

Discussion On Three Optimization Plans for Photovoltaic Systems

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Abstract. In the context of the global energy structure, photovoltaic (PV) generation plays a critical role in reducing greenhouse gas emissions and improving energy sustainability. However, PV systems differ significantly from conventional power generation like coal and nuclear power due to their dependence on environmental factors such as weather and seasons, resulting in significant load fluctuations. To mitigate this issue, the optimization of PV systems is widely accepted, involving techniques such as energy storage and performance enhancement. Three methods are proposed to address the issue of power instability in photovoltaic systems: changing the tilt angle between photovoltaic panels and sunlight, changing the electrical parameters of photovoltaic cells, and compensation using liquid air energy storage technology. Based on these three methods, corresponding implementation directions and applicable ranges are provided for different needs. The advantages and disadvantages are also discussed.

Keywords: Photovoltaic panel; Photovoltaic system; MPPT; LAES.

1. Introduction

Under the present energy structure, solar energy is a vital component of green energy, which reduces the production of greenhouse gases and lessens reliance on fossil fuels. The photovoltaic power system, at both the generation and consumption ends, differs significantly from thermal power and nuclear power, as it is easily affected by weather and other factors, leading to heavy loads on the grid when unexpected situations occur. To address the issue of mismatch between demand and production, two widely recognized methods are energy storage and performance optimization.

2. Methods Strategies for Stability Enhancement

2.1. Adjusting Photovoltaic Panel Tilt Angle

One of the obstacles to the large-scale implementation of the photovoltaic system is its seasonal and annual instability. According to research conducted by M. Hartner et al. in 2015, the difference in the tilt angle of PV panels could be more than 10% under high voltage output when calculating the average annual electricity consumption [1]. D. Mondol et al. reveal that due to weather and sunlight conditions, the in-plane insolation differs by seasons, with values ranging from 1066-2045 Wm² in summer to 3450-4135 Wm² in winter [2]. This data shows that sunlight in winter is more abundant and unstable than in summer. Based on the installation location of the photovoltaic system, two options are available to address this situation.

The first option is suitable for areas lacking power supply or having a strong inclination towards using green energy. In such cases, the supply issue needs to be addressed by changing the angle between the solar cell and the ground based on the solar altitude angle and weather information to adapt to changes in sunlight availability. To implement this, it is necessary to connect the weather forecast system with mechanical devices that adjust the angle between the electrical board and the ground. In areas where weather factors have little impact on the solar energy system, such as central mainland or oceanic climates, it is recommended to adjust the angle once a year based on the yearly weather forecast, typically around -22 degrees Celsius. After determining the optimal tilt angle, apply this angle to the solar panel manually or mechanically. For offshore photovoltaic power stations and

facilities built in coastal areas, the adjustment frequency needs to be more frequent, ideally once a month. Research by M. Bojić et al. shows that power generation in summer is about 16% higher than in winter [3]. Adjusting the angle of solar panels is expected to increase the power generation efficiency of the entire photovoltaic system by 5% - 8%, with performance varying in different regions [2].

The second option is suitable for areas with relatively sufficient electricity supply and balanced demand throughout the year. For most basic power plants, the cost of stopping work or adjusting work intensity is extremely high. Therefore, when there is an overflow of power production capacity, it is necessary to suppress excess green energy generation to avoid high grid load and losses to power generation stations. A commonly used method in wind power plants is to align the fan blades with the direction of the wind, decreasing power generation efficiency as the rotating speed decreases. In photovoltaic power generation, a similar approach is to minimize the angle between sunlight incidence and the solar panel during winter or other periods of relatively high light intensity, thereby reducing the rate of photovoltaic effects. Research by M. Hartner et al. suggests adjusting the angle four times a year: from December to the end of February, from March to the end of May, from June to the end of August, and from September to the end of November. The angle range is from -50 degrees (winter) to 11 degrees (summer). After applying this scheme, power generation in summer is 11% higher than in winter [3]. According to Á. Bognár et al., it is possible to monitor local shadow coverage based on the grey box model to adjust the angle of the solar panel for that area [4]. This method is more flexible and efficient, requiring further technical validation through experimentation.

2.2. Optimizing Electrical Parameters of Photovoltaic Cells

By changing the voltage and current at both ends of the photovoltaic panel, reverse control of the photovoltaic effect can be achieved to regulate the output of the entire photovoltaic system. The most mature technology for this method is photovoltaic maximum power point tracking (MPPT) technology.

MPPT technology aims to maximize the power output of photovoltaic panels. The I-V curves of the photoelectric effect exhibit slight differences under various external conditions. Thus, MPPT facilitates the operation of photovoltaic systems at peak efficiency. The overall operational logic and subsystems of MPPT are depicted in Fig. 1.

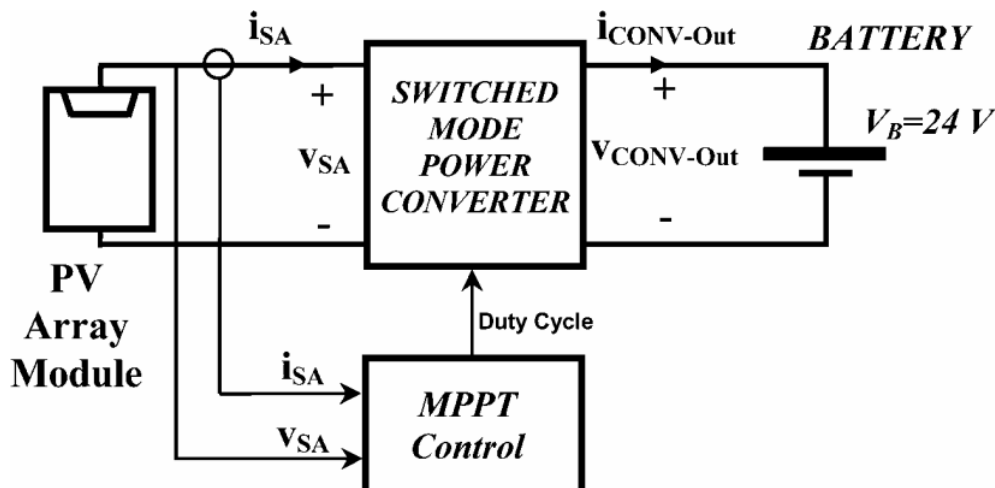


Fig. 1 Block diagram corresponding to the MPPT subsystem [5].

It should be noted that MPPT technology necessitates continuous impact on system components, although not all required electronic components will operate at full power. To achieve maximum efficiency, its energy consumption is undoubtedly substantial. Therefore, the introduction of hot spot technology to prevent damage to critical components is of practical significance and has been tested on a small scale [6].

2.3. Leveraging LAES Technology for Compensation

In addition to the aforementioned options for direct intervention in photovoltaic systems, the construction of compressed air energy storage or liquid air energy storage (LAES) can also be utilized to optimize photovoltaic systems. Energy storage technology, as a new energy generation optimization scheme that is gradually moving towards marketization and maturity, enables short-term and long-term regulation in the field of photovoltaic power generation. Depending on the installed capacity and scheduling regulation, its economic value and contribution to the stability of the power grid are substantial.

The overall process of LAES is as follows: first, the air is cleaned and dried, then, the excess energy from the photovoltaic plant that isn't being fed into the grid is used to refrigerate and compress the air, generating 'liquid air'. The liquid air is then stored in a cold insulated tank at low pressures. As the energy is needed, the liquid air is pumped to a high pressure and evaporated. This expansion of the gas turns a turbine which releases energy to be harnessed and put back into the grid. The operational logic of the LAES system is illustrated in Fig. 2.

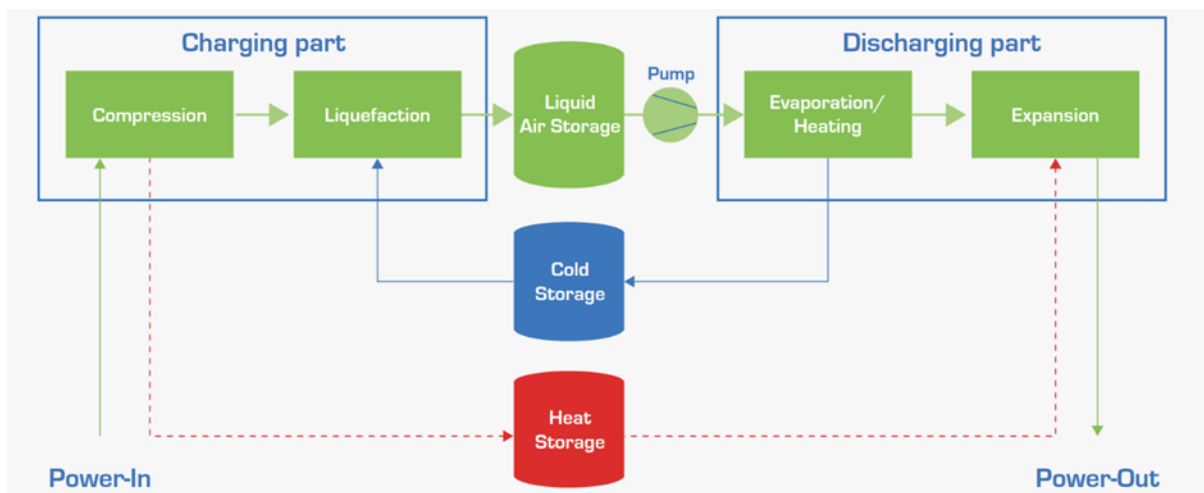


Fig. 2 LEAS schematic diagram

This storage system is one of the cheapest energy storage systems over 30 years (which is well within the lifetime of these facilities), with only pumped hydro and CAES being cheaper [7]. LAES also boasts a high energy density and an energy return efficiency of over 50% [8]. Both of these storage solutions have geographical limitations that make it difficult to implement in solar systems.

3. Comparative Analysis

The method of changing the tilt angle is limited to the mechanical structure and service life and cannot accommodate large angle changes. Moreover, its application prospects in offshore photovoltaic farms and high-altitude areas are not extensive. Additionally, the degree of change is also restricted. Nevertheless, its greatest advantage lies in the fact that it requires no alteration of other parameters, and its operation is relatively convenient.

Current photovoltaic control systems primarily regulate their power generation efficiency through inverters and MPPT systems. Combining energy storage facilities with other control methods can enhance system stability and meet the requirements of the power grid. This approach necessitates preliminary experiments and data analysis but yields relatively positive outcomes. However, the MPPT system requires external energy supply and consumes significant power. When deployed on a large scale, the addition of a large surface heat sink is necessary, rendering it more suitable for indoor or small-scale applications. Moreover, it is imperative to devise solutions for handling abnormal situations at the outset of the design to prevent damage.

The LAES energy storage structure, as an emerging system, offers significant economic benefits and exerts a robust balancing effect on the instabilities inherent in non-basic power generation

methods. Nonetheless, the technology is not flawless, and considerable investment and risk management are essential to address potential hazards associated with factors such as high-pressure gases [9].

4. Conclusion

In summary, this paper has examined the critical necessity for performance monitoring and optimization in PV systems, addressing the inherent challenges posed by environmental factors and the imperative for enhanced efficiency. Through a comprehensive analysis of three main control strategies—changing the tilt angle between photovoltaic panels and sunlight, adjusting the electrical parameters of photovoltaic cells, and compensation using LAES technology—we have identified the strengths and limitations of each approach in the context of improving the operational performance of PV installations. When enhancing photovoltaic systems, it is crucial to conduct experimental operations and targeted adjustments based on the characteristics of the method itself to adapt to different geographical and climatic conditions. However, none of the three methods mentioned in this article can achieve complete and stable operation of photovoltaic systems comparable to thermal or nuclear power. They can only strive to make the power curve as smooth as possible, acknowledging that changes in photoelectric efficiency due to day-night cycles and weather variations are inevitable [10]. Hence, it is essential to make advance estimates and implement preventive measures for abnormal situations. In specific implementation, the above three methods individually possess high universality; therefore, it is imperative to integrate and redesign these methods before practical implementation.

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