Impact of Using Photovoltaic Cells on Power System Stability

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Abstract

Photovoltaic technology is a fast-evolving technology that is considered to be efficient and sustainable for the growing energy needs of the world. Although it is a promising technological breakthrough, it needs to remain stable amidst different technical disturbances and survive under adverse conditions. Any loss of load can lead to voltage instability. Currently, it is a challenge for the scientific community to achieve the recommended protocols for solar cell stability. Diverse cooling techniques are known to enhance thermal and electrical efficiency and keep the photovoltaic cell temperature steady and raise its electrical efficiency. The paper discusses the key metrics and obstacles faced when using photovoltaic technology for commercial purposes. However, the stability of the Photovoltaic technology cells still remains limited, and there is a growing interest in the scientific community to improve stability, performance, and lifetime of Photovoltaic cells and explore the promising potential of Photovoltaic technology for higher performance.

Keywords: Power Stability, Renewable Energy, Solar, Photovoltaic cells

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Introduction

Photovoltaic technology is fast making progress, and for good reasons. The energy resources fast depleting in the world and the rising energy consumption have reinforced the needs and efforts to develop more efficient and sustainable technologies to suffice energy needs. Photovoltaic (PV) Cells are seen as a technological breakthrough because of their low environmental impact as well as economic cost. Although Photovoltaic technology is promising and compatible with cheap processing, it must pass strict standards to ensure power and environmental stability.

1.1 Photovoltaic Cells

Solar power generation has grown dramatically as it carries low maintenance cost, is noise-free, and is considered pollution-free. Solar power makes use of solar panels to change sun irradiation into electric energy with the help of the PV effect (Saidi, Slimene, & Khlifi, 2018). Solar photovoltaic and concentrated solar thermal are the two distinct methods for making solar power. However, out of these two, it is the photovoltaic option, which is the more mature and financially viable option for gentling solar power, as asserted by (Shah, Mithulananthan, Bansal, & Ramachandaramurthy, 2015).

Photovoltaic systems are the most widely used resources of the different kinds of renewable resources. A worldwide survey reports that by 2040 about 28% of the energy demand of the world would be fulfilled by solar energy (Paital, Ray, Mohanty, & Dash, 2018). When a PV cell is exposed to solar radiation, the P-N junction of the cell absorbs the photons that create a potential difference across the connections. As a consequence of the resulting photocurrent, the charge-carriers start to flow and are denoted as IPV (Siecker, Kusakana, & Numbi, 2017). The operating temperature on the surface plays an essential role in the energy conversion process and can impact the performance of a PV cell. High ambient temperatures can overheat the temperatures of the PV panel surface and lower the efficiency of the PV cell. The current PV panels are like a thin film made of crystalline silicon solar cells that exhibit better transient stability under sudden technical disturbances or changes in weather conditions (Budiansyah, Putra, Aryani, and Utomo, 2019).

1.1.1 Major Energy Resource

Solar PV has become a major energy resource at the global level, and there is a steady rise in the Solar PV power penetration in renewable energy power plants. The upcoming utility-scale solar plants are expected to handle grid stability and support much more efficiently (Kumar & Selvan, 2017). PV system doesn't have a turbine or a rotor, unlike the traditional generators, and therefore, there is no kinetic energy or inertia, which is essential for maintaining stability during disturbances. Thus, the inertia-less PV system is likely to face instability in case of any fluctuations. The frequency stability is maintained in a power system with inertial and primary support as well as automatic generation control (Gandhi, Kumar, Rodríguez-Gallegos, & Srinivasan, 2020).

As stated by Meng, You, & Yan (2018), photovoltaic technology is known to carry a high-power conversion efficiency, and organic-inorganic metal halide perovskites are seen to be the most promising photovoltaic materials in terms of high efficiency. Simulation analyses on LVRT or the low-voltage ride-through capability of PV inverter reflect that although photovoltaic cells with LVRT capability are set up on the grid system, they can get disconnected due to any fault in the grid or the voltage sag. Thus, it is essential to think about the transient stability and how it can be enhanced for power systems as asserted by Yagami, Ishikawa, Ichinohe, Misawa, & Tamura (2016).

1.1.2 Growing Market Demand

The market demand for PV energy is increasing by 40% annually, given the uncertainty of conventional fuel and the issues of carbon emissions (Budiansyah, Putra, Aryani, and Utomo, 2019). The local governments must incorporate the PV in the existing network and install the new technology without interfering with the performance of the current energy system. However, the performance and characteristics of PV are very dependent on the local weather condition. Solar Energy Technologies support development projects that research how to increase the efficiency of PV technologies and evaluate new materials. The hybrid organic-inorganic perovskite solar cells have shown significant progress in recent years and are highly efficient. However, there are still a number of issues and challenges, and one of the major issues concerns the stability and control of PV systems that need to be addressed. Stability issues such as low-frequency oscillations can be challenging, as asserted by Paital, Ray, Mohanty, & Dash (2018). While the stability issues can be handled with power system stabilizers, but sudden large and varying disturbances can be problematic.

1.2 Power Stability of Photovoltaic Cells

Power stability is the ability of the power system to remain stable amidst different types of technical disturbances. It should be able to survive under adverse conditions and restore conditions to acceptable conditions. The two categories of power stability are, namely, angle stability and voltage stability. Voltage stability is best understood as large-disturbance and small disturbance voltage stability. Any loss of load or faults in the system can lead to large-disturbance voltage instability, while gradual changes in load lead to small-disturbance voltage instability (Budiansyah, Putra, Aryani, and Utomo, 2019). The voltage stability of a power system is its ability to maintain stable voltages on all buses even during deviations.

1.2.1 Issues of instability

Any continuous increase or decrease in the voltages can lead to instability. Static Voltage and frequency stability are two important parameters of electric power quality. The imposed voltage level at one node has a direct impact on the voltage at other nodes, and it is essential to have the stability of the voltage within the system nodes (Sultan, Diab, Kuznetsov, Ali, & Abdalla, 2019). The transient stability relies on any large disturbance, such as a three-phase fault due to sudden disconnection of the PV system or the shutting down of the PV inverters. Any such disconnections in the PV system can have a negative impact on the transient stability of the power system (Saidi, Slimene, & Khlifi, 2018).

According to Shah, Mithulananthan, Bansal, & Ramachandaramurthy (2015), the large-scale research on photovoltaic cells must focus on all stability constraints instead of just a few. Thus, for a secure and reliable operation system, the equally important issues on stability constraints such as Small-signal stability, Rotor angle stability, Voltage stability would be equally important issues. As asserted by Munkhchuluun, Meegahapola, & Vahidnia (2020), any loss of voltage stability of the power system can cause widespread blackouts and lead to a voltage collapse. The dynamic voltage stability is the short-term voltage stability (STVS) or long-term voltage stability (LTVS).

1.2.2 Examining the instability

Changes in oscillation frequencies damping and mode shapes under different control strategies and parameters can impact the high PV penetration. The oscillation damping is seen to rise with an increase in PV penetration, and it means that one can create new oscillation modes by controlling PV (You et al., 2017). The high PV penetration in many countries could have serious consequences on the stability and reliability of power systems. It is the characteristics of PV systems that bring inherent challenges. The PV systems need to be examined in terms of voltage, frequency, rotor angle stability, protection, and flexibility (Gandhi, Kumar, Rodríguez-Gallegos, & Srinivasan, 2020). Power system stability is examined with multiple approaches to study the short-term effects on voltage stability of PV systems. It is equally essential to study transient stability in a PV system (Remon, Cantarellas, Mauricio, & Rodriguez, 2017). There is still a gap of knowledge regarding the effects of advanced controllers on the power system frequency and the stability of the transmission.

1.3 Current studies and challenges

An investigation of large-scale solar photovoltaic (PV) generation and the phenomenon of long-term voltage stability (LTVS) reveals that certain parameters of the solar-PV system like the reactive power gain, current limiting strategies leave an impact on LTVS (Munkhchuluun, Meegahapola, & Vahidnia, 2020). Lifetime and degradation rates are the stability-related parameters and recommended protocols for the tests for organic solar cell stability. The environmental impact of the solar cells can be by replacing materials such as spiro-OMeTAD in order to achieve record efficiencies and good stabilities. Ternary or quaternary cations in (FA-MA) PI active layers and the 2D/3D approach in devices are known to improve their life. However, the complex processing of spiro-OMeTAD adds to its limitations and makes it difficult to make cheap, perovskite solar cells. It is essential to look for alternatives in inorganic metal oxides and other carbon derivatives to extend the stability without loss of efficiency (Urbina, 2020).

1.3.1 Voltage stability analyses

Recent studies that made a comparative investigation of solar photovoltaic (PV) impact on system stability at different penetration levels under different scenarios find that the distributed solar PV generators are much more advantageous from the stability point of view (Tamimi, Canizares, & Bhattacharya, 2013). The loadability and voltage stability analyses are typically based on slow system dynamics and are linked to load evolution all through the day. It is a known fact that the efficiency of PV cells can decrease with the temperature increase, based on the kind of cell material (Saidi, Slimene, & Khlifi, 2018). Different types of power system stability are known to impact the power stability of photovoltaic cells in different ways. The impact of low and high photovoltaic generation has been used to study the eigen-values and voltage stability in PV systems.

The larger PV power plants should remain integrated within the grid utility in case of heavy disturbance in grid voltage (Sultan, Diab, Kuznetsov, Ali, & Abdalla, 2019). A study of the transient stability of various penetration levels of PV reveals the positive and negative impacts of PV. Simulation results show that a PV penetration level up to 30% can improve the transient stability of the power system while a negative impact is seen on a higher penetration level of 40% or more (Mohamed, Jeyanthy, & Devaraj, 2017). The critical modes in the system and their damping ratio rises with penetration level, and the improvement in the damping ratio is the connectivity of the larger number of PV plants and their ability to regulate voltage and frequency. With the increase in PV penetration, there is a reduction in the duration and amplitude of frequency (Remon, Cantarellas, Mauricio, & Rodriguez, 2017).

1.3.2 Cooling techniques

Diverse cooling techniques are known to enhance the PV system performance, and proper cooling is known to enhance thermal and electrical efficiency and increase the life span of the PV module. The cooling arrangement which is selected should keep the photovoltaic cell temperature steady and low so as to increase its electrical efficiency. For example, the photonic crystal cooling technology of high-quality tungsten photonic crystals preserve stability to 1400 °C (Siecker, Kusakana, & Numbi, 2017). When the influence of SPVG penetration level on the stability of Ontario power system was examined for different penetration levels in terms of small-signal stability and voltage stability, it was found that D-SPVG units can improve system stability considerably in comparison to the C-SPVG (Tamimi, Canizares, & Bhattacharya, 2013).

The work cycle of the PV cooling system can be optimized for higher energy gain with greater cooling. The cooling phase of the cycle must be short but long enough to achieve a significant temperature difference between the two steady states. The maximum energy sustainable pump head relies on weather conditions. However, there are other parameters for global plant optimization apart from the energy balance for the cooling system, and one has to consider plant installation cost and water consumption (Schiro, Benato, Stoppato, & Destro, 2017). AC transmission system (FACTS) devices are known to improve power system stability by controlling the rotor angle oscillations due to any load variation. Particle Swarm Optimization (PSO) is the new hybrid optimization approach and the differential search algorithm (QODSA), which are used for picking the optimal parameters to improve the PV system performance (Paital, Ray, Mohanty, & Dash, 2018). Results demonstrate that the QDSA based PID is the most effective for minimizing the oscillations and improve the system stability efficiently

1.3.3 Perovskite solar cells

According to Urbina, 2020), the important parameters for further development of perovskite solar cells are the stability of the devices keeping in perspective the economic cost and environmental impact. In order to achieve the successful commercialization of photovoltaic technology, the technology should be stable as well as environmentally and economically viable. While the single perovskite cells show good promise because of their low manufacturing costs and higher efficiency, it is their stability that is quite problematic. Currently, the longest lifetime of PSCs is for about one year, which is much less than the commercialized PV technologies. Thus, the stability issue of perovskite PV remains a key technological barrier in commercialization, and there are on-going studies on how to increase both efficiency and lifetime of the perovskite single cells (Meng, You, & Yang, 2018). Stability protocols such as ISOS can be used to assess stability in perovskite solar cell research and define the research roadmap and make further recommendations (Urbina, 2020).

In order to raise the capacity of the large-scale grid-connected photovoltaics, the capacity of the synchronous generator needs to be reduced. However, a lower capacity of the generator leads to lower system inertia and higher generator reactance, and that can further impact the transient stability negatively (Yagami, Ishikawa, Ichinohe, Misawa, & Tamura, 2016). However, there are technical challenges in large scale solar power generation because of the low inertia and variability in power output. Any reduction in conventional generator capacity leads to lower system inertia that can impact the transient stability of the power system negatively (Saidi, Slimene, & Khlifi, 2018). It is essential to treat the PV without a battery carefully before its installation on the power system and assess its stability against weather factors. Any disturbance in the PV can lead to fluctuations in the power supply and voltage drop. However, it can be taken care of by releasing the load in the substation (Budiansyah, Putra, Aryani, and Utomo, 2019)

1.4 Conclusion.

Due to the increasing demand for electricity and the rising costs of conventional sources, there is a growing interest in photovoltaic energy, which is seen as a promising alternative. PV technology is considered the most promising as the focus of energy development in the future as the world looks for more efficient and sustainable technologies. Although photovoltaic technology is progressing at a fast rate, there are still issues about efficiency and stability that need to be addressed. The above discussion concludes that it is essential to consider the key metrics when transferring photovoltaic technology from the lab to commercial products. The industry still faces the challenges of how to keep the costs low, get high power conversion efficiency, and achieve a higher stability and longer lifetime. Perovskite solar cells have shown promising potential for higher performance, but the stability of perovskite solar cells is still limited when compared to leading PV technologies. There is a tremendous interest in the fundamental research regarding extended lifetimes and improved stability. It is essential to further research and review the technical challenges that could influence the stability of the system. There is no denying that PV has emerged as the most promising renewable source for bulk power generation. Investigation of new materials and innovative device architectures needs to continue for subsequent improvements in the performance and stability of photovoltaic energy.

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