A Review on Trends and challenges of grid-connected photovoltaic systems

DRK. MAHESH
Asst. Professor,
MRCE

P. MANIKYA RAO
Asst. Professor,
MRCE

Abstract:

This paper presents a literature review of the recent developments and trends pertaining to Grid-Connected Photovoltaic Systems (GCPVS). In countries with high penetration of Distributed Generation (DG) resources, GCPVS have been shown to cause inadvertent stress on the electrical grid. A review of the existing and future standards that addresses the technical challenges associated with the growing number of GCPVS is presented. Maximum Power Point Tracking (MPPT), Solar Tracking (ST) and the use of transformer-less inverters can all lead to high efficiency gains of Photovoltaic (PV) systems while ensuring minimal interference with the grid. Inverters that support ancillary services like reactive power control, frequency regulation and energy storage are critical for mitigating the challenges caused by the growing adoption of GCPVS.

II.INTRODUCTION

It is generally accepted in the scientific community that human activity is affecting climate change and that a majority of this impact comes from fossil fuel combustion caused by the electric utility industry [3]. Conventional fossil-fuel generating facilities have in past met the majority of global electrical energy demands. However, environmental and climate change implications of fossil fuel-based generation present serious challenges to society and the environment [1]. Distributed Generation (DG), particularly Photovoltaic (PV) systems, provides a means of mitigating these challenges by generating electricity directly from sunlight.

Unlike off-grid PV systems, Grid-Connected Photovoltaic Systems operate in parallel with the electric utility grid and as a result they require no storage systems. Since GCPVS supply power back to the grid when producing excess electricity (i.e., when generated power is greater than the local load demand), GCPVS help offset greenhouse gas emissions by displacing the power needed by the connected (local) load and providing additional electricity to the grid. As such, during peak solar hours (maximum solar irradiance), fewer conventional generation plants are needed. In addition, GCPVS reduce Transmission and Distribution (T&D) losses. Although average T&D losses amounted to 5.7% in the U.S. in 2010, losses during peak hours are higher [2]. For example, the estimated T&D losses for Southern California Edison and Pacific Gas & Electric exceeded 10% in 2010 [4]. Locating DG assets close to loads can help to partially mitigate these losses.

This paper is organized as follows: section II summarizes the current state and trends of the PV market. Section III discusses regulatory standards governing the reliable and safe operations of GCPVS. In section IV we discuss the technical challenges caused by GCPVS. Since there are a number of approaches for increasing the output power of PV systems, i.e., Maximum Power point tracking (MPPT), Solar Tracking (ST), a combination of both [5] or by using transformless inverters, section V examines each method independently. We present evidence that these methods can indeed help improve the efficiency of GCPVS. In section VI, we explore recent developments in inverter technology and conclude with the changing role of GCPVS inverters in section VII.

II.Standards and requirements for safe operation of Grid-Connected PV Systems

The increase in the number of DG resources has introduced several technical challenges that have necessitated the development of applicable standards. These standards are intended to foster, rather than hinder the reliability, safe operation and further proliferation of grid-tied DG resources. Connecting large numbers of PV systems to the electrical grid without the appropriate regulatory standards and requirements poses a significant threat to the integrity and stability of the grid. A number of industry professionals, organizations and researchers have been working on defining and addressing the potential impacts of the mass adoption of GCPVS on existing electrical infrastructure and how to better prepare for and respond to the upcoming challenges. These organizations have had several technical sessions between 2013 and 2015 and some are close to completing their findings.

A. IEEE 1547

IEEE standard 1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems) is the technical guide[6]. This standard provides the guidance requirements for the design, construction, installation, safe operational performance and maintenance of these resources by ensuring compliance with local, regional and national codes. In addition, IEEE 1547 specifies the power factor, frequency and voltage tolerances, fault detection and anti-islanding characteristics that dictate the conditions with which a DG may remain connected to a utility. Inverters are required to detect unintentional islanding and disconnect from the grid such that there is no back-feeding onto a utility line that has been isolated for maintenance.

B. IEEE 929

While IEEE 1547 applies to all distributed resources under 10 MVA, IEEE standard 929 (Recommended Practice for Utility Interface of PV Systems) applies to GCPVS and several other inverter-based technologies that operate in parallel with the electric utility and that are 10 KVA or less.

IEEE 929 requires the inverter to continuously monitor the grid. It defines the behavior of the GCPVS when any utility abnormalities are present. For example, responses to abnormal conditions like loss of synchronization between the GCPVS and the utility, fault monitoring, PV system protection, isolation mechanisms and the maximum allowable trip time in cycles are specified when there is an abnormal voltage condition on the grid.

Table 1

Standards and Requirements for grid-connected distributed generators (GCPVS included)

General	Safety and protection	Power quality
Voltage regulation	Voltage disturbance	Harmonics mitigation
System frequency	Frequency disturbance	Direct current injection
Synchronization	Isolation device	Flicker
Monitoring provisions	Disconnect for faults	Power factor
Grounding	Reconnection	
Voltage unbalance	Anti-islanding	
Immunity	Surge capability	

III. Challenges caused by Grid-Connected PV Systems

As the overall costs of installing and owning GCPVS systems are declining, residential, commercial and utility scale adoption of this technology is on the rise. Although there are many benefits of GCPVS, such as its long working life (25–30 years), low operations and maintenance costs and obvious environmental advantages over fossil-fuel power plants, however, GCPVS have their own set of challenges. Due to their volatility, Hossain and Ali referred to the interoperability of GCPVS with the grid as a major concern [7]. According to Omran et al., due to the high penetration of GCPVs and its unpredictable output power, in the near future, several utilities and independent system operators will begin to enforce more stringent regulations regarding the inter-connection of GCPVS to the grid[8].

At the root of these claims is the inherent functional nature of GCPVS, primarily because their output generation decreases as the sun goes down. Consequently, they are unable to adequately contribute to the grid when demand increases in the hours following sunset (when demand for electricity is greatest). The California Independent System Operator (CAISO) created the duck curve (Fig.1.) to show the impact of GCPVS on the electric grid'soperations based on CAISO's real-time analysis and forecast of electricity net demand from 2012 to 2020. The net demand load represents the amount of conventional generation plants (excluding renewables) that will need to be on-line during different times of the day.

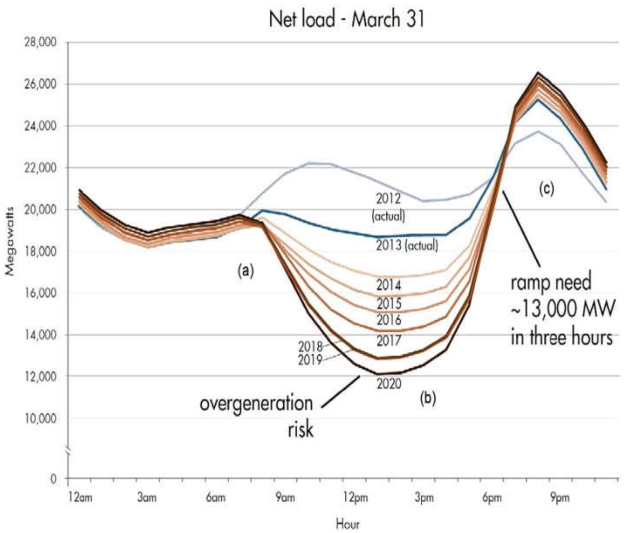

Fig. 1. CAISO's duck curve[9].

A.Optimizing the efficiency of Grid-Connected PV Systems

As discussed in the preceding section, the inherent nature of how PV systems operate makes it difficult to predict the power delivered to the load. However, GCPVS with higher efficiency tends to have less interference with the electric grid and the loads they are serving. By increasing system efficiency, it is possible to maximize output power during times of low solar irradiance and high unpredictability. Three methods of improving system efficiency are presented below.

B. Using MPPT to improve output performance

While several studies have been conducted on making GCPVS economically attractive [10-12], other research has focused on maximizing output power under varying temperature, lighting (irradiance) and load (current) conditions. In general, PV systems have low solar-to-electric conversion efficiencies that mostly depend on the amount of available unobstructed sunlight in the sky[14].

Secondly, the nonlinearity of the current/voltage curve and the power/voltage relationship exhibited by solar PV panels impacts the ability of PV systems to obtain higher efficiency rates [13]. Depending on the irradiance level and temperature, at any given time, PV cells operate at a fixed point.

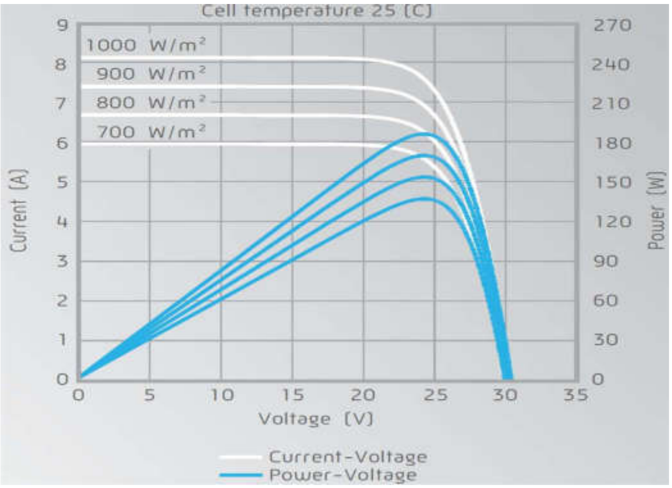

Fig. 5. The effect of irradiance on theI–Vcharacteristics of a PV solar module[13].

C. Effects of solar tracking

Solar trackers, unlike inverter based maximum power point trackers, are mechanical rotors that guide the PV panels in such a way that the panels are constantly position at an angle that allows them to receive the most sunlight. Stationary positioning of panels limits the surface area with direct exposure to the sun [15]. There are a number of interesting investigations that have been devoted to correctly determining the position of the sun.

Transformless inverters

The power available on the grid and for use by end utility customers is Alternating Current (AC) and as such, the Direct Current (DC) power provided by the output of Solar PV modules will need to be converted to AC in order for it to become useful. An inverter is needed to convert DC power into AC. In many inverter designs, transformers are added to provide galvanic isolation between the DC and AC components – for safety and to prevent damage to the sensitive electronic devices on the DC side of the inverter. Galvanic isolation ensures that there is no physical connection (or wires) between the primary and secondary sides of the transformer.

IV. Conclusion

Although the solar PV market has experienced astronomical levels of growth and cost reductions in recent years, there are many technical challenges and economic realities that need to be reconciled in order for DG resources like GCPVS to be at parity with conventional generation. For successful mass adoption ofGCPVs, new technologies must be developed that will allow the inverter to do more than just provide DC/AC conversions. Modern grid-interactive inverters will need to provide Volt/VAr control (power factor and voltage stabilization), frequency regulation, enable storage and utilize modern communications protocols, all at a reasonable cost. This new generation of inverters has been rightly termed "smart inverters" [16-18].

REFERENCES

1. Omer AM. Energy, environment and sustainable development. Renew Sus-tain Energy Rev 2008:2265–300.
2. U.S. Energy Information Agency. United States electricity profile. Summary statistics for supply and disposition of electricity, 1990–2012; 2012. URL http://www.eia.gov/electricity/state/unitedstates/.
3. Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Eickemeier P, et al. Intergovernmental Panel on Climate Change (IPCC): mitigation of cli-mate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014.
4. Wong L. A review of transmission losses in planning studies. Technical report. Electricity Analysis Office, Electricity Supply Analysis Division, Cali-fornia Energy Commission; August 2011.
5. HECO. Available from: http://www.hawaiianelectric.com/ (online) [acces-sed 18.12.2014].
6. IEEE Recommended Practice for Grid Interface of Photovoltaic systems, IEEE Standard 929.2000.
7. Hossain MK, Ali MH. Small scale energy storage for power fluctuation minimization with spatially diverged PV plants. In: Southeastcon, 2013 Proceedings of IEEE; 2013. p. 1–6.
8. Demand response and energy efficiency roadmap: maximizing preferred resources. Folsom, California: California Independent System Operator; 2013.
9. Ice Energy lauds landmark California energy storage bill. PR Newswire, http://www.prnewswire.com/news-releases/ice-energy-lauds-landmark- california-energy-storage-bill-104106193.html[Accessed06.09.2014.
10. Dalton DG, Lockington D, Baldock T. Feasibility analysis of renewable energy supply options for a grid-connected large hotel. Renew Energy 2009;34 (4):955–64.
11. Enslin JHR. Maximum power point tracking: a cost saving necessity in solar energy systems. In: IEEE industrial electronics society, vol. 2, 1990. p. 1073–7. http://dx.doi.org/10.1109/IECON.1990.149286.

12. Faranda R, Leva S, Maugeri V. MPPT techniques for PV systems: energetic and cost comparison. In: 2008 IEEE power and energy society general meeting— conversion and delivery of electrical energy in the 21st century; 2008. p.1–6.

13. Mitsubishi Electric Technical DataSheet, PV-UD185MF5 185Wp.

14. Shmilovitz D.On the control of photovoltaic maximum power point tracker via output parameters. IEE ProcElectr Power Appl 2005;152(2):239–48.

15.Koyuncu B, Balasubramanian K. A microprocessor controlled automatic sun tracker. IEEE Trans Consum Electron 1991;37(4):913–7.

16. Reno MJ, Broderick RJ, Grijalva S. Smart inverter capabilities for mitigating over-voltage on distribution systems with high penetrations of PV. In: IEEE 39th photovoltaic specialists conference; 2013. p. 3153–8.

17. Carnieletto R, Suryanarayanan S, Simoes M, Farret F. A multifunctional single- phase voltage source inverter in perspective of the smart grid initiative. In: Industry applications society annual meeting; 2009. p. 1–7.

18.Xue Y, Divya KC, Griepentrog G, Liviu M, Suresh S, Manjrekar M. Towards next generation photovoltaic inverters. IEEE Energy Convers Congr Expos 2011:2467–74.