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Detecting clipping in photovoltaic solar plants using fuzzy systems on the feature space

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Abstract

We propose the use of a fuzzy system evaluating a feature space extracted from the daily power production profile of a photovoltaic solar plant. The fuzzy system proposed is able to detect inverter power limiting situations, as well as stages where the photovoltaic solar plant is showing steady state power production. The approach has been validated using an experimental real grid connected photovoltaic plant located in Spain. The results demonstrate that the method is suitable for online detection, as well as for labeling incoming online data from the photovoltaic power production for a posteriori off-line analysis.

Keywords: Power limiting; Clipping; Fault detection; Fuzzy system; Feature space; Sliding window

1. Introduction

Nowadays, energy obtained from fossil fuel is still, by far, the most used source of energy in the world (World Bank, 2011). During the last years, renewable energy sources are attracting more and more attention, and all over the world the number of Photovoltaic (PV) systems is rapidly increasing (Ossenbrink, 2009). Thus, Grid-Connected Photovoltaic (GCPV) power plants — domestic plants with few kWp only or utility scale plants with several MWp – represent the power technology with the highest rate of growth (Chine et al., 2014). The decreasing price of photovoltaic modules has supported the fast development of PV systems (Feldman et al., 2014; McCrone et al., 2012) (compare also (Pacas et al., 2012) for additional reasons).

An important key factor for a further growth of renewable energy sources is to improve the reliability of such alternative power plants. For solar panels, several test parameters for ensuring quality during power production are known at the level of singular solar cells (Agilent Technologies, 2009).

But even with quality assured solar panels, situations occur where the generation of electricity exhibits steady states. Usually these states happen when the maximum power of the inverter is reached and, by security reasons, the inverter limits its maximum output power (Luoma et al., 2012; Guerrero-Perez et al., 2014). However, steady states may also occur due to aging or malfunctioning of the inverter or other components in the system, and they might be eliminated by repairing or replacing the related components. Since the profile of the power generation might, nevertheless, look like the same in such situations

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as it would be in case of clipping, there is a demand and need for advanced techniques for differentiating the cases.

Note that today the usage of microinverters is spreading, allowing to pursue the maximum power point for each panel separately. Thus, a panel in a string of panels in series that produces less current will not affect the other panels. However, the microinverters generally are not monitored, so it is more difficult to find clipping effects in any of them. The technique described in this article can also be applied to determine if at some point, one of the panels is affected by clipping. This situation is specifically interesting to detect mismatches between a PV module and its inverter.

This work present a Fault Detection (FD) method allowing to determine an irregular energy production of a GCPV due to entering a steady state generation phase. The method will allow online monitoring and online labeling of data for an a posteriori analysis of the GCPV. The online monitoring will provide a fault signal as fault detection indicator during the GCPV system operation, if clipping occurs in a situation when it should not appear. Such situation should be specified by the inverter manufacturer and is typically related to the tolerance of the nominal output power at the operation conditions.

The work is organized as follow: Section 2 describes the problem to tackle, Section 3 presents previous knowledge about fuzzy systems, Section 4 describes the method developed in detail, Section 5 describes the data used to validate the method and Section 6 presents the results obtained during the experiments. Finally, Section 7 discusses conclusions of the work.

2. Problem description

Since the beginning of the development of photovoltaic technology, the most important and so long the most expensive element has been the photovoltaic solar cell and thus the solar module. However, during the last years its price has decreased up to 70% compared to its price five years ago, becoming more cost effective to increase the peak power Pp[Wp] of the solar plant, even over the nominal power $Pn[Wn]$ of the inverters. By doing so, the total energy generated during a year is higher than if the solar modules don't overpass the maximum or nominal power of the inverter. The due price is a higher investment in solar panels, so it must be applied in the optimum point. Also the maximum voltage and current allowed by the inverter in its direct current (DC) side should never be overpassed. The effect of applying this strategy is the "clipping" of the power signal. The name clipping comes from the fact that this power limiting effect produces a flattening effect on the daily production profile of the system. Fig. 1 shows an example of the phenomena.

When clipping happens, usually the V_{dc} input increases and the I_{dc} input decreases, moving the generated power to a point that is not the maximum power point, so part of the solar energy is not converted into electricity, but the lower cost of the inverter compensates this fact. In this sense, clipping is an effect that should be controlled in order to avoid an excess in the energy that could be used, despite of the economic benefits of this strategy. Also, clipping should only appear when the output alternating current (AC) power reaches the nominal limit of the inverter. It will be useful to analyze if clipping effects occur at different power levels or in situations where it shouldn't happen. This is the objective of the use of a fuzzy system exposed in this work. The results would be combined with the analysis of the status of the specific inverter to determine if clipping in such a situation is normal or not. A fault situation detected by this strategy will contribute to an early detection and replacement of damaged inverters, thus leading to a decrease in energy losses.

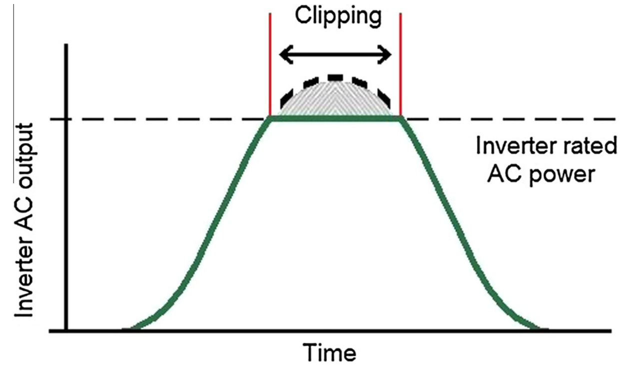

Fig. 1. Power limiting (clipping) example.

3. Fuzzy sets and fuzzy systems

Fuzzy set theory, introduced by Lotfi Zadeh in 1965 (Zadeh, 1965), established a line of research claiming to be a substantive departure from the conventional quantitative techniques of system analysis (Zadeh, 1973). The main features of a fuzzy system are: (i) linguistic variables, (ii) conditional statements establishing simple relations among variables and (iii) algorithms characterizing complex relations. All the development spun around the assumption that the key elements in human thinking are not numbers, but linguistic expressions and that fuzzy sets and in particular the labels assigned to them as linguistic interpretations may better describe the human understanding of particular (control) problems and relations. The following paragraphs highlight the main definitions in Zadeh (1965, 1973).

Fuzzy sets. A fuzzy set A differs from an ordinary (crisp) set because, instead of allowing membership degrees only from $\{0,1\}$, it assigns to each object x from a universe of discourse X a degree of membership $\mu_A(x)$ to the fuzzy set A, from the unit interval $[0,1]$. Thus, given a space of objects X, a fuzzy set A is characterized by its membership function, thus

$$\mu_A(x) : X \rightarrow [0,1], \quad (1)$$