PV systems is imperative, as they often have lifespans exceeding two decades.

Cost remains a central consideration. Although the cost of PV technology has significantly decreased over the years, the initial investment in solar PV systems can still be prohibitive for many. Reducing the overall cost of solar energy generation through innovative materials, manufacturing processes, and installation techniques is a crucial focus for research and development. Moreover, PV systems can have environmental impacts associated with the production, disposal, and recycling of PV modules. To address these issues, research into sustainable manufacturing processes and responsible end-of-life management is pivotal. The significant contribution of the article lies in its exploration of the complex issues surrounding the development and implementation of solar PV technology. The paper delves into the challenges associated with optimizing the efficiency and performance of solar PV systems, including issues related to design, installation, and maintenance. Through a detailed analysis of the latest innovations in solar PV technology, the paper provides valuable insights into the methods and techniques used to optimize solar energy production.

2. Concentrated PV Technology

Scientific progress in optical equipment led to the creation of concentrated PV (CPV) cells. The CPV employs an optical concentrator, such as a curved mirror or lens, to direct sunlight onto PV cells. The additional photons focussed by the concentrator boost the productivity of the solar cells. According to the published research, a cell's functioning voltage and current can both benefit from the addition of a concentrator. Optical performance has a direct and substantial effect on the CPV's productivity, making it crucial to choose the right concentration technique. To maximize the effectiveness of CPV systems, it is occasionally necessary to combine two (or more) concentration systems. Between 114 kW in Japan and 67.68 MW in the China region, the installed power of CPVs will vary widely between now and 2021. The average CPV output of the worried nations is 22.43MW. The United States is in second place with 21% of the mounted CPV volume, while China has 50%. The majority (81%) of CPV power plants are high concentrations (HCPV), whereas just 19% are low concentrations (LCPV). This means that of all the electricity created, 93% comes from HCPV whereas just 7% comes from LCPV [5].

3. PV-CSP Hybrid System

Researchers all around the world have taken an interest in the novel field of PV-CSP hybrid technology. According to the IEA's solar thermal energy technology roadmap, this is especially promising when used for the widespread deployment of hybrid power plants. This choice is motivated by the intriguing features of such a combination, which can improve system stability, energy quality, LCOE, heat losses, and power plant efficiency. Battery energy storage system (BESS) facilities are part of the plan for large-scale hybrid photovoltaic (PV) and concentrated solar power (CSP) power plants, according to recent studies. The future cost-effectiveness of this strategy may be enhanced by the anticipated reduction in battery prices and standardized photovoltaic thermal solar power plants. PVT solar systems combine a regular photovoltaic module with a thermal accumulator to collect energy from the sun-concentrated photovoltaic and photovoltaic thermal solar hybrid systems. Despite the high conversion rate, CPV technology has a major drawback in the form of excessive PV cell heating. This can be avoided with the use of a cooling method [6].

4. Solar Energy Optimization Method

Neither noise nor pollution is produced by solar energy systems, even when they are being operated or maintained. Alternative electrical energy sources can be more harmful to the environment than photovoltaic cell technology. Power conversion efficiency may be increased by analyzing the factors that influence the optimization of solar energy systems and their operating characteristics. The dependability of solar energy systems is significantly impacted by environmental factors. Therefore, optimization strategies are essential for improving the solar system's dependability and efficiency. To do this, methods for addressing tough PV system optimization challenges must be created [6].

Hybrid energy systems combine renewable sources like wind and solar with conventional power sources like hydroelectric dams and fossil fuels. These systems range in size from those that can power a single house to those that may sustain a whole colony or island. Hybrid power systems will help many off-grid areas, especially those in underdeveloped nations where it is not financially or technically feasible to have a central power provider. The system provided enough energy to run the community's washing machine, refrigerator, sewing machine, lights, and water pumps until the hamlet was linked to the electric grid. To meet consumer load requirements, the inverter (DC/AC) changes the voltage from direct current to alternating current. The terminals of the battery charger, the storage battery, and the (DC/AC) converter's input are all connected in series and parallel, respectively [7].

PV System

The largest standalone PV-generating plants in the world are in California and the Agua Caliente Solar Project. Both power stations have a combined capacity of more than 250 MWP. However, because solar panels are so expensive, their use is confined to fewer than 1% of the world's total energy generation. PV energy systems are thought to be one of the most cost-effective ways to meet rural energy demands. Following wind and hydro, solar photovoltaic is the third-largest established renewable energy source in the entire globe [8]. Solar cells directly convert solar radiation from the sun into a usable grid system as illustrated in Figure 1.

A hybrid PV system for decentralized electricity production has been created and is economically feasible for small communities of up to 100 dwellings. Using the hybrid PV system optimization approach, the best mix may be found based on the amount of energy produced, which is further supported by the distance angle, tilt, and azimuth angle from the closest power line. The efficiency of a PV hybrid system is assessed by how consistently it produces power under various load conditions.

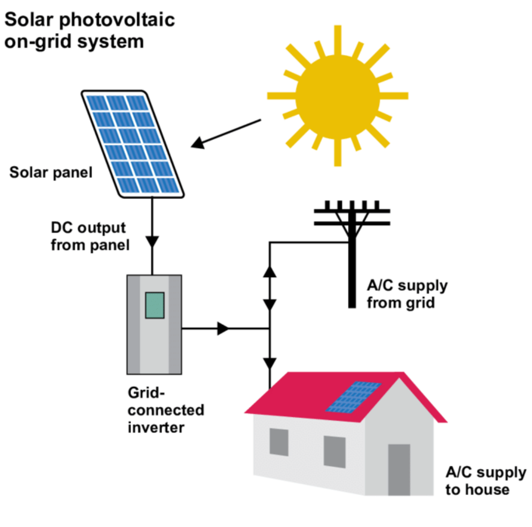

Figure 1 : The diagram of Grid-tied PV system for homes

Optimization method for PV Based Grid System

Grid-connected solar energy is very variable depending on factors such as solar irradiation, the surrounding temperature, demand for capacity, and location. Finding the top, the answer to the question of how to boost the efficiency of a system with radial distribution lies in the optimal placement and size of solar photovoltaic installations.

Power system network analysis and mathematical modeling are requirements for designing the PV system to connect with AI techniques used in the radial distribution network. Together, the PSO and a MATLAB simulation as presented in Figure 2, help determine where and how much solar photovoltaic power should be added to the distribution system. PV on-grid system integration is vital for improving network capacity and system dependability as it allows for fluctuations in demand for electricity over time [9].

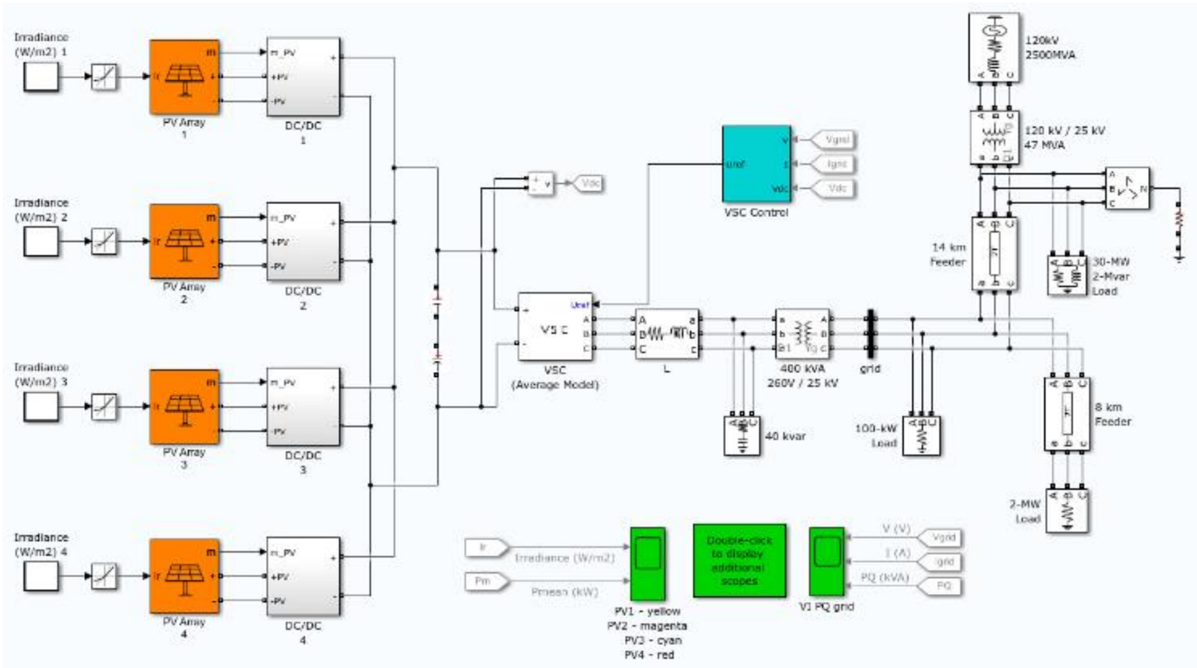

Figure 2 : The diagrams for PV-based hybrid system implemented in MATLAB [9].

A solar power system that is "on-grid" means that it is connected to the utility grid. The key benefit of such a system is that it allows for backup power to be provided by the PV system if electricity cannot be supplied from the utility grid. The use of batteries in these connected-to-the-grid setups is optional. These systems combine batteries, a charge controller, solar modules, and inverters to provide reliable, long-term utility service to a wide variety of loads while also enhancing the reliability of the grid-based electrical system.

Connecting a solar system to the grid necessitates the use of high-power electronic converters for converting DC to AC and power conditioning. Solar optimization research in operational power systems is proposed. Modeling methods, criteria for limiting models, and optimization strategies are all investigated. The PV module system has great promise since it is clean, environmentally benign, and offers stable electrical power.

Optimization method for PV Based Stand Alone System

An independent PV system's ability to power the demand or meet energy needs should never be interrupted. Using the proposed method, which is predicated on hourly energy analysis, one may generate a curl (statistics) for the ratio of the battery bank necessary to meet demand throughout all periods. Given the unpredictability of solar power output, the battery bank must be large enough to deliver adequate power after any number of charge/discharge cycles.

This implies that once the sun goes down, the grid will switch to a backup power source to continue charging the batteries until more solar energy can be collected. A PV system's efficiency is calculated using the amount of available solar radiation, the size of the PV array, and the amount of space available for batteries. Freestanding PV systems' dependability, then, is directly proportional to their size. There are several approaches to size, including intuitive methods, analytical sizing methods, and numerical approaches. The first class of algorithms is highly imprecise and unreliable, with a pretty significant chance of producing wrong results since it relies on intuitive information (as opposed to the use of cognitive processes).

This optimization was performed using the concept of the optimal periodic inclination angle, which allows for maximum incidence on the panels while simultaneously optimizing the household's real energy usage. Although total apparent power overestimates the load demand by 18%, the computation of solar radiation for sloping surfaces using different solar geometry factors and incoming solar radiation suggests that the inclination angle varied seven times each year. However, these tweaks improve both panel production and PV station dependability [10-12]. Despite the limitations, the load profile must be adhered to, as shown by the examination of random load variation. Even moderate increases in load demand could cause the plant to experience a power shortage.

5. Optimization Issues

There are substantial challenges facing solar energy that could slow down its widespread adoption. Technology, politics, economics, and dependability are all categories that might be used to describe these roadblocks. However, rectifying these problems lessens their impact and increases the solar energy system's dependability. Therefore, improved solar energy optimization can reduce anxiety about production [12-15]. Large sums are being invested in PV power technology to increase its efficiency and commercial viability.

Extra Investment

PV cells are sold independently from inverters and batteries. Inverters change DC into AC so it can be used on the power grid. When it comes to providing constant electrical power, on-grid connections rely heavily on storage batteries. However, if the occasional issues with PV cells can be resolved, the increased costs may be worthwhile.

Issues with Intermittency

Outages can occur with solar energy and photovoltaic cells, just like they can with any other renewable energy source. It suggests that there are times when it cannot be used to generate electricity, for instance at night or when the weather is cloudy or rainy. Therefore, PV cells are not likely to be able to supply an entire electric power system's needs.

Easily Broken

While photovoltaic (PV) solar panels require no maintenance and have no operating costs, they are easily broken. You can prevent financial loss by purchasing supplementary insurance to cover your investment.

Expensive

The market price of PV systems is still very high and out of reach for many people's budgets. Non-renewable technology faces market competition due to the higher production costs of non-conventional energy sources and the availability of cheaper fossil fuel alternatives. Small-scale PV systems cannot be expanded to large-scale or commercial facilities due to the absence of economic models to promote renewable energy technology.

Conventional fuel sources are given an unfair advantage due to the more equitable distribution of subsidies. To maximize the benefits of renewable applications in the public sector, government-driven markets, and loan and cash markets, governments must encourage the market for PV technology. Installation of PV capacity is hindered by the need for inputs such as land and water for PV plants.

Low Productivity Level in the Future

When the panels installed during the early phases of the energy boom approach the end of their expected lifetime and are eventually thrown into landfills, the technology will face another significant challenge in the near future. According to the manufacturer, these panels lose some of their effectiveness after around 25 years of use. Given that retired PV panels can be repaired and redeployed, recycling solar panels is a rational solution to the anticipated global PV waste. Solar waste may be effectively recycled, which not only helps the environment by reducing the amount of energy spent on resource recovery but also saves money. Japan, the USA, India, Australia, and Europe are just some of the places where research and development on solar PV recycling have begun.

Environmental Disadvantages

There is a lack of familiarity with the environmental and economic benefits of PV recycling technology due to a lack of comprehensive case studies. Although it's beneficial to recover elements, doing so requires more effort than is saved by recycling old PV panels for their metal content. The cost of recycling PV panels is low, however, recycling processes are not economically viable.

According to studies, the recovery price of copper indium gallium selenite (CIGS) solar panels is less than the profit made from selling recycled material. However, c-Si and p-Si solar modules do not generate enough revenue to cover their purchase price. Businesses often choose landfill disposal over recycling due to the lower initial cost of dumping, despite the financial benefits of reselling recovered items and the positive environmental impact of recycling.

6. Optimization Challenges

Since the early 20th century, researchers have given considerable attention to the creation of alternative energy sources. While many developed nations have already made the transition to renewable energy, the vast majority of developing nations have put it off. The use of fossil fuels has increased CO2 emissions and accelerated global warming. Most countries have shown reluctance to adopt renewable technologies due to a wide variety of obstacles [16-18]. Policy implementation, such as energy auctions, integration of PV technologies with non-conventional energy sources, and timely completion of PV projects, is crucial in light of the current market. These economic models then help to lower monthly electric costs, stabilize electricity prices, and promote the growth of PV systems for homes. There is a big push to improve productivity by investing in renewable energy innovations. According to IRENA, the cost of producing renewable energy continued to drop in 2017. There hasn't been a complete cost-benefit analysis of the policies and investments needed for developing and deploying renewable energy technology.

Energy Optimization Challenges

Since the weather might change at any time, solar PV faces the challenge of not knowing how much sunlight it will receive. Therefore, it would be difficult to know how much energy to store for later usage. Despite the lack of daylight, electrical power is still necessary. Significant challenges may slow the rapid spread of solar energy.

These obstacles can be broken down into four categories: technology, politics, economics, and dependability. However, resolving these issues lessens the drawbacks and boosts the dependability of solar energy systems [19-22].

7. Conclusion

In conclusion, the challenges and optimization of solar photovoltaic (PV) systems are intricately linked to the global transition towards cleaner and more sustainable energy sources. As we face the pressing need to mitigate climate change and reduce our dependence on fossil fuels, solar PV technology has emerged as a powerful solution. However, the journey to harness the full potential of solar energy is not without its challenges. Moreover, efficiency, intermittency, reliability, cost, and environmental impact are the key challenges that researchers, engineers, and policymakers must grapple with. The optimization of solar PV systems is essential to overcome these challenges. Efforts to enhance the efficiency of PV cells, inverters, and components, as well as reduce energy losses in conversion and transmission, are critical to maximizing the benefits of solar energy.

Addressing intermittency and variability through energy storage solutions, grid integration, and smart grid technologies is fundamental. Ensuring the durability and reliability of PV systems over their decades-long lifespan is equally vital, as it not only impacts the return on investment but also the sustainability of these systems. Cost optimization is essential to make solar PV technology more accessible to a broader range of consumers. Innovations in manufacturing processes, materials, and installation techniques continue to drive down the upfront expenses associated with solar PV systems. This article provided a comprehensive study and comparative analysis of solar technology for clean power generation for governments around the world. The article found that there are two distinct categories of technology: complicated technologies, including PTC, PV, and STP, with a combined installed capacity of 7,828.5MW and an efficiency of 10-16%, LCEO of $0.1-0.24/kwh, and promising environmental and technical outcomes.

The installed capacity of these technologies is only 390MW, but they show promise in terms of environmental impact and technological efficacy. Furthermore, due to their early phases of development, CPVT and CPV have not yet been implemented in large-scale power facilities. Scientists from a variety of countries, however, are currently at the forefront of CPV and CPVT development. Due to the unpredictable nature of solar energy, solar PV material, design, and complicated computation of optimization challenges, increasing energy efficiency through the use of solar power has been a source of concern..

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