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Control strategies to use the minimum energy storage requirement for PV power ramp-rate control

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Abstract

Over the last few years, the considerable increase in the number of multi-MW PV plants has led transmission system operators (TSO) to express concern over potential PV power fluctuations caused by transient clouds. As a result, new grid codes are being issued in order to include new criteria that make it easier for the TSO to react appropriately to harmful short-term power fluctuations. Faced with this situation, some type of energy storage system (ESS) is required in order to smooth out these fluctuations and comply with the regulations. Previous studies dealt with the ESS capacity required to comply with the maximum allowable ramp-rates stated in the grid code regulations, for any PV plant size for the worst fluctuation model. As the sign of the first fluctuation is unknown, a double capacity battery is required to absorb both the upward and downward fluctuations. In this paper we propose two innovative management strategies which make it possible to half the size of the ESS state of the art. The general validity of both strategies has been confirmed through simulations carried out with real operational PV power output data taken every 5 s in the course of one year at the 38.5 MW PV power plant of Moura (Portugal).

Keywords: Grid-connected PV plants; Power fluctuation smoothing; Ramp-rate control; Energy storage sizing

1. Introduction

The variability of irradiance due to cloud passage can produce significant fluctuations in the power generated by large grid-connected PV plants. Although these fluctuations are directly absorbed by the power system in the form of frequency variations, if they exceed the permitted limits then there is a risk of a power system failure. This, together with the high levels of penetration achieved by the PV power generation sector over the last few years, has alerted grid operators and promoted research initiatives to study these fluctuations (Marcos et al., 2011a, 2011b). Specifically, a PV output ramp-rate as high as 63% of the rated capacity/minute was revealed at the 1.2 MW La Ola island power plant (Jolmson et al., 2012), whilst power variations of up to 90–70% per minute were recorded, respectively, at 1 MW and 10 MW PV plants (Marcos et al., 2011a) and variations of 70% per minute were found at a 5 MW PV plant (van Haaren et al., 2014). Other multi-megawatt PV plants showed ramp-rates per minute of up to 50% for a 4.6 MW (Hansen, 2007) system and 45% for a 13.2 MW PV plant (Mills et al., 2011). Furthermore, we measured variations of up to 54% per minute for a 38.5 MW (250 Ha) PV plant in Moura (Portugal)

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(Marcos et al., 2014). Transmission system operators (TSO) have been observing with great concern the considerable increase in the number of grid-connected multi-MW PV plants. As a result, they have issued new grid codes to deal with this issue, including new criteria to make it easier for the TSO to react appropriately against harmful irradiance fluctuations, i.e., fluctuations with a time scale of less than 10 min (CRE, 2014; NERSA, 2012; PREPA, 2012). This risk is particularly significant for places with high PV penetration rates and small grids such as islands. It is precisely in islands (Puerto Rico) where new grid codes (PREPA, 2012), are becoming more restrictive and are limiting the maximum fluctuations over a period of time, typically 1 min, for a specific value, 10%, based on the transformer power (P_N) of the PV plant under consideration. Furthermore, in other countries such as Mexico (CRE, 2014), the target stipulated in the regulations is even more restrictive, being around 1–5% per minute. In this context, the PV power fluctuations are greater than the restrictions imposed by these regulations and, as a result, some type of energy storage system (ESS) is required in order to comply with the same. ESS are considered to be a key factor in the construction of new PV plants given the fact that such a system increases the price of PV electricity production. Consequently strategies that are able to comply with the regulations whilst using the least possible storage capacity are absolutely necessary.

A number of energy storage technologies and controls for smoothing out fluctuations have been proposed in the literature. As regards the storage technology, electric double-layer capacitors (EDCL) (Kakimoto et al., 2009; Kinjo et al., 2006; Monai et al., 2004), battery energy storage (Hund et al., 2010; Traube et al., 2013) or fuel cells (Rahman and Tam, 1988) are just some of the possibilities.

Furthermore, at present, the most-used strategies are ramp-rate control (Alam et al., 2014; Kakimoto et al., 2009; Khanh et al., 2010; Li et al., 2013; Ruifeng and Saha, 2010; Wang et al., 2012) and moving average control (Chanhom et al., 2013; Datta et al., 2011; Hund et al., 2010; Khanh et al., 2010; Monai et al., 2004; Moumouni et al., 2014; Tesfahunegn et al., 2011). There are also other strategies available as the constant production (Beltran et al., 2013; Darras et al., 2012), however this goes beyond smoothing out the fluctuations in short periods of time and require a much larger ESS. One of the advantages of the moving-average control is the use of less ESS capacity at the expense of an energy increase through the ESS which implies higher losses and cycling degradation. Some studies (Perez and Hoff, 2013) propose to solve this issue with the use of both forecast prediction and the clearness index. In any case, the great advantage of the ramp-rate control is that only acts when the fluctuation exceeds the maximum allowable ramp-rate value, a fact that implies lower cycling degradation. In previous studies (Marcos et al., 2014), the ramp-rate control strategy was reviewed and analysed in order to quantify the capacity needed to comply with a given allowable ramp-rate variation. In particular, an equation was given to calculate the storage capacity required to support the worst case fluctuation at a PV plant. In other words, a fluctuation when the PV plant is in full operation in clear sky conditions compared to completely cloudy conditions, or vice versa. As the sign of the first fluctuation is unknown, a double capacity battery is required to absorb both the upward and downward fluctuations. Hence, the state of charge (*SOC*) reference must be set at 50%. Considering the fact that this increased capacity involves high PV plant overheads, it therefore follows that a second control, making it possible not to double the storage system would be extremely useful. In order to reduce the capacity of the ESS we propose two new strategies that make it possible to resolve this issue by improving the state of the art and halving the ESS requirements for the ramp-rate control.

The paper first discusses the state of the art of the ramp-rate control strategy (*Strategy* 0) and then goes on to present the two novel strategies implemented. For the first strategy, all the inverters are involved in the PV plant control limiting them to comply with a certain variation per minute during upward fluctuations. For the second strategy, the control is based on the two PV plant production limits: the maximum PV plant power which occurs under clear sky conditions ($P_{PV,Max}(t)$) and the minimum PV plant power which occurs with complete cloud cover ($P_{PV,Min}(t)$). Therefore, as a function of the instantaneous PV power, it is then possible to obtain the *SOC* needed to smooth out any potential fluctuations. These strategies have been successfully validated through real operational one year, 5 s PV power data at the 38.5 MW PV power plant at Moura (Portugal).

2. Experimental data

The strategies were validated with PV production data already used in other studies (García et al., 2014; Marcos et al., 2014) and which have been available since May 2011, corresponding to 5 s synchronized records of the output power of all the inverters at the 38.5 MW Amareleja (South Portugal) PV plant (Fig. 1). In this case, the period chosen for the study was the calendar year of 2012. This

Fig. 1. Aerial view of the Amareleja PV plant.