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ScienceDirect

Procedia Computer Science 86 (2016) 301 – 304

Procedia Computer Science

2016 International Electrical Engineering Congress, iEECON2016, 2-4 March 2016, Chiang Mai, Thailand

Voltage Stability Analysis of Grid-Connected Photovoltaic Power Systems Using CPFLOW

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Abstract

This paper proposes a CPFLOW-based algorithm for analyzing voltage stability of grid-connected photovoltaic (PV) power systems. The main advantages of this algorithm are its computational speed and the ability to overcome the numerical difficulty near the point of voltage collapse. Using the proposed algorithm, a numerical study is conducted to analyze voltage stability of IEEE 14-bus and 39-bus systems under varying conditions. It is shown via numerical results that higher PV penetration levels can greatly improve the overall system voltage stability. An evaluation of PV installation locations also shows that each location on the grid has different degrees of suitability, regarding stability impact. Integrating PV generations at bad locations can cause serious degradation to system voltage stability.

Peer-review under responsibility of the Organizing Committee of iEECON2016

Keywords: Continuation power flow; voltage stability; photovoltaic system

1. Introduction

According to Thailand's Power Development Plan of 2015 (PDP 2015), solar energy is considered one of the most promising renewable resources in the country, and grid-connected solar farms will be increasingly developed in the next 20 years[1]. Due to the stochastic nature of PV generation and distinct characteristics from conventional synchronous generators, a significant increase in solar power generations in the grid may present technical challenges and major impacts on system stability.

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Peer-review under responsibility of the Organizing Committee of iEECON2016
doi:10.1016/j.procs.2016.05.082

Various studies have been conducted to simulate and investigate the effects of solar power on power system stability. In [2], voltage stability of grid-connected PV power systems is analyzed by using P-V curves. Transient stability and voltage phenomena related to PV generator interconnections are studied in [3]. A comparative study is conducted in [4] to investigate the effect of photovoltaic integration on system stability at different penetration levels.

This paper proposes a CPFLOW-based algorithm for computing the steady-state P-V curves of grid-connected PV power systems. By employing the techniques of CPFLOW [5], we developed a computationally fast and reliable tool for analyzing voltage stability of power systems that incorporate solar power generations. The proposed algorithm is applied to IEEE 14-bus and 39-bus systems to assess voltage stability and compute load margins under different conditions. The numerical results show that the impact of PV integration on system voltage stability depends on both installation locations and PV penetration levels.

2. Power Flow Analysis for Grid-Connected PV Power Systems

The model for grid-connected PV generation systems presented in [6] is composed of three parts: the DC part, the inverter part and the AC part as shown in Fig. 1. The DC part, which represents solar panels and cables, can be mathematically described by an I-V equation using the five-parameter model. A PV array is normally built from multiple PV cells connecting in both series and parallel. The voltage and current of a PV array can be computed by $V_{PV} = N_s N_{ss} V_{cell}$ and $I_{PV} = N_{pp} I_{cell}$ respectively, where I_{cell} and V_{cell} are the current and voltage of a PV cell, N_s is the series number of PV cell in a PV module, N_{ss} is the series number of PV module, and N_{pp} is the parallel number of PV module strands. The model used for the inverter is based on a three-phase half-bridge inverter circuit and sinusoidal pulse width modulation. The voltage output from the inverter can be computed by $\bar{V}_i = V_i \angle \alpha = (\sqrt{2}/4) M V_{PV} \angle \alpha$. where M represents the amplitude modulation ratio and α phase shift angle. Based on the principle of instantaneous power balance, the real power exported by the inverter P_i is equal to $P_{PV} = V_{PV} I_{PV}$ which is the DC power delivered by the PV array. The AC part can be characterized by the AC circuit transformation shown in Fig. 1. The total complex power exported by the PV system is $P_g + jQ_g$ and $\bar{V}_g = V_g \angle \theta_g$ is the voltage at the point of common coupling (PCC).

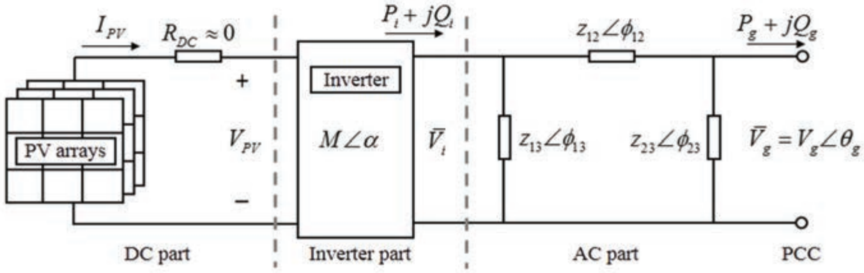

Fig. 1. Grid-connected PV generation system

The model presented in this paper is employed under the following conditions:(1) only steady state operations at the maximum power point (MPP) are considered, (2) all meteorological parameters are given under the standard test condition (STC) using irradiance of 1000W/m^2, cell temperature of 25°C and AM1.5, (3) voltage magnitudes and phase angles at PCC are computed by traditional power flow analysis, and (4) Q_g is predetermined which is the typical application of PV system. Under these conditions, power flow analyses of grid-connected PV power systems can be carried out by using the iterative algorithm proposed in [6] as illustrated in Fig. 2 .

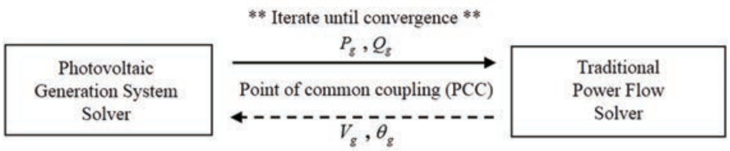

Fig. 2. Iterative power flow algorithm (PQ type) for grid-connected PV power systems