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Photovoltaic system assessment considering temperature and overcast conditions: Light load efficiency enhancement technique

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ABSTRACT

Currently, there is an ongoing trend to promote photovoltaic systems as they are a sustainable option for power generation. However, the efficiency conversion of solar energy into electric energy can diminish due to adverse environmental conditions and the performance of power processing circuits. Several approaches have been proposed to mitigate the negative effects of high temperatures and light load operation on power converters. Nonetheless, in areas with hot climates and overcast conditions, the efficiency consequences must be specifically evaluated. In this paper, the assessment of an approach to enhance the converter efficiency at low power levels is presented. The approach employs hybrid-switches within a transformerless converter topology, in such a way that, under light-load operational conditions, soft-switching is achieved. The technique is evaluated for ten specific sites from which there is ample meteorological data available. Results indicate that a 1.35 percent increase in overall efficiency can be obtained with the proposed approach, with an annual surplus energy of 7220 W h for a 1 kW system.

1. Introduction

Nowadays, the fast development in solar energy sources has fostered the deployment of photovoltaic (PV) systems, which are being installed throughout the world, at power levels ranging from a few hundred watts, up to large solar farms rated at mega-watts. As shown in Fig. 1, a PV system includes a set of solar panels, followed by a power-electronic stage aimed at adapting the electric energy to levels suitable for consumption by the connected loads.

Due to the high initial investment required, the profitability of a PV system depends on the capability to take maximum advantage of the solar resource available at the installation site. PV systems are typically installed outdoors, and the exposure to all kinds of environmental conditions can affect the energy conversion. The capability might be affected by external circumstances such as ambient temperature (Mulcué-Nieto and Mora-López, 2014; Popovici et al., 2016), full or partial shading conditions (Bai et al., 2015) and dirt on the panels surface (Kimber et al., 2007).

In the panels, the energy conversion is altered by multiple factors, such as the module type (Aste et al., 2014; Carr and Pryor, 2004; Huld et al., 2009; Rabosky, 2015), and mismatches between individual panels within a PV array (Chamberlin et al., 1995; Shirzadi et al., 2014). Further, the performance can also be affected and enhanced by manipulating the system on site with sun tracking devices and reflectors (Abd Malek et al., 2010; Arlikar et al., 2015; Poulek et al., 2016) and by the accuracy of maximum power point tracking (MPPT) algorithms (Chen et al., 2015; Eldin et al., 2016; Rezk and Eltamaly, 2015; Verma et al., 2016).

In areas with a combination of warm weather and overcast conditions, power generation can be reduced due to, first, the effect of high temperature on the panels (Day et al., 2016; Hasan et al., 2015; Kant et al., 2016), and, second, to a light-load operational regime which forces the inverter to operate at low efficiency power levels. Such is the case of sites located at the Gulf of Mexico shore. It has been found that the payback period is larger than in other areas of the country, and potential users are reluctant to invest in PV systems.

Several approaches have been taken to improve the inverter efficiency. One approach is to use configuration without transformers, which provides efficiency improvements ranging from 1% up to 4% (Calais et al., 1999; Islam et al., 2015; Patrao et al., 2011). Since a large percent of the inverter losses are due to the dissipative characteristics of the hard-switching regime, especially at high operating frequencies, a second approach is to apply soft-switching techniques (Fathabadi, 2016; Madani et al., 2011; Xuewei and Rathore, 2014). A third approach is to apply efficient modulation techniques, such as the selective harmonic elimination technique

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Nomenclature

EN_{AC}	output inverter power (W)
G	irradiance (W/m^2)
$\mathbf{G}$	irradiance vector (W/m^2)
G_{pOA}	measure plane of array irradiance (W/m^2)
G_{STC}	irradiance at STC (W/m^2)
I_L	inverter series current (A)
$\mathbf{P_{LLET}}$	output power vector supplied by the LLET inverter (W)
$\mathbf{P_{PV}}$	output power vector available at the module (W)
PR_{corr}	corrected performance ratio
$\mathbf{P_{ref}}$	output power vector supplied by the non LLET inverter (W)
P_{STC}	installed power rating (W)
T_{air}	air temperature (°C)
T_{amb}	ambient temperature (°C)
T_{cell}	cell temperature (°C)
$\mathbf{T}$	cell temperature vector (°C)
T_{STC}	cell temperature at STC (°C)
V_{DS}	switch drain-source voltage (V)
V_G	switch gate voltage (V)
V_{wind}	wind speed (m/s)
δ	temperature coefficient (−%/°C)
$\boldsymbol{\eta}_{\mathbf{LLET}}$	LLET inverter efficiency vector
$\boldsymbol{\eta}_{\mathbf{PV}}$	module electric efficiency vector
$\boldsymbol{\eta}_{\mathbf{ref}}$	non-LLET inverter efficiency vector

Abbreviations

a-Si/μc-Si	micromorph tandem-cell
c-Si	crystalline silicon solar cell
LLET	light load enhancement technique
MPPT	maximum power point tracking
multi-Si	polycrystalline solar cell
NOCT	nominal operating cell temperature
OPV	organic solar cell
POA	plane of array
PV	photovoltaic
SPWM	sinusoidal pulse width modulation
STC	standard test conditions
ZCS	zero current switching

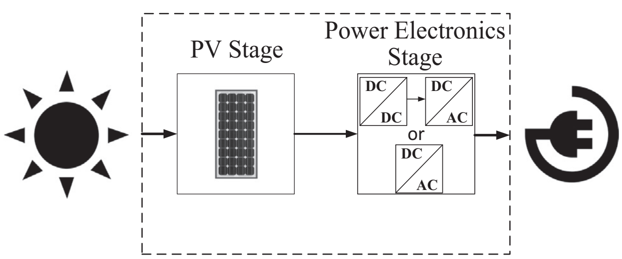

Fig. 1. Photovoltaic system.

(Moeed Amjad and Salam, 2014). This modulation has been successfully applied to conventional single-phase configurations (Khemissi et al., 2012), and to multilevel inverters (Sanchez Reinoso et al., 2012).

In this paper, the evaluation of an efficiency enhancement technique at low power levels is presented. The technique employs hybrid-switches to build a transformerless converter topology, in such a way that, under light-load operational conditions, soft-switching is achieved. The annualized surplus energy generated is assessed for ten sites selected along the Gulf of Mexico coast, and numerical results of daily, monthly and annual energy production are presented. The performance ratio of each site is compared with the surplus energy produced, and its feasibility is evaluated in systems with frequent light load operational regimes.

2. PV converter

The PV converter, shown in Fig. 2, is a transformerless full-bridge inverter configuration, widely used as a single phase grid tied converter due to its good performance and simplicity (Ahmad et al., 2013; Serban, 2015; Thang et al., 2015; Vijayarajan et al., 2016). Its efficiency will be compared with the efficiency exhibited by a conventional full bridge converter, comprised of IGBTs without soft-switching conditions.

As can be seen in Fig. 2, in each leg the upper switch is an IGBT, and the lower switch, the so called hybrid switch, is a parallel combination of an IGBT with a MOSFET. The MOSFET is kept off when the system is operating at medium and high load, in such a way that only the IGBTs commute to generate the output AC voltage waveform. At light load conditions, zero current switching (ZCS) is performed by the series connection of the IGBT and MOSFET. Fig. 3a shows the schematic of the current flow when S1 and S4a are conducting. Fig. 3b shows the corresponding current and voltage waveforms. From t_0 to t_1, the current is flowing through S1 and the S4a. At t_1 both switches are turn-off. Since the current I_L flows through both switches, turning off the MOSFET effectively eliminates the tail current in the IGBT.

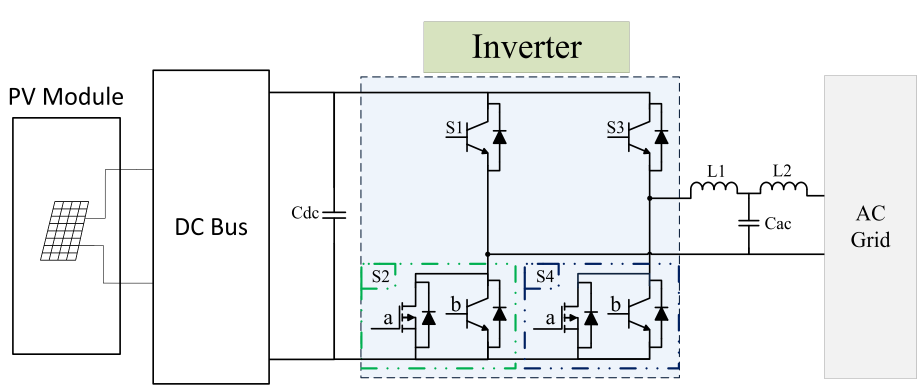

Fig. 2. Small scale PV system with the proposed transformerless inverter.