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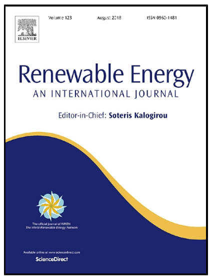

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Gaussian Process Regression based Inertia Emulation and Reserve Estimation for Grid Interfaced Photovoltaic System

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Abstract

Accurate power reserve estimation for a Photovoltaic Generator (PVG) is of paramount importance to combat frequency changes in a smart grid. Standalone PVG lacks inertia, or an internal power reserve due to power electronic converter grid-interface. Operating a PVG at deloaded percentage of its maximum power capacity mimics an internal power reserve, simulating the Automatic Generation Control (AGC) feature of synchronous machines. Thus, a deloaded PVG releases or absorbs the reserve according to the frequency variations for the grid stability. Moreover, an efficient switching between various reserves during grid operation is required. The common reserve estimation technique is to apply PVG manufacturer's specification based deterministic approach. In this work, we compare the deterministic modeling results with a statistical learning model of Gaussian Process Regression (GPR). The GPR model is trained by dataset of PVG maximum power values evaluated by load line analysis in a simulation, according to the irradiance and historical temperature of Abbottabad, Pakistan. The trained model performance is compared with the deterministic model in a simulation, where the PVG is saturated to turn on a synchronous generator. Time difference of turning on the backup generator between GPR model and deterministic modeling validates the importance of accurate reserve estimation.

Keywords: Deloading; Machine learning; Microgrid; Photovoltaic systems; Regression; Solar Power Forecasting

1. Introduction

Utility grid integration of converter based Distributed Generators (DGs) hampers the grid's inertial response during contingency events. Automatic Generation Control (AGC) of synchronous generators is a grid stabilizing feature in such events, and represents the majority of system inertia. However, the storage-less nature of majority of the DGs accounts for a minimum inertial response. The coupling of non-inertial DGs in a grid burdens the synchronous generators to impart more inertial response. For instance, continuous inclusion of DGs in the NORDIC power system is expected to reduce system inertia by 35 percent between 2010 and 2020 [1]. International Energy Commission cites that the renewable energy based DGs will account for half the global energy mix by 2035 [2] and appropriating the inertia of synchronous generators is a lucrative renewable research domain. Storage-less inertial support for DGs, particularly the Photovoltaic Generator (PVG) is a relatively new research frontier. The prospects of a deloaded inertial response in PVG are simplified energy resource management schemes and reduced economic stress by maintaining separate reserves to combat frequency excursion.

The contribution of PVG in global Renewable Energy Technology (RET) mix has doubled, since 2010 [3]. Photovoltaic (PV) systems are particularly conspicuous in energy market due to zero emissions, maintenance free nature, and an omnipresent supply of solar irradiance. However, the inherent storage-less characteristic of PVG dwarfs the benefits for utility grid interface. Thus, inducing inertia in a PVG requires a backup storage mechanism to gauge the power imbalance by the grid frequency deviation. Battery and ultracapacitors collaborating with a conventional generator are utilized for frequency correction [4], [5]. Wind turbine [6], flywheel [7], and dump load [8] also validated a merit in frequency support. Generally, a synchronous generator attempts to overcome grid frequency faults by forcing the speed governor to run slower or faster. AGC monitors the grid frequency and manages a multilayered architecture of primary and secondary frequency compensating reserves [9]. Rotating mass in a synchronous generator represents backup power reserve, and is equivalent to the overall system inertia [9], [10], [11]. Backup power reserve management is of paramount importance in a microgrid operation to maintain system frequency within secure margins. The alteration of Maximum Power Point (MPP) of a PVG with the grid frequency variations is an explored domain [12]. The deloaded PVG reserve to combat frequency deviations is proven equivalent to a battery based inertial support [13]. A modified controller computes the backup reserve and enforces PVG with more reserve to impart more inertial response, and vice versa. The reserve calculation technique relies on an assumption that the ambient MPP location is linearly proportional to the MPP under Standard Test Conditions (STC) [14]. According to [15], the magnitude of