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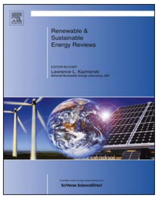

Review of state-of-the-art: Inverter-to-array power ratio for thin – Film sizing technique

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ABSTRACT

Numerous sizing methodology for the combination of inverter and PV array components have appeared in the literature including guidelines and third-party field studies. In this paper, the state-of-the-art is presented to collect a relevant information related to the sizing ratio around the globe as well as introduces a new concept of inverter sizing strategy via power-voltage (P-V) technique for grid-connected photovoltaic (GCPV) system installations. According to the literature survey, the sizing ratio had been identified as an important role in preventing the power clipping as well as achieving the system optimization. Most of the researchers noted that the sizing ratios was determined based on geographical latitude because of different irradiance distribution and operating temperature at specific site. This study will lead to the identification problem by summarizing the existing derating factor related to sizing ratio and formulas with sizing technique available, which makes it difficult to obtain reliable and optimized performances for the application of grid-connected photovoltaic system. The result showed that the proposed technique could optimally solve the problem of design and also effectively reduce overall return-on-investment (ROI) under the different scenarios and diverse meteorological conditions due to the dynamic behaviour of the TFPV technologies.

1. Note

Solar Photovoltaic (PV) technology has many advantages which is freely and abundant sources as well as eco-friendly attractive to harvest energy from the sun for various applications around the globe. However, several weaknesses and challenges in solar PV technology has encountered when designing and sizing which have been constantly discussed as the disorder nature of the instability phenomenon called Light-induced degradation (LID) normally occurred in Thin-film (TF) and Potential-induced degradation (PID) in crystalline PV module technology that could lead to the long-term technological risk in terms of durability and reliability on its real field performance [1,2]. However, two challenges in solar PV performance have been constantly discussed are durability and reliability because of the potential that has not been fully utilized until nowadays.

2. Introduction

Numerous researchers were agreed that the biggest factors contributing to the decrease performance in GC system's operation is a temperature derating factor, f_{temp} [3]. Traditionally, PV module technology from crystalline Silicon has been the preferred choice of the commercial market due to the higher energy conversion efficiency and the most significant drawback normally came from the temperature coefficient during operated in harsh environments. In contrast, the Thin-film PV technology also had proven its advantage in terms of energy yield under humid and warm climates due to a broad spectral response as well as a superior temperature coefficient.

Towards optimization, many efforts have been made towards the needs of the PV array and inverter to be suited with an accurate design methodology in optimizing the GCPV system [4–8], this issue still arising until nowadays in a number of systems installed [9–11]. Especially in TFPV technology, this issue was neglected in terms of the inverter sizing with this type of LID phenomenon, and mostly energy losses in the event of power clipping, thus deoptimized the system. Consequently, undersizing the system by several researchers

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Abbreviations: a-Si, Amorphous-Silicon; BOS, Balance-of-system; CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain; FSEC, Florida Solar Energy Center, USA; IAP, Inverter-to-Array Power; IFC, International Finance Corporation; IEA, International Energy Agency; LID, Light-Induced Degradation; NREL, National Renewable Energy Laboratory; PID, Potential-Induced Degradation; SNL, Sandia National Laboratories; STC, Standard Test Conditions, 1000 W/m2, 25ºC Module Temperature and AM 1.5 Spectral Distribution; UFSC, Universidade Federal de Santa Catarina, Florianópolis, South Brazil

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and designers will affected the selective BOS component such as grid-inverter and other system protections when dealing with this type of PV module technology [12].

When dealing with the type of PV module technology and inverter, the combination of both components are becoming more vital in achieving and optimizing the system installed. Both derating factors such as sizing ratio values whether *c*-Si or TF PV technologies have different methodologies under sizing and designing stages. Most of the surveyed studies were focused on the optimal ways using *c*-Si PV module technology, and only four examples related to the TF derating factor as empirically studies were conducted in [13–16]. Generally, the best practice of sizing ratio is under-sizing inverter about 10% to 40% with respect to PV array power capacity, led to the system optimization for *c*-Si PV technology under long-term operation [17–19]. However, TF derating factor, f_{k_tf} has been seen as the most problematic during sizing stage. Additionally, the current practice of inverter design strategy, several factors need to be considered based on local geography and climate, interval measurement, types and characteristics of PV module technology and inverter chosen in determining the optimum value of the derating factor in GCPV system, especially in the use of TFPV technology for low-latitude regions.

This paper attempts to bridge this gap by empirically analyzing and summarizing associated with the sizing ratio's state of-the-art based on the type of PV module technology used around the globe as well as introducing a new concept of inverter sizing strategy via power-voltage (P-V) technique with ability to give an optimum value of the sizing ratio. It also contains a framework related to the sizing ratio with systematically reviewed by collecting and dividing third-party publications into five major different climates based on Köppen-Geiger climate classification as an input in formulating the current issue based on the multiple studies. The digital world map for Köppen-Geiger climate classification is freely available online at [20].

Surprisingly, many empirical studies focused on the local real impact with most of the researchers were investigated due to the sizing optimization via crystalline Silicon (*c*-Si) PV module technology. It will focus or strengthen our study by collecting relevant information on regional and worldwide as significant input and make comparison related to Inverter-to-Array Power (IAP) ratio derating factor.

3. Review of the literature

For TFPV technology, stability remains a topic of active research about more than 35 years and most of the LID mechanisms have been discussed and still persists as a fundamental problem for use of TFPV modules. A brief context of the several situations under outdoor measurement related to the impact of derating factor towards TF GC system was discussed in this section.

Atmaram et al. [21] conducted a study on the a-Si PV modules performance of 15 kWp GC system found that about 16% degraded in the power output and stable in the first 6 months under warm temperate climate, fully humid with hot summer (Cfa) at Orlando, Florida. L. Mrig et al. [22] presented field study in Golden, Colorado for over two years at NREL test site under BSk climate. Both of a-Si PV modules were demonstrated a different number of power degradation rates by 25% to 30% (SJ) and 20% to 25% (DJ) due to LID phenomenon. These PV modules were experienced a strong degradation during 5 months of outdoor exposure.

Wirth et al. [23] claimed that the initial behaviour of a-Si PV modules could be illustrated by an exponential decay curve and completed stable within 3 to 10 months with the degradation rate was about 22% in Freiburg, Germany under Cfb climate. A recent study by Munoz-Garcia et al. [24] evaluated that the initial power output and stabilization period tested at CIEMAT, Spain. The a-Si TFPV module has experienced a rapid decline in power of approximately 20% after first 6 weeks of outdoor exposure under warm temperate climate with dry, hot summer (Csa).

A review from various groups regarding with LID phenomenon and stabilization period was extensively discussed in [25], which classify this metastable behaviour under various geographical and climatic conditions.

3.1. Derating factor and recommendation for TFPV technology

The derating factor in *c*-Si PV technology was not complicated than TFPV technology in terms of system design considerations. As noted by numerous researchers, they more concerned related to the number of electrical parameters such as power, current and voltage outputs generated by TFPV modules which typically higher in the early outdoor exposure as compared to the case of *c*-Si PV technology. Only three researchers have expressed a negative impact on the use of *c*-Si PV technology in respect of the sizing consideration due to the LID phenomenon. Only one study was carried out by Marion et al. [26], which takes into account the value of sizing ratio was about 0.98. The recommended value should be varied in the range from 0.90 to 0.99 when designing and sizing stages. Other authors by. Munoz et al. [27] investigated that the initial power stabilization of *pc*-Si showed less than 1%, and *mc*-Si PV technology exhibited about 1% whereas only a few cases more than 4%. All of them were demonstrated a stability in several days of exposure. One recent study summarized by Köntges et al. [28] have shown that the initial light-induced degradation (LID) usually occurs in the range of 2% to 4% in *c*-Si technology and the power reduction mostly dominated by potential-induced degradation (PID).

From the point of view in terms of TFPV technology, Köntges et al. [28] was summarized that the potential of the LID phenomenon in TFPV technology especially a-Si PV modules normally can be generated by 10% up to 30% within the first months of outdoor exposure.In dealing with TFPV technology, it required more consideration if using the undersized inverter because of the LID phenomenon. Only a few of these considerations found in a number of guidelines and PV manufacturers, as listed in Table 1.

3.2. Review of sizing methodology

Several sizing methods were developed by researchers and solar industry players collected and divided into two approaches. All information was summarized in an effort to collect the best design based on inverter strategies related to the sizing ratio as follows:

- Guidelines and PV manufacturers
- Analytical work of third-party publication

3.2.1. Matching derating factor of sizing ratio based guidelines and PV manufacturers

According to the Clean Energy Council (CEC), Australia's guideline [39] reported that the size of inverter could be determined by multiplying the peak power of the PV array capacity at STC rating with the values of derating factor for TF and *c*-Si PV technologies given at 0.889 and 0.76, respectively. These values for two types of PV module technologies were determined by three types of derating factors such as manufacturing tolerance, dirt and temperature. In the case of an efficient design, the nominal AC power output of the inverter could be designed not less than 75% of the rated PV array power. In dealing with TFPV technology, the selection of inverter size must be considered an additional initial output of LID phenomenon that could generate up to 25% of the