A review on Solar power integration into grids

Aanchal1, Vinod Kumar2

1,2Department of Electrical Engineering

UIET, Babasaheb Bhimrao Ambedkar University, Lucknow, India

**Abstract**

A study on the review of solar power's integration into electrical grids is made available. In addition to the fact that solar energy integration into non-renewable sources is important as it reduces the rates of consuming non-renewable resources hence reduce the dependence of fossil fuels, integration technology has become important due to the world's energy requirements which imposed significant need for different methods by which energy can be produced or integrated. By using the sun's energy and converting it from DC to AC, photovoltaic or PV systems are driving this transformation. Due to the current energy demand, the depletion of fossil fuel reserves, and environmental concerns, researchers and scientists are increasingly interested in integrating renewable energy from this source into networks.

Keywords: solar PV system, integration challenges, integration impacts.

Introduction

Photovoltaic (PV) power can be effectively injected into the national utility grid thanks to a network called solar-grid integration. This is a crucial technological innovation since the integration of standardized PV systems into grids optimizes building energy balance, enhances the PV system's economics, lowers operational costs, and adds value for both consumers and utilities [2]. As there is an increasing need for the use of alternative clean energy sources instead of fossil fuels, solar-grid integration is now a widespread practice in many nations throughout the world [1].

Solar-grid integration technology includes advanced inverters technology, anti-islanding technology, grid-plant protection tech­nology, solar-grid forecasting technology, and smart grids technol­ogy. “Inverter ranges from Light duty inverters typically (100–10,000 W), Medium duty inverters typically (500–20,000 W), and Heavy duty inverters typically (10,000–60,000 W) continuous output. Energy created by the solar array powers the loads directly, with any excess being sent to the utility, resulting in net metering [3]. Due to this interaction with the grid, inverters are required to have anti-islanding protection, meaning they must automatically stop power flow when the grid goes down [4]. Currently, advanced inverters devices that convert direct current solar power into alter­nating current power for the grid have features that could be used to help control voltage and make the grid more stable. During manu­facturing inverters are validated their advanced photovoltaic (PV) capacities by using the ESIF’s power hardware-in-the-loop system and megawatt-scale grid simulators.”

During simulation inverters are put into a real-world simulation environment and see the impact of the inverter’s advanced features on power reliability and quality [5]. “Islanding is the phenomenon in which a PV power distributed continues to power the grid even though electrical grid power is no longer present. According to IEEE 1547 Section 4, PV system power must be de-energized from the grid within two seconds of the formation of an island; this means PV Plant interconnection system shall detect the island and cease to energize the grid within two seconds of the formation of an island. Further, the inverter must not connect within 60 s of the grid re-establishing power supply after a power failure, sometimes called Reconnection Tim­ing Test” [4]. “This is often achieved through autonomous island detection controls. Such controls use one or more of a wide variety of active or passive methods to detect an island. Normally grid tie Inverters undergoes anti-islanding tests during manufacturing to check whether they connect and disconnect to the broader elec­tricity grid safely [5]. An additional new requirement concerns grid and plant protec­tion (G/P protection). This is the protective device that monitors all relevant grid parameters and disconnects the plant from the grid, if necessary.” “A freely accessible disconnection point for plants with more than 30 kVA of apparent power is no longer required, but more extensive grid monitoring including the power frequency and single error safety is usually stipulated [6]. Plants with less than 30 kVA of apparent power may still be operated with G/P protection integrated in the inverter. If all inverters include separate stand-alone grid detection with grid disconnection via the tie breaker integrated in the device, separate stand-alone grid detection may be omitted in the central G/P protection. This solution is a considerable cost-saver and is possible with all SMA inverters [6]. Grid forecasting involve assessing the grid’s health in real time, predicting its behavior and potential intervention and quickly responding to events which require understanding vital parameters throughout the electric infrastructure, from generation to the end use [5]”.

A smart grid technology is designed to “achieve a high penetration of photovoltaic (PV) systems into homes and businesses, it is an intelligent system capable of sensing system overloads and rerouting power to prevent or minimize a potential outage of power over the grid. According to Kempener et al. [7], when grid upgrades are required, whether to accommodate any renewable energy or for other reasons, it is typically much more cost-effective to include smart grid technologies than to use only conventional technology. Normally there are three different levels of renewable energy pene­tration in electricity systems – low, medium and high. These three levels are defined according to the grid modifications necessary to afford renewable. Renewable resources capacity penetration levels above 30% are considered to be high and usually require the use of smart grid technologies to ensure reliable grid operation [5]. A smart grid technology makes use of sensing and automated controls in the power transmission and distribution systems”.

Solar-grid integration has been researched by numerous researchers. P. Swain, S. Jagadish, and K. N. S. Uma Mahesh make an effort in [8] to identify the problems that result from integrating renewable energy sources with the current power grids and look for solutions to some of them, particularly the stability of voltage, through the control of reactive power and active power. After reviewing solar photovoltaic technologies, Parida et al. [9] came to the conclusion that these technologies have found use in a variety of energy-related projects, including the construction of integrated systems, pumps, solar home systems, desalination plants, and photovoltaic and thermal (PVT) collector technology. N. D. Kaushika and Anil K. Rai [10] studied load mismatch of grid-connected photovoltaic systems and examined the potential implications in an urban setting. Investigated is the sensitivity of solar cell characteristics to changes in the array's output power. The parameters of ageing and brand-new cells utilised in prototype field systems have been used to calculate the decline in the amount of power that is available. It was discovered that as solar cells age, the fractional power loss in a series string would rise from 2 to 12 percent. But with the right series-paralleling, this fractional power loss can be decreased to 0.4–2.4 percent. A new cascaded converter topology appropriate for large-scale solar power integration in a three-phase grid is presented by S. K. Yadav and B. Singh [11]. The novel method of cascading the voltage source converter connections from the output AC end is given. This connection offers a multilevel operation with five levels of in-phase voltage and nine levels of in-line voltage. In this design, a solar photovoltaic (SPV) panel is not need as much.

According to the study, the load match index for the case-study district is 42.4 percent when shadowing effects are not taken into account, and it drops to 38.6 percent when it is assumed that 10% of solar energy is blocked by the environment. This project was an example of how solar integration in buildings might be applied traditionally in relation to neighbourhood activities. There are numerous additional projects integrating renewables aside from applications to power networks. Degradation/aging difficulties, open-circuit faults in PV strings or modules, hot spots of defective PV modules, and bypass diode failure were all covered by Satyendra Vishwakarma et al. in their study [12]. One of the fundamental ideas behind smart grids is the integration of renewable energy sources with electrical infrastructure. There are various difficulties with integration because of the unpredictability and fluctuation of these sources. This essay examines how solar power technologies are integrated into power grids. The strategy is concentrated on coupling photovoltaic (PV) systems to power grids. Since power inverters are primarily responsible for transforming solar-generated DC voltage into AC, attention is being paid to inverter technology. One form of renewable energy, solar electricity, also has some major environmental effects. Various factors, including the particular technology employed, the location in which it was utilised, and a number of others, affect how severe the environmental effects are. Therefore, it is crucial to consider how solar integration may affect the environment. In this research, the advantages and disadvantages of solar-grid integration are also covered.

**Solar power generation system**

Concentrated solar power (CSP) and photovoltaic (PV) power are the two main solar energy generation technologies that are integrated with grid power. Similar to traditional thermal power generation, or solar thermal power generation, CSP generation turns thermal energy (steam) into electricity. However, Photovoltaic (PV) solar panels are different from solar thermal systems in that they use sunlight through the "Photovoltaic effect" to generate direct electric current rather than using the sun's heat to generate thermal power (DC). After that, inverters and other components are typically used to convert the direct current to alternating current so that it can be disseminated across the power grid network. PV systems do not create or store thermal energy because they solely produce electricity, which is difficult to store (in batteries, for example), especially at high power levels.

However, thermal energy storage methods can be used by concentrated solar power (CSP) systems to store energy. The capacity to store thermal energy has allowed solar thermal technology employing CSP to become more widely used in the power generating industry because it makes it easier to deal with the intermittent issues that are typically present in PV systems. These circumstances make CSP systems more appealing as thermal energy storage technology for large-scale power generation. Although CSP has greater grid integration performance, its large-scale expansion and deployment are now being constrained by the technology and high cost as it requires both steam and solar facilities, both of which have significant starting prices. Photovoltaic installations are currently advantageous due to declining PV costs and even the energy market environment [11,13].

**Solar system connected with Grid**



Fig. 1. Diagram of a PV power generating station.

The technology known as solar-grid integration enables the penetration of the current electrical grid with large-scale solar power generated by PV or CSP systems. Consideration and care must be given to this technology in all aspects, including the production, installation, and use of solar componentry. Effective connectivity of the degrees of solar energy penetration onto the transmission grid is necessary; this interconnection necessitates a thorough comprehension of the effects on the grid at various locations. The inverter is arguably the most crucial element for integration in a photovoltaic plant that employs PV modules to feed into the grid. However, the plant itself is made up of a number of distinct parts. The PV generator (solar modules), Generator Junction Box (GJB), Meters, Grid connection, and DC and AC cabling are some more parts. These are depicted in Figure 1. Any solar energy system depends on inverters, which are frequently referred to as the project's brains. The primary purpose of an inverter is to convert direct current (DC) output into alternating current (AC), the standard current type utilised by all commercial appliances. Despite variable load conditions, inverters must maintain constant voltage and frequency and, in the event of reactive loads, must either supply or absorb reactive power [3]. Inverters do more than just invert; they also reconcile the systems with one another and feed solar energy into the grid as efficiently as feasible. Thus, both the orientation, interconnection, and quality of the PV modules as well as the reliability and efficiency of the inverter have a significant impact on the yield of a PV system [14,5,4,6].

**Challenges, benefits and environmental impact of solar-grid integration**

Power typically travels from centralised generators to substations, then to consumers, in most electric utility systems. Power can be generated using solar energy in both directions. The majority of electrical distribution systems, however, were not created to support two-way power delivery. If the load and PV generation are not closely matched, even tiny amounts of PV may have an influence on system parameters for distribution feeder circuits that are long and serve rural or developing areas [15]. The likelihood of damage to the utility grid and effects on other utility customers served by the same distribution circuit increases when PV generation exceeds local energy demand [15]. Energy will also likely pass via the local substation if PV generation is greater than local energy demand.

Transmission lines are frequently needed for large-scale PV projects or farms, the majority of which are found distant from populated areas, in order to transport the electricity over long distances to the intended purpose. Since some of the energy is transformed into heat during transportation and lost, this necessitates greater expenditure in the construction of the transmission lines. Voltage stability issues, frequency instability issues, and general power quality issues are a few prominent difficulties with solar-grid integration. A distributed system is regarded as large-scale, in accordance with Belcher et al. [16], when its load exceeds 10 MW. Systems below this threshold are not eligible for power integration and frequently experience power quality problems. However, power quality issues also affect large-scale systems. Photovoltaic generating does not have the luxury of producing electricity on demand, whereas power generation plants that spin turbines conventionally profit from having total control over generation [16]. Issues with power quality include harmonics in addition to voltage and frequency. The main source of the harmonics issue is the power inverters used to convert sustainably generated DC voltage into AC. Certain loads that contribute frequencies that are multiples of 50 or 60 Hz create harmonics, which can prevent equipment from functioning as it should [16]. Voltage generation fluctuations that were not previously present in the grid are made possible by the inherently non-dispatchable qualities of PV systems (i.e., creation of electrical energy that cannot be turned on or off to meet society's fluctuating electricity needs). Storage and other immediate power-producing options are at the forefront of current PV research and development to address these voltage challenges [16]. Grid-connected voltage quality problems as well as the sporadic nature of PV generation itself must be taken into account. In order to function without interruption, power plants must be able to ride-through varied voltage level sags. Due to this, PV plants must be able to respond to voltage sags in the same way as traditional power plants [16].

“PV is also the only solar power generation technique that does not result in inertial power generation which proves to be a chal­lenging problem with large-scale grid integration. The absence of a spinning machine in PV integration is the cause of the lack of inertia fed into the grid” [16].

The fluctuation of insolation is another significant difficulty. The amount of insolation, or sunshine, at any particular location and time determines how much electricity is generated by photovoltaic, or PV, systems. Over- and under-generation have the potential to cause grid instability. The steps in a solution sequence for this problem are [17]:

* Using more precise forecasting algorithms to enable predictions of the potential fall in solar generation to the lowest penetration capacity.
* Installing solar over a wide area to lessen the effects of generation unpredictability brought on by local cloud cover.
* electricity demand by enticing consumers to utilize electricity when it is more readily available. shifting electricity supply by storing excess energy for later use.

The unpredictability of solar PV can also be reduced by distributing solar farms over a large geographic area or by deploying them very incrementally; there is no required minimum capacity size. The size of PV generating can range from hundreds of kilowatts to hundreds of megawatts, which gives it a great deal of flexibility in this aspect [18]. A utility can mitigate any site-specific cloud variability and concomitant rapid ramping up and down by spreading out the deployment of solar farms in smaller amounts across a larger area. When it comes to localized voltage issues, where it can be difficult to operate production assets (especially those with emissions), the utility may be able to address them by focusing on specific geographic areas for PV installations [18].

The integration of solar power into the grid has environmental implications. There are some important environmental effects associated with solar energy sources. The specific technology employed, the geographic location, as well as a variety of other elements, typically affect the environmental impacts' severity in different ways. Steps can be taken to successfully avoid or limit these impacts by knowing the existing and potential environmental challenges related with each renewable energy source, particularly solar energy sources. Larger utility-scale solar farms may cause issues about habitat loss and land degradation depending on their location. As stated in the Union of Concerned Scientists study [19], Depending on the technology, the geography of the site, and the intensity of the sun resource, different solar farms require different amounts of total acreage. According to estimates, CSP installations require between 4 and 16.5 acres per megawatt, whereas PV systems require between 4 and 10 acres. There is less opportunity for solar projects to share land with agricultural purposes than there is for wind installations. However, by placing solar systems in low-quality areas like brown fields, abandoned mining land, on the sea or a lake, or along existing traffic and transmission routes, the effects on the land can be reduced [19].

The majority of the hazardous compounds utilized in the PV cell production process are used to clean and purify the semiconductor surface. These substances consist of acetone, hydrogen fluoride, sulfuric acid, nitric acid, hydrochloric acid, and hydrochloric acid. Based on the type of cell, the degree of cleaning required, and the size of the silicon wafer, the quantity and kind of chemicals employed are determined [19]. Inhaling silicon dust while working poses concerns as well. In order to prevent worker injury from exposure to these chemicals and to ensure that manufacturing waste is disposed of appropriately, PV manufacturers must abide by the legislation [19,20].

**Conclusion**

Integrating PV systems into national grids can minimize generation costs, boost grid resilience, decrease transmission and distribution line losses, and lessen the need to invest in additional utility generation capacity. The purpose of this article was to evaluate current and upcoming discussions surrounding the generation of large-scale solar energy and its integration into a traditional grid that is dominated by fossil fuels. The majority of integration research has produced promising findings. Therefore, significant consideration should be given to this integration's implications on system stability and security even before plant deployments. Prior to the installation of the plant, the use of advanced integration technologies should be taken into account; this will enable the generation and distribution firm to anticipate any potential effects of PV integration and generation on system stability.

**References**

[1] V.C. Akubude, K.N. Nwaigwe, E. Dintwa, Production of biodiesel from microalgae via Nano catalyzed transesterification process: A review, Materials Science for Energy Technologies, Volume 2, Issue 2, 2019, Pages 216-225, ISSN 2589-2991,

[2] Sterling, J., McLaren, J., Taylor, M. and Cory, K., 2013. Treatment of solar generation in electric utility resource planning (No. NREL/TP-6A20-60047). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[3] WEC. Energy Resources. Retrieved from [https://www.worldenergy.org/data/](https://www.worldenergy.org/data/resources/) [resources/](https://www.worldenergy.org/data/resources/), 2018

[4] H. Anderson, Nelson, Austin, Miller, Brian, Chakraborty, Sudipta, Bell, Frances, and McCarty, “Michael. Experimental Evaluation of PV Inverter Anti-Islanding with Grid Support Functions in Multi-Inverter Island Scenarios.” United States: N. p., 2016.

[5] NREL. Renewable Electricity-to-Grid Integration. Retrieved from [https://www.](https://www.nrel.gov/) [nrel.gov/](https://www.nrel.gov/), 2011

[6] Scientists, U. of C. How Solar Pannel Works. Retrieved from [https://www.](https://www.ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work#.WrJAN3tuJZQ) [ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work#.WrJAN3](https://www.ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work#.WrJAN3tuJZQ) [tuJZQ](https://www.ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work#.WrJAN3tuJZQ), 2015

[7] [R. Kempener, P. Komor, A. Hoke, Smart grids and renewables–a guide for](http://refhub.elsevier.com/S2589-2991%2819%2930057-6/h0050) effective deployment, Int. Renew. Energy Agency November (2013) 47

[8] P. Swain, S. Jagadish and K. N. S. Uma Mahesh, "Integration of renewable sources of energy into power grid," 2017 IEEE Region 10 Symposium (TENSYMP), 2017, pp. 1-5.

 [9] [B. Parida, S. Iniyan, R. Goic, A review of solar photovoltaic technologies,](http://refhub.elsevier.com/S2589-2991%2819%2930057-6/h9000) [Renewable and Sustainable Energy Reviews 15 (3) (2011) 1625–1636](http://refhub.elsevier.com/S2589-2991%2819%2930057-6/h9000)

[10] Kaushika, N.D.; Rai, A.K. An Investigation of Mismatch Losses in Solar Photovoltaic Cell Networks. Energy 2007, 32, 755–759.

[11] S. K. Yadav and B. Singh, "Large-Scale Solar Photovoltaic Grid Integration with New Cascaded VSC Arrangement and Modified Switching Technique," 2021 IEEE 6th International Conference on Computing, Communication and Automation (ICCCA), 2021, pp. 20-25.

 [12] Satyendra Vishwakarma, Study of Partial shading effect on Solar module using MATLAB, IJAREEIE, 6(7), 5303-5308, July 2017

[13] IEC MSB, Grid integration of large-capacity renewable energy sources and use of large-capacity electrical energy storage, Iec 3 (2012) 102.

[14] [D. Ton, G.H. Peek, C. Hanley, J. Boyes, in: Solar Energy Grid Integration Systems, Sandia National Laboratories, 2008, pp. 4–19](http://refhub.elsevier.com/S2589-2991%2819%2930057-6/h0095)

[15] J. Katz. Grid-Integrated Distributed Solar: Addressing Challenges for Operations and Planning, Greening the Grid (Fact Sheet) (n.d.).

[16] B. Belcher, B.J. Petry, T. Davis, K. Hatipoglu, The effects of major solar integration on a 21-Bus system: technology review and PSAT simulations, Conf. Proc. - IEEE SOUTHEASTCON (2017).

[17] E. Mulenga. Impacts of integrating solar PV power to an existing grid Case Studies of Mölndal and Orust energy distribution (10/0.4 kV and 130/10 kV) grids, 1–142.Retrievedfrom[http://studentarbeten.chalmers.se/publication/](http://studentarbeten.chalmers.se/publication/218826) [218826](http://studentarbeten.chalmers.se/publication/218826), 2015.

[18] SMA. PV Grid Integration - Backgrounds, requirements, and SMA solutions. Technology Compedium 3.4, (May) (2012).

[19] E.M.A.A. Report. About the Energy Market Authority (Ema) (2011).

[20] Ashden. Solar for the grid. Retrieved March 18, 2018, from [https://www.](https://www.ashden.org/sustainable-energy/ashden-guides/) ashden.org/sustainable-energy/ashden-guides/, 2016