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Comparative analysis of the variability of fixed and tracking photovoltaic systems

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Abstract

Growing penetrations of PV generation in electrical networks pose new challenges for electricity industry operation and planning. Characterising the variability of PV generation can assist in these tasks. This paper presents a comparative short-term (5 min) variability analysis for fixed-tilt, single-axis tracking, dual-axis tracking and concentrator PV systems using time-synchronised data from The Desert Knowledge Australia Solar Centre (DKASC) in Alice Springs, Australia. A number of analysis and data presentation techniques are presented to assess different aspects of this variability over the course of the day, and across different seasons. Results highlight the very different variability characteristics of fixed tilt and tracking PV systems, and hence the importance of differentiating between different PV system types when analysing their potential operational impacts on the electricity grid.

Keywords: Photovoltaics; Solar tracking; Solar power generation; Intermittent generation

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1. Introduction

Grid connected photovoltaics (PV) has made remarkable progress over recent years and is now achieving significant penetrations in a number of electricity industries around the world (Energy Policy Network, 2012). The technology presents a major opportunity to reduce the environmental impacts of electricity industries, and its costs have fallen markedly over recent years (Morgan et al., 2012). However, the very variable and somewhat unpredictable nature of the solar resource by comparison with the conventional energy option poses some challenges for power system integration (Panel on Climate Change, 2011). PV system output can vary significantly from time frames of seconds through hours to days, seasons and even years. Secure and reliable power system operation requires that supply precisely meet demand (and losses) at all times and locations within the network. There are ever present challenges for maintaining this supply/demand balance. Load varies on daily, weekly and seasonal cycles and exhibits considerable uncertainties. A wide range of possible contingencies also have to be considered, including the sudden loss of a large conventional generator or network element. PV's operational characteristics therefore do not represent an entirely new challenge for power system operation, however it does potentially add to the complexity of operational decision making. PV generation exhibits marked daily and seasonal cycles. It also exhibits

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potentially considerable variability within these cycles depending on the weather and, particularly, cloud cover. The actual operational characteristics of particular PV systems therefore depend greatly on these conditions at their particular location. However, they will also be impacted by other design and engineering choices including the technical specifications of key equipment such as the PV panels and system size, and its spatial arrangement. A particular issue is the orientation and tilt of fixed panel systems, and the potential use of tracking mechanisms or concentrator systems. Tracking systems orient the PV panels so that they follow the sun across the sky over the day. Concentrator systems orient reflecting surfaces towards the sun in a similar manner, but then concentrate this direct solar insolation onto the PV cells. The overall amount and general daily and seasonal timing of PV generation is, naturally, of key interest to PV system owners and operators as well as other electricity industry participants. This has been a key consideration in the choice between fixed and tracking systems given the generally greater output and extended morning and evening performance of tracking systems, yet also their greater complexity and cost (Drury et al., 2013). However, the variability and unpredictability of this PV generation is also a key issue for power system operations. Such variability changes supply/demand balance and hence system frequency generally, and local network flows and hence voltages, locally. Power systems are generally required to operate within strict frequency and voltage standards and high penetrations of PV may often increase the challenges of meeting these. However, PV outputs that are well correlated with load can actually reduce power quality challenges while modern PV inverters offer opportunities to both mitigate adverse PV impacts, and even reduce underlying-pre-existing voltage problems, through active and reactive power management (Demirok et al., 2009; Liu et al., 2008; Kerber et al., 2009; Hen-Geul et al., 2012; Wenxin et al., 2013; Goodwin and Krause, 2013; Huijuan et al., 2012). Characterising the expected 'unmanaged' output of PV generation yet also its variability, is required before these potential adverse impacts and management opportunities can be ascertained. Of particular focus in this paper, are the potential implications of fixed orientation and tilt PV systems versus tracking and concentrating configurations on the nature of such short-term output variability. The solar insolation reaching a PV panel generally reflects some mix of direct (that is, directly transmitted) and indirect (reflected) insolation. The amount and mix of these depends on the particular weather conditions, and the orientation of the panels with respect to the position of the sun. Sunny skies and panels oriented directly towards the sun maximise the direct component of total insolation. For fixed tilt panels, mornings and evenings will often see a high component of indirect insolation falling upon the panels. Adding to the complexities, concentrator systems can only concentrate direct insolation onto the PV receiver. As such it might be expected that the variability of fixed versus tracking and concentrator systems might differ significantly. Solar monitoring has long recognised the importance of accurate estimates of both direct normal insolation (DNI) and diffuse insolation in determining expected system performance, although the expense of DNI stations has often limited their application. With respect to actual experience with PV systems, however, there have been challenges in performing comparisons of the variability of these different possible system designs given all of the other factors driving variability. Work to date addressing the variability of PV systems has generally been concerned with the impacts of PV generation on the electricity grid at the system and distribution level due to its intermittent nature. Typically the PV generation profile used for the impact analysis is presented but without an associated analysis of its dynamic behaviour. Such a dynamic characterisation might include for example, how the level of PV generation variability changes over the course of a day or season, ramp rates, temporal and spatial correlation and variability across different time scales from seconds to minutes to hours and beyond (see, for example, Bai et al., 2007; Bebic et al., 2008; Lew et al., 2010; Saadat et al., 2011; Ueda et al., 2008; Miyamoto and Sugihara, 2009; Papaioannou, 2008; Enslin and Heskes, 2004; Tan and Kirschen, 2007; Batrinu, 2006; Enslin, 2010). Work which does provide some discussion on the characterisation of PV variability includes (Renne et al., 2008) which present an analysis of ramp rates. The PV output data set used in this analysis is computed using the PVWatts model for 1 min irradiance measurements fixed at a given latitude. Mills et al. (2009) provides a brief analysis on the aggregate variability of a number of single-axis tracking systems. As part of an investigation utilizing battery storage to mitigate PV intermittency, (Mossoba et al., 2012) presents the results of three deployments of one, three and 17 irradiance sensors finding that ramp rates reduce with spatial diversity, and that the frequency and magnitude of ramp rates are much greater over 1 min averages compared to one-second measurements. In Curtright and Apt (2008) the data set used for analysis includes three single-axis tracking systems and a distribution function on the frequency of the percentage change in output is presented along with the power spectrum and a correlation measure between the three sites. Spatial and temporal correlation of PV output is again discussed in Lave and Kleissl (2010) where data from four sites across Colorado is analysed, finding that correlation reduces with distance and increases with time period. Hoff and Perez (2010) presents a model showing how the aggregate variability for a fleet of PV systems reduces according to the number of systems, cloud transit speed and the area of which the systems span. Hoff and Perez (2012) expands on this work and verifies the model against actual measured irradiance data. In Click et al. (2012), a variability analysis of various PV generation deployment scenarios for Florida, USA is presented. In contrast to (Renne et al., 2008; Mills et al., 2009; Mossoba et al., 2012; Curtright and Apt, 2008; Lave and Kleissl, 2010;