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Determination of maximum solar power under shading and converter faults—A prerequisite for failure-tolerant power management systems

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ABSTRACT

According to the fact that the performance of power management systems depends on generation forecasts, a scheme is proposed to detect the shading fault and the converter failure in a PV system and determine the maximum available solar power in the presence of these faults. Since the MPP of a PV array under uniform and partial shading faults is smaller than that of non-shading condition, for MPP tracking operations, difference between acquired and estimated power is an indicator for the shading fault. However, when the load power is small enough to be satisfied by the shaded PV array, the defined voltage ratio is used to detect the shading fault. In the case of shading fault, maximum available solar power is determined based on the output power of the PV system. Converter failure, which is modeled as the switch stuck-open fault or the switch stuck-on fault, is also considered in this paper. It is shown that under the switch stuck-open fault, the output power of the PV system will be zero; while, under the switch stuck-on fault, the output power shows a sinusoidal behavior. Based on the PV system power analysis, a procedure is also proposed to detect the converter failure and determine the maximum available solar power under this fault.

1. Introduction

The demand for reducing pollutant emission in electricity generation field, and also expansion of distributed generation systems, micro grids are the most significant reasons for increasing attention to the renewable energy resources [1]. Micro-grids are defined as a cluster of loads, distributed energy resources, and storage devices. It is accepted that for excellent operation of the micro-grid, a power management system (PMS) is essential to manage power flow in the micro-grid [2].

Regarding PMSs, optimization-based approaches have gained more attention in the literature, in which power flow is supervised by minimizing a cost function, which is derived based on performance expectations of the micro-grid and considering some operational constraints. It should be remarked that, although optimization-based approaches guarantee the optimal power flow under any conditions, it heavily depend on generation forecast for the renewable energy resources. Errors in estimating maximum available power may severely affect the obtained optimal solution, such that the optimal solution may no longer be optimal or even feasible. Hence, PMS must be adopted to appropriately treat the errors of the estimated parameters. In this context, some works are reported which mainly deal with designing a PMS to manage power flow in the absence of failed resources [3–8]. In these works, no effective failure detection schemes are reported and failures

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Nomenclature

MPP	Maximum power point.
PMS	Power management system.
PV	Photovoltaic.
A	Cell deviation from the ideal p-n junction characteristic.
C_B	Capacitance in the model of battery bank.
E_B	Voltage source in the model of battery bank.
E_{go}	Band-gap energy of the semiconductor used in the cell.
f_{sw}	The switching frequency of the power IGBT.
h_1, h_2	Sliding manifolds.
i_c, v_c	Current and voltage of a cell.
i_D	Current of the diode.
I_{mp}	Maximum power current of the PV module.
i_o	Output current of the dc/dc converter.
i_R	Load current.
I_{or}	Reverse saturation current.
I_{ph}	Generated photocurrent of a cell.
i_{PV}, v_{PV}	Current and voltage of the PV array.
I_{rs}	Reverse saturation current at reference temperature.
I_s	Short-circuit current of the PV module.
I_{sc}	Cell short-circuit current.
i_w	Represents the contribution of the wind generation system.
K	Boltzmanns constant.
K_I	Short circuit current temperature coefficient.
L, C	Electrical parameters of the dc/dc converter.
n_{Batt}	The number of charge/discharge cycles of the battery bank.
P_{avg}	Average output power of the PV system.
P_D	Demanded power.
P_f	Fictitious power.
P_{mp}	Maximum power point of the PV module.
P_{PV}	Output power of the PV array.
$P_{\mathrm{PV}}^{\max}$	Maximum available solar power.
P_R	Load power.
q	Charge of an electron.
R_B	Resistance in the model of battery bank.
R_s, R_{sh}	Series and shunt resistance of the PV cell.
R_v	Voltage ratio.
T	Cell temperature.
T_r	Cell reference temperature.
v_B	Battery bank voltage.
V_{mp}	Maximum power voltage of the PV module.
V_{oc}	Open-circuit voltage of the PV module.
η_{PV}	An indicator for the system efficiency.
λ	Solar insolation.

are assumed to be known *a priori*. Moreover, the failed resources are not utilized for power demand satisfaction, which can hamper the efficiency of the system.

As stated above, micro-grid means a group of interconnected loads and distributed energy resources. Solar energy is one of the most important renewable energy resources, which its use in micro-grids is now increasing rapidly all over the world [9]. Although control issues and schemes in PV systems have been reported by so many researchers in the past few years, however, failure or possible faults in such systems and maximum solar power under these faults have not been extensively investigated. Partial shading is one of the main faults in a PV system which decreases the output power of the PV system [10–12]. Partial shading can be caused by things such as snow, tree shadow, birds, and moving clouds. It makes PV cells reverse biased and act as an external load consuming the produced power by the other PV cells; this phenomenon is called hot-spot. Bypassing shaded PV cells through bypass diodes has been proven to be an effective strategy in protecting hot-spot damage and helping to reduce the decrease of output power of the PV system. However, bypass diodes leads to a few local maximum power points (MPPs) existence in the power-voltage profile of the PV system [13,14], where some works are presented to track the real MPP in this case [15–20].