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Active damping network in DC distributed power system driven by photovoltaic system

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Abstract

An instability phenomenon may occur in DC electrical systems due to undesirable source–load interaction and the behavior of power electronic loads that act as a constant power load. The present study focuses on DC electrical systems associated with constant power behavior. The phenomenon occurs such that each converter has its own internal control function for its output voltage regulation. The converter tends to draw a constant power which therefore produces negative incremental input impedance within its bandwidth. An active damping technique is proposed to improve the stability of a DC electrical system consisted of photovoltaic arrays, an LC filter and a constant power load. The active damping network was controlled to behave as a small-signal effective damping resistor over a DC network so that any instability in the DC bus will be reduced and eliminated. This technique eliminates the oscillations produced by the constant power load. MATLAB/SIMULINK modeling and simulation are used to confirm the validity of the proposed technique.

Keywords: Active damping network; Distributed power system; DC bus instability phenomenon; Constant power load; Photovoltaic arrays

1. Introduction

Commonly, there are two types of loads in the electrical systems, namely; the conventional positive resistive load that requires constant voltage for its operation and the constant power load (CPL) that consumes a fixed amount of power regardless of the received voltage (Rivetta et al., 2005). A CPL is a power electronic converter that sinks a constant power from the system bus and produces a constant power characteristic in which the supply voltage reduces when the input current increases. This subsequently leads to an incremental of negative impedance (Cespedes et al., 2010).

The behavior of constant power load becomes a concern for DC distributed power systems (DPS) such as those found on More Electric Aircraft (MEA) and electric vehicles. The increasing use of CPL will result in complex DPS with multiple power electronic converters to supply various static and dynamic loads (Emadi et al., 2006). However along with many benefits associated with DPS, such as reduction in overall system weight, cost, and maintenance, it may present several problems. One possible problem might be a loss of system stability in the DC bus bar due to the undesirable source–load interaction and the negative incremental resistance produced by constant power loads (Cespedes et al., 2010; Xinyun et al., 2007). The analysis of DPS becomes more complicated due to system complexity and involvement of different types of load converters that act as constant power loads. Nevertheless, the study and analysis of these systems become easier if one considers only a single load converter that has been

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Nomenclature

K_r	active damping input resistance gain	V_{in}	input voltage
AC	alternating current	V_o	output voltage
ω	angular frequency	L	inductance of the converter
I_c	capacitor current	C	capacitance of the converter
CPL	constant power load	ω_f	high pass filter corner frequency
I_{in}	converter inductor input current	Z_D	input impedance of active damper
P_{in}	converter input power	Z_i	input impedance of load converter
R_L	CPL input resistor	S	laplace operator
$h(s)$	current controller	I_L	load current
K_a	current controller gain	MPPT	maximum power point tracking
ω_{co}	current controller loop bandwidth	MEA	more electric aircraft
h_r	current controller transfer function	Z_0	output impedance of LC filter
R	damping resistor	R_p	parallel resistor
V_s	DC bus supply voltage	PV	photovoltaic
DC	direct current	PVA	photovoltaic array
DPS	distributed power system	R_s	series resistor
D	duty ratio	K_v	voltage controller gain
V_c	filter capacitor voltage	ω_{vo}	voltage controller loop bandwidth

supplied by any primary source such as Photovoltaic system.

As energy demands around the world increase, the need for renewable energy sources that will not pollute the environment has been increased (Moradi and Reisi, 2011). Solar energy is one of the renewable sources that depends on weather factors, essentially the irradiation (Teng-Fa et al., 2009). The photovoltaic system is practically suited for distributed resource applications and has now emerged as an established commercial technology with a number of major manufacturers producing the equipment (Chin et al., 2011). However, as it is a renewable source, care is required if the diffuse and variable energy resource is to be converted into electricity at a reasonable cost. The photovoltaic (PV) System is the most promising as a source of future electricity generation (Wang, 2006). The main problem of the PV system is that natural irradiation causes voltage and power fluctuation problems at the load side (Uzunoglu et al., 2009). In addition to that the power available from PV source is difficult to be completely captured. For PV, the maximum power is depending on the voltage under different conditions (*i.e.* temperature and irradiance) (Moradi and Reisi, 2011; Saloux et al., 2011).

One of the techniques utilized to compensate the instability problem associated by CPL and PV power fluctuation is by using passive damping in which a resistance and high value of capacitance are used. However, this technique will result in a large amount of power dissipation and the passive components can be bulky (Rahimi and Emadi, 2009a; Yushan et al., 2012). Another technique for compensating is the use of active damping. Active damping is generally a network that draws or returns current to the DC bus in order to damp any instability (Jusoh, 2004a; Xinyun et al., 2007). The active damping network is a bidirectional DC–DC converter in which its control loop forces it to draw an input current that is proportional to the DC bus voltage to present positive impedance to the supply. This positive impedance plays an important role in compensating the negative impedance represented by CPL and thus ensuring the system stability (Jusoh, 2004b).

In this paper, the implementation of active damping network is presented. The proposed active damping is intended to stabilize the system that consists of photovoltaic arrays (PVA), an LC filter and CPL. This paper has been organized as follows. The modeling of solar photovoltaic cell/module is discussed in Section 2. In Section 3, constant power load and its negative incremental resistance are reviewed. Section 4 describes the application of the active damping method to the DC bus of the photovoltaic system. It is clearly shown that the DC bus system that supplies the CPL can be stabilized effectively using this method. Simulation results to prove the effectiveness of the proposed method are presented in Section 5, and finally, the conclusions are drawn in Section 6.

2. Solar photovoltaic system

The photovoltaic system directly converts sunlight into electricity that can be used for multiple-purposes. In this paper, a large PV system consists of a set of PV cells connected in series and parallel to produce the power required by the DPS source in a system that consists of constant power load. Fig. 1 shows the typical equivalent circuit representing a PV cell (Chin et al., 2011; Yuncong et al., 2011). This circuit contains a photo current source I_{sc}, a diode D_1, series, R_s and parallel R_p resistors (Saloux et al., 2011).