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Opinion

An Opinion on Strategic Management, Economy and Implementation of Clean Energy Driven by Photovoltaic-Phase Change Materials System

Yousaf Ishrat[1], Raza Gulfam[2], Liu Wenbin[2] and Wang Wenping[1]*

[1]School of Economics and Management, Southeast University, Jiulonghu Campus, Nanjing, China

[2]School of Energy and Environment, Southeast University, Jiulonghu Campus, Nanjing, China

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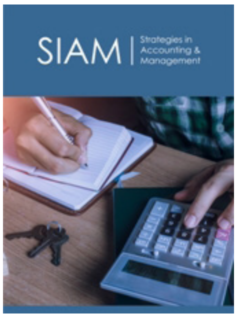

***Corresponding author:** Wang Wenping, Jiangning District, Nanjing, Jiangsu Province, China

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Abstract

Aiming at reducing carbon emissions demands the proper strategic management, effective economy and appropriate implementation of the clean energy systems. Together with this objective, enhancing the operational life and thermally managing the clean energy systems, such as photovoltaic panels, is equally indispensable. Herein, attention has been paid on photovoltaic-phase change materials (PV-PCMs) system, bridging the gap between the management and policymaking at institutional and government levels. The working principles, benefits and challenges of PV-PCMs have been discussed, along with solution-oriented recommendations. It is expected that this opinion will pave the way to properly adopt and manage the clean energy technologies in the future.

Keywords: Energy economy; Energy conservation; Photovoltaics; Power enhancement; Cooling; Thermal management; Social impact; Energy impact

Introduction

The energy economy of Photovoltaics (PV) or solar power plants has been growing rapidly in recent years, driven by the increasing demand for clean and renewable energy sources [1,2]. The whole world has recognized the importance of investing in solar energy as a way to reduce the dependence on fossil fuels and meet the energy needs in a sustainable and eco-friendly manner [3-5]. Especially, the countries with the hottest environment have taken a great interest in managing and economizing solar technology [6]. For example, in Pakistan, the government has launched various initiatives to promote the development of solar power plants [7]. In 2015, the government launched the National Energy Policy, which aims to increase the share of renewable energy in the country's energy mix to 10% by 2025. The country has a total installed capacity of around 2.5 GW, with most of the projects being located in the Punjab and Sindh provinces [8]. Similarly, in China, the management on energy economy of solar power plants has also been growing rapidly in recent years, enabled by the government's commitment to promote the development of clean energy sources. According to the China Energy Administration [9,10], the installed capacity of Photovoltaic (PV) power generation increased from 130.25 million kW in 2017 to 609.49 million kW in 2023, a cumulative increase of 149 %. As a result of these efforts, the solar power sector in China has grown rapidly in recent years, with the country now having a total installed capacity of around 200GW, making it the largest market for solar energy in the world [11,12]. Most importantly, it is essential to address the challenges posed by the intermittency of solar power generation, which can impact the strategic management, stability and reliability of the grid. Governments can invest in research and development initiatives aimed at improving energy storage solutions and can implement smart grid technologies to help manage the integration of solar power into the grid. In energy storage solutions, Phase Change Materials (PCMs) have a great potential to help balance the supply and demand by managing the reliability of the energy systems. The integration of PCMs with photovoltaics can have a significant impact on the energy economy of these systems. PCMs are materials that can store and release thermal energy, and they have the potential to improve the efficiency and performance of PV by reducing the energy losses associated with thermal cycling [13]. Consequently, the energy economy is deemed to be upgraded with the help of PCMs, opening a way for the best strategic management and implementation of photovoltaics.

Economic prediction and working principle of PV-PCM system

The schematic of working principle of PV-PCM system is shown in Figure 1a. In PV systems, the radiation of the sun are absorbed by PV panels, which convert the energy into electricity. The heat generated by the PV panels can cause thermal losses, which can reduce the efficiency of the system and result in lower energy output. By integrating PCMs with PV, the heat generated by the PV panels can be absorbed and stored by the PCMs, and then released as needed to maintain optimal operating temperatures. This can help reduce the thermal losses and improve the efficiency of the system. For example, a PV system has been integrated with Phase Change Composite (PCC), focusing on the efficiency enhancement, energy production enhancement and temperature control, as demonstrated in Figure 1b & 1c. Theoretical results depicted that PV-PCC system is highly efficient and economized, e.g., the cost for the overall system has been estimated to be $290 compared with a stand-alone PV system costing $224. Such results signify the practical importance of PV-PCM systems [14].

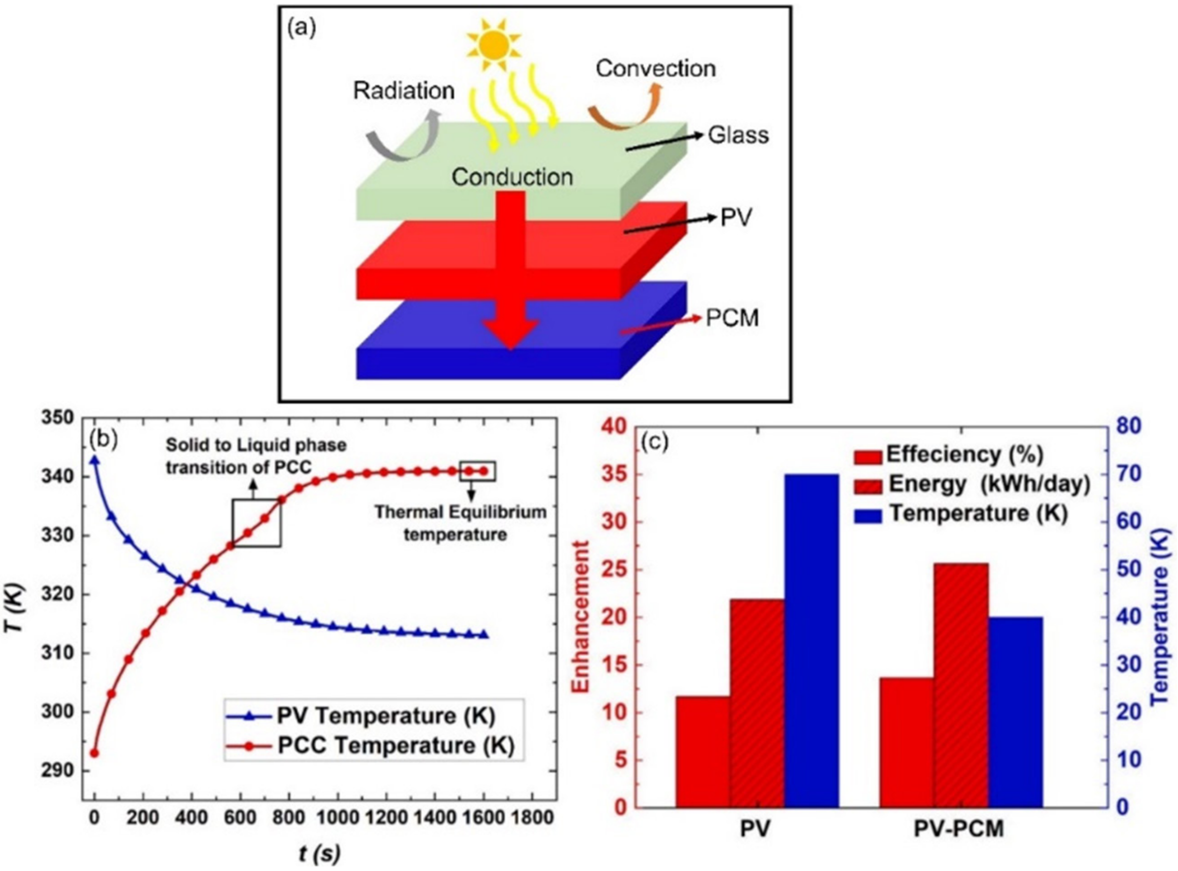

Figure 1: (a) PV-PCM system and its working.
(b) Heat dissipation and heat storage mechanism of PV-PCM system [14].
(c) Comparison of PV and PV-PCM system [14].

Benefits and limitations of PV-PCM systems and impact on implementation

There are several benefits associated with the integration of PCMs with PV. Firstly, it can help increase the energy output of the system, as the stored thermal energy can be used to maintain optimal operating temperatures, which can result in higher efficiency and performance. Secondly, it can reduce the need for cooling systems, as the stored thermal energy can be used to regulate the temperature of the PV panels, which can help reduce energy consumption and lower operating costs. In addition to these benefits, the integration of PCMs with PV can also help improve the safety and reliability of the system. By reducing the thermal stress on the PV panels, the risk of damage and degradation can be reduced, which can help extend the lifespan of the system and reduce maintenance costs. For example, theoretical results depict that the life of PV system can be increased by three years after equipping with PCM [14]. Despite these benefits, there are also some challenges associated with the integration of PCMs with PV. For long-term strategic management, one of the main challenges is the need for reliable and durable PCM materials, as well as effective integration and installation methods. In addition, the cost of the materials and the installation process can be a barrier for some developers, especially in countries where the cost of solar energy is already high.

In all, the integration of phase change materials with PV can have a significant impact on the energy economy, as it can help increase the energy output (Figure 1c), reduce energy consumption, and improve the safety and reliability of the system. Despite the challenges, the potential benefits of this integration make are worth exploring and investing in, especially as the world continues its transition to a clean and sustainable energy future. Regarding implementation, there are several factors that need to be considered when integrating PCMs with PV. Firstly, it is important to select the appropriate PCM material, as different materials have different melting points and thermal storage capacities, which can affect the performance of the system. Common Phase change materials include inorganic PCM, organic PCM [15] and composite PCM [16]. Among them, inorganic PCMs are mainly crystalline hydrated salts, molten salts, metals or alloys, etc.; organic PCMs mainly include paraffin, fatty acids and other organics; composite phase change heat storage materials came into being, which can effectively overcome the shortcomings of a single inorganic or organic phase change heat storage materials and improve the application of the phase change materials as well as to expand the scope of its application.

Once the appropriate PCM material has been selected, the next step is to integrate it into the system. This can be done in several ways, including using PCM-coated PV panels, PCM-integrated solar collectors, or PCM-embedded structures. In each case, it is important to consider the specific requirements of the system and the environment, as well as the longer strategic management cost, reliability, and safety of the implementation. PCMs absorb sensible heat, start melting when the internal temperature reaches the melting temperature, and then absorb latent heat. During the melting process, the temperature of the PCM does not change, but after the phase change is complete, its temperature increases [17]. PCM should fulfil the following requirements [16]: (1) phase change temperature within the required range; (2) high latent heat, specific heat and thermal conductivity; (3) low volume expansion and low/no subcooling during freezing; (4) non-toxic, non-corrosive, non-flammable, non-explosive and chemically stable; and (5) low cost.

In terms of economic benefits, the integration of PCMs with PV can result in a number of cost savings, including lower energy consumption, reduced maintenance costs, and extended lifespan of the system. By increasing the efficiency and performance of the system, it can also lead to higher energy output and lower costs for energy generation, making it more competitive with traditional energy sources. It is also worth noting that the integration of PCMs with PV can have positive environmental impacts, as it can help alleviate greenhouse gas emissions and promote the use of renewable energy sources. This is particularly important in countries like China, India and Pakistan, where the energy demand is growing rapidly, and the need for clean and sustainable energy sources is becoming increasingly urgent.

Future directions and scope

The use of PCMs in solar power plants is still a relatively new concept, and there is ongoing research and development taking place to further optimize the technology. This includes exploring new materials, improving integration methods, and developing innovative storage solutions to increase the thermal storage capacity of the PCMs. One area of research that is particularly relevant to the integration of PCMs with solar power plants is the development of advanced PCM materials with improved thermal storage capacities and enhanced stability. For example, there are ongoing efforts to develop new PCMs based on phase change alloys [18], which have higher melting points and improved thermal stability compared to traditional materials. Another area of research that is relevant to the integration of PCMs with solar power plants is the development of innovative storage solutions that can increase the thermal storage capacity of the PCMs [19]. For example, researchers are exploring the use of PCM-based thermal energy storage systems that can store and release large amounts of thermal energy, which can help to further improve the performance of solar power plants.

It is also worth noting that the integration of PCMs with solar power plants is not limited to the use of traditional solar Photovoltaic (PV) panels. Researchers are exploring the use of alternative technologies, such as Concentrator Photovoltaics (CPVs) and Building-Integrated Photovoltaics (BIPVs) [20], which can further enhance the performance of the system and improve the energy economy of the solar power plant.

In terms of implementation, it is important for developers and policymakers to consider the specific requirements of each solar power plant when integrating PCMs. This includes the climate and environment, the size and capacity of the plant, and the specific requirements of the energy grid. It is also important to consider the cost, reliability, and safety of the implementation, as well as the potential benefits in terms of energy efficiency and performance.

In addition to the research and development efforts aimed at improving the integration of PCMs with solar power plants, there should be initiatives to promote and facilitate the wider adoption of the technology. For example, there should be government programs and subsidies aimed at supporting the development and deployment of PCM-based energy storage systems, as well as training and education programs aimed at increasing awareness and understanding of the technology among industry professionals and the general public. There should be further efforts to promote the use of PCMs in new construction projects, such as commercial and residential buildings, by incorporating PCM-based systems into building codes and standards. This can help improve the energy efficiency of these buildings, while also reducing energy costs and greenhouse gas emissions. Finally, there should be initiatives to promote collaboration and information exchange between industry professionals and researchers, in order to encourage the development and dissemination of best practices for the integration of PCMs with solar power plants. This can include the sharing of data and information, as well as the development of industry standards and guidelines for the implementation of the technology.

Conclusion

The integration of phase change materials with solar power plants is a promising area for improving the energy economy of these systems. By reducing the thermal losses, increasing the energy output, and improving the safety and reliability, PCMs have the potential to play a significant role in the transition to a clean and sustainable energy future. There are also many issues of worth studying. For example, due to the particularity of phase change materials, the main use is their latent heat of phase change, which means that phase change materials need to be specifically selected based on the application environment (melting and boiling points) to meet the requirements of temperature and pressure. Secondly, after selecting the phase change material, how to enhance heat transfer (cooling) or reduce heat transfer (insulation) according to the objectives are also problems of worth studying. This includes but is not limited to the material properties of (composite) materials, structural parameters, and flow states. It is important for researchers, policymakers, and developers to continue exploring and investing in this area, in order to maximize its potential benefits and overcome the challenges associated with its implementation.

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