ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Voltage regulation mitigation techniques in distribution system with high PV penetration: A review

Priyanka Chaudhary*, M. Rizwan

Department of Electrical Engineering, Delhi Technological University, Delhi 110042, India

ARTICLE INFO

Keywords:
Solar photovoltaic
Distribution systems
Voltage regulation
Energy demand

ABSTRACT

The share of power generated from solar photovoltaic (SPV) is increasing drastically worldwide to meet the ever increasing energy demands. The power generated from the solar PV is mainly connected to low voltage (LV) distribution systems. However, the power generated from solar PV is intermittent in nature as a results it creates a problem in grid stability and reliability. The technical impacts of high PV penetration into distribution systems are mainly on the current and voltage profiles, quality of power, power balancing, protection, losses in system, power factor, etc. To address aforesaid issues lot of research is required, therefore an extensive literature review is performed considering the current status, impacts and various technical challenges due to high PV contribution. In addition, the proposed study also provides the insights to the possible solutions for voltage rise problem due to high PV penetration in LV distribution system.

1. Introduction

The demand of electrical energy is increasing drastically because of urbanization, growth in population and industrialization etc. The renewable energy sources (RES) are being utilized globally to meet the energy demand due to various advantages. These advantages includes sustainability, increased economic growth, new employment opportunities, intensify human welfare as well as contribution towards climate safe future etc. The power generation from renewable energy resources was 28% as on December 2015. However it is expected to increase exponentially to fulfill the demand in the near future. The leading forces behind the increased deployment of SPV technology are declining cost of solar PV systems and incentives provided by the governments of various countries. The global capacity of PV during 2005–2015 is presented in Fig. 1 [1].

The integration of SPV into electric power system is increasing drastically. This provides more power from renewable energy sources but cause adverse effects as well in the distribution grid like voltage limit violation at point of common coupling, frequency disturbances, grid stability issues etc. Grid codes and regulations has been modified by the authorities to accommodate the grid connected PV systems. IEEE 1547, IEC 61727 and VDE-AR-N4105 are major standards for SPV integration as a distribution generator (DG) in low voltage distribution systems [2]. These standards define and used to maintain the stability and power quality specified by grid codes for SPV interconnections. Comparison based on power and voltage levels used by various standards is provided in Table 1.

Authors in [3] presented current and historic status of integration of renewable energy sources (RES) into utility grids, control and network planning. Codes and standards are also described by researchers with the technologies of grid integration. Voltage fluctuations are major concern for grid connected SPV systems which may lead to voltage limit violations. Overvoltage or voltage rise occurs when the PV penetration increases and cause reverse power flow which may cause unstable operation of grid. A typical low voltage (LV) system is usually design in such a manner that the power will flow from a high voltage (HV) substation to the low voltage consumer loads. Introducing SPV at distribution system level with high penetration distorts the voltage limits and with high voltage at consumer end reverse power flow starts. This undermine the security of the distribution network and stability of the grid.

With the massive utilization of solar photovoltaic energy generation as a distribution generation, it becomes mandatory to deploy efficient and coordinated control measures for the integration and measurement related issues. These control approaches are helpful in accommodating and facilitating the integration of SPV systems into distribution grid with benefits. Numerous approaches have been proposed by researchers to mitigate the voltage rise issues. The distribution voltage regulation techniques for high PV penetration can be broadly classified into three categories.

1. Electrical energy storage (ESS) based strategies
2. Strategies based on active power curtailment of SPV systems
3. Reactive power control based techniques

* Corresponding author.
E-mail address: priyankach.iilm@gmail.com (P. Chaudhary).

http://dx.doi.org/10.1016/j.rser.2017.10.017
Received 21 December 2016; Received in revised form 13 September 2017; Accepted 26 October 2017

Please cite this article as: Chaudhary, P., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.10.017

Nomenclature

E	Energy stored in battery storage
I	Current flowing in two bus network
P	Active power
P_{av}	Available active power
P_c	Charging power of battery storage
P_{cmax}	Maximum limit of charging power of battery storage
P_d	Discharging power of battery storage
P_{dbmin}	Minimum active power of dead band interval
P_{dmax}	Maximum limit of discharging power of battery storage
P_{dbmax}	Maximum active power of dead band interval
P_{min}	Threshold active power below which PV inverter should with minimum capacitive power factor
P_{max}	Threshold active power below which PV inverter should with minimum inductive power factor
ΔP	Change in active power
Q	Reactive power
Q_{lim}	Maximum possible reactive power
Q_{max}	Maximum reactive power generated by the inverter
Q_{min}	Minimum reactive power generated by the inverter
ΔQ	Required change in reactive power
R	Resistance
t	Time taken by battery to store energy E
ΔV	Voltage drop across the line
V_{dbmax}	Maximum voltage of dead band interval
V_{dbmin}	Minimum voltage of dead band interval
V_h	Higher voltage threshold
V_{max}	Threshold voltage below which maximum capacitive reactive power should be supplied by controller
V_{min}	Threshold voltage below which maximum inductive reactive power should be supplied by controller
V_R	Receiving end voltage of a two bus network
V_{ref}	Reference voltage for dead band selection
V_T	Lower threshold voltage limit
X	Reactive impedance

Greek symbols

∂	Partial derivative operator
η_c	Charging efficiency of battery storage
η_d	Discharging efficiency of battery storage

The energy storage system (ESS) used to store the excess power generation from solar PV systems in order to control the active or real power flow between the utility and the SPV power generation system. There are various types of storage systems are available for grid connected SPV systems. Different type of energy storage and their use in grid connected SPV system for distribution voltage regulation are provided in further sections with detail insight. Active power curtailment is another method to provide voltage regulation support in distribution systems. An inverter can be used to curtail the active power from PV system. Another method for active power control are also available in previous works which are also being discuss further in this paper. To maintain the voltage within limits at point of common coupling (PCC) one can provide reactive power support. This can also be done by using PV inverters and other technologies also. FACTS devices can also be used as voltage fluctuations mitigation devices as they can provide better voltage control functionality. Devices like STATCOM, SVC and shunt capacitor banks devices gives better voltage control and fast response in case of sudden voltage rise. These methods are also presented in detail further in this study.

Many review studies on voltage regulation in distribution system during high SPV penetration are available in literature. A comprehensive review on the problems associated with intermittent nature of SPV system power output when it is integrated with the distribution grid and mitigation methods is presented in [4]. The researchers provided a discussion on the methods for mitigating PV output power fluctuations for individual PV installation using energy storage, diesel generators, fuel cell, maximum power point tracking (MPPT), power curtailment and dump loads. A review study on the voltage regulation challenges raised from increased renewable distribution generation interconnection with LV distribution networks is presented [5,6]. Challenges of high PV penetration with voltage control strategies to mitigate the adverse effects on voltage profile is also presented. In addition, various topologies available in literature also discussed with favorable features of each method. However, review on detail description of mitigating methods especially on active power curtailment and reactive power control by PV inverter is rarely available in literature.

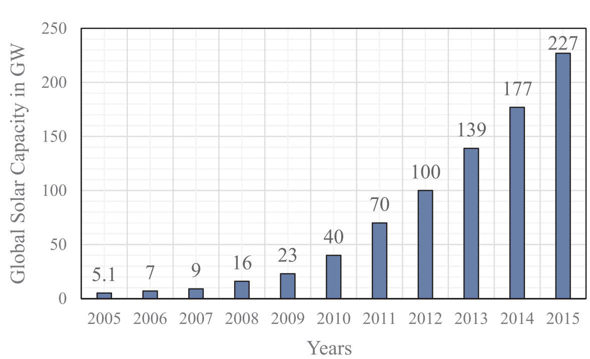

Fig. 1. Global PV capacity in GW between years 2005–2015.

In this paper, a comprehensive review on control strategies to mitigate the issue of voltage regulation due to increased PV interconnection in distribution networks is presented. Also, it was found that the inverter capability to curtail active power along with reactive power control in coordination with energy storage provides better voltage regulation. Based on the thorough discussion and qualitative analysis, the best features of each method are highlighted for future work.

This paper is organized as follows: Section 2 presents the impacts of high PV penetration at distribution network voltage. Section 3 provides a detail description of the energy storage systems (ESS) including battery storage and electric vehicle storage for overvoltage mitigations. Reactive power control for voltage rise mitigations is discussed in Section 4. Active power curtailment for voltage rise mitigations is presented in Section 5. Other methods for voltage rise mitigation in distribution systems for high PV penetration are presented in Section 6. The detailed discussion is presented in Section 7. Conclusion followed by the references is presented in Section 8.

2. Impacts of high PV penetration at distribution network voltage

High PV penetration in distribution networks may lead to various technical impacts on the system. Voltage rise issue is one of the most likely negative effect of the high PV penetration. This problem is

Table 1
IEEE standards for different renewable energy sources.

S. No.	Standard	System type	Voltage level	Power
1	IEEE1547	All RES	Primary/Secondary Distribution Voltages	≤ 10 MVA
2	VDE-AR-N4105	All RES	Voltages less than and equals to 1 kV	≤ 100 KVA
3	IEC 61727	Solar PV	Low voltages	≤ 10 KVA