



Examination of the effect of the reactive power control of photovoltaic systems on electric power grids and the development of a voltage-regulation method that considers feeder impedance sensitivity

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ABSTRACT

When relatively high-capacity renewable photovoltaic (PV) systems are connected to a grid, they can increase or decrease the voltage along feeders because of reverse power flow, even exceeding \pm five percent of the rated voltage. Nowadays, grid-connected inverter-based PV systems that can control reactive power can alleviate such an increase or decrease in voltage by adjusting the reactive power, which is referred to as Volt/VAr control and management. Therefore, the objective of this paper is to (a) perform case studies to analyze the steady-state response of a large distribution network (i.e., with more than 1000 buses) with high-capacity PV systems that can control Volt/VAr (i.e., either producing or consuming reactive power) and (b) present a Volt/VAr-control method for three-phase voltage regulation that uses the positive-sequence sensitivity impedance matrix with power-factor constraints. This method is verified in the IEEE 34-bus test feeder. Thus, the proposed methods can be used to regulate the voltage of a bus to which a PV system is connected if the system controls reactive power. These proposed methods can also be used for various impact studies for the operation or planning of distribution systems with such PV systems.

1. Introduction

Photovoltaic (PV) systems with a capacity from tens to thousands of kW that are connected to a distribution network below 30 kV can reduce losses and daytime peak demand, which is known as peak load shaving. However, if these systems are not adequately regulated, they can increase or decrease the voltage because of reverse power flow. Thanks to inverters that can control reactive power, modern inverter-based PV systems that are connected to grids can actively control reactive power, which is referred to as Volt/VAr control and management. However, the connection of such PV systems to grids requires mutually well-coordinated voltage-regulation agreements between utilities and PV owners (or PV operators) if the PV systems regulate voltage. In fact, variations in the power output from PV systems can be regulated by utilities so that the feeder voltage can be maintained within a set range of the rated voltage (i.e., ANSI C84.1–2016 Range A [1] or EN 50160 [2]). In addition to voltage regulation, a distribution network that hosts PV systems should be able to detect abnormal or limited conditions according to the voltage ranges and clearing times, as presented in

[3,4]. Furthermore, settings for dynamic or static voltage regulation can be allowed only under mutual agreement between PV owners and utilities [3,4].

Many studies examined the steady-state response of distribution networks that are enhanced by grid-connected PV systems (with the unity power factor). The most well-known benefits of using distributed generation (DG), particularly PV in this study, is peak load shaving [5,6]. One study claimed that utility distribution systems would experience a substantial increase in DG systems over the following few decades and addressed issues regarding changes (i.e., overcurrent protection conflicts during operation with DG, instantaneous reclosing, improved reliability from installing DG, and transformer connections) [7,8]. Another study examined reverse power flow, voltage rise and fluctuations, and reactive power fluctuations that are caused by grid-connected PV systems during the steady state [9]. Furthermore, an analytical method that was based on voltage sensitivity analysis for a linearized power system model was proposed in [10]. Then, the maximum limits of acceptable power that a DG system could inject while not violating five percent of the rated voltage at the steady state were

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