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DC–AC switching converter modelings of a PV grid-connected system under islanding phenomena

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ABSTRACT

Nonlinear modeling of a dc–ac full-bridge switching converter PV grid-connected system under islanding phenomena is proposed. It is a model that can be easily derived by using simple analytical techniques. A state-space averaging technique (no linearization) and voltage source inverter with current control are performed as "large-signal modeling" that is used to analyze the dynamic response of load voltage under 3 different resistive loads: 125%, 100% and 25% of inverter output and RLC when the grid system is disconnected as well as a step change of load. The nonlinear equation from the proposed modeling is handled by MATLAB/SIMULINK. The results of the proposed model are compared with experiments and PSpice simulation which shows good agreement among them. Moreover, it is found that the proposed model consumes much less computation time than PSpice and does not encounter any convergence problem.

1. Introduction

In a distribution system, when a grid system is disconnected for any reason, the distributed generation still supplies to any section of local loads. This phenomenon is called "Islanding Phenomena". When the islanding situation occurs, the grid system cannot control voltages and frequencies in the islanding area and this can create the possibility of damaging equipment. To avoid the occurrence of islanding phenomena, many control schemes have been devised to reliably sense the islanding [1–6]. Apart from the research on various control schemes for anti-islanding detection, a study of the impact of a multiple-inverter installation was also investigated [7], which showed that if inverters from different inverter manufacturers were installed, they would have difficulty in identifying the absence of the grid. Multiple interconnections of PV systems in terms of automatic voltage regulation have also been studied by using a simulation program [8]. Eung-Sang Kim et al [9] used a PSCAD/EMTDC program for analyzing transient, steady-state voltage variation and voltage rises at interconnected feeders and nearby feeders.

The modeling of a switching power converter has evolved into two basic approaches, discrete-time and averaging approaches [10]. Most of the previous work focused on modeling and analyzing different switching converter topologies. Large-signal modeling using averaging approaches has been analyzed [11,12,14,15]. The discrete-time approach for large-signal modeling of boost converters with output filters was presented [13] and solved with ACSL. Guinjoan et al [16] also proposed the discrete-time approaches for boost converters in a current-programmed mode and development of a stability graph for the design of dc–dc switching regulators. Modeling of PV grid-connected applications under islanding phenomena has not been developed yet.

In this study, the goal is to develop a mathematical model of a dc–ac full-bridge switching converter voltage source with current control of a PV grid-connected system under islanding phenomena with the state-space averaging technique developed by Middlebrook and Cuk. To evaluate the islanding phenomena of a PV grid-connected system which has nonlinear behavior, no linearization is implemented. A state-space averaging technique, performed as large-signal modeling, is used to analyze the dynamic response of load voltage while a grid system is removed. Two load cases are implemented as (1) resistive load, R, and (2) resistive, inductive and capacitive loads, RLC, in parallel connections as well as a step change of load. To simplify the mathematical models and equivalent circuits, some basic assumptions have been neglected such as the exclusion of parasitic element's effects (equivalent series inductance, ESL, of inductor-winding resistance and core loss or equivalent series resistance, ESR, of filter capacitors). The

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Nomenclature

CT	current transformer
L_f	inductive filter
C_f	capacitive filter
R_L	resistive load
C_L	capacitive load
L_L	inductive load
R_1,R_2	resistive for PI controller
C	capacitive for PI controller
K_p	R_2/R_1, parameter of PI controller
K_i	R_2/R_1C, parameter of PI controller
v_e	error voltage
V_p	peak amplitude of saw-tooth signal
f_s	switching frequency in hertz
i_{Lf}	current flowing through the filter inductor
v_o	output voltage
v_s	DC input voltage
d	duty cycle, t_{on}/T_s
i_{LL}	current flowing through the load inductor
C_{new}	combination of filter capacitor and load capacitor
m	modulated duty cycle variation
v_{iLf}	voltage which senses the current inductor flowing through the filter
V_{ref}	amplitude of reference signal
r	voltage conversion ratio from the sensed current inductor flowing through filter

proposed modeling, implemented by MATLAB/SIMULINK, is verified with the experiments and PSpice.

2. The system study

A general block diagram for a PV grid-connected system with feedback current control and two PWM blocks provided by inverter manufacturer: (1) PWM(MPPT) for maximum power generation and (2) PWM(dc–ac) for dc–ac converter in current mode, are shown in Fig. 1. The main components consist of: (a) a PV panel which generates direct current from sunlight, (b) dc–dc with isolated transformer designed for achieving the maximum power with PWM control produced by a simple method, namely Perturbation and Observation technique (P&O)($dP/dv = 0$) where P represents the PV output power and V the PV voltage; (c) dc–ac full-bridge converter, which is used to generate ac waveform from dc signal with current-mode PWM scheme; (d) switching filter, used for eliminating the unwanted signal; and (e) other parts, for example Phase Lock Loop (PLL) and load in parallel connection.

The direct current and voltage from the PV panel are measured and formed as inputs for the MPPT block to generate a PWM signal for the dc–dc converter in order to operate in maximum power generation. The current amplitude at maximum operation from the MPPT block is multiplied with in-phase sinusoidal unit-vector waveform which is produced from the Phase Locked Loop (PLL) block. The result is designated as current reference signal. At the output of dc–ac converter stage, the actual current from the inductor current flowing through the filter is sensed and compared with the current reference, then the error is compensated with the PI controller. This stage is called error amplification. Finally, this output is compared with the saw-tooth signal to generate a PWM signal for the gate drive of dc–ac converter in the comparison stage.

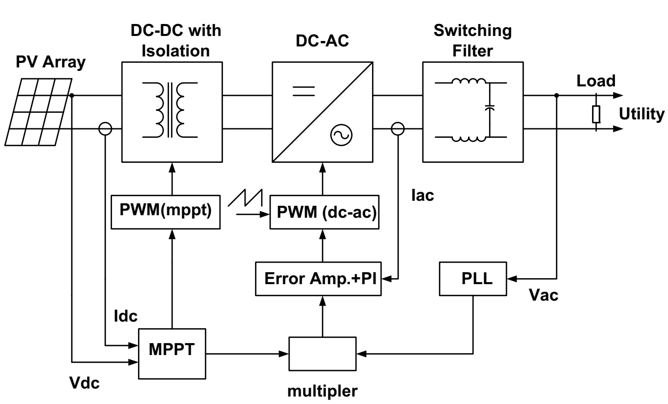

Fig. 1. Block diagram of a PV grid-connected system.

3. Proposed modeling: the dc–ac full-bridge switching converter modeling

As shown in Fig. 2, a dc–ac full-bridge switching converter with feedback current control scheme mainly consists of a power stage and a feedback current control loop stage. The basic operation of the dc–ac full-bridge switching converter is that each pair of switches, S1–S3 and S2–S4, are operated alternately for each switching period with their duty cycle (d). The duty cycle (d) is a ratio of an ON time (t_{on}) to a switching period (T), $d = t_{on}/T_s = t_{on}f_s$, as shown in Fig. 3. The general procedure for deriving the state-space averaging method is described.

Firstly, a state equation of a converter for ON and OFF periods of switching can be derived by applying Kirchoff's voltage and current laws as follows [21,22]:

For interval d

$$\dot{\mathbf{x}} = \mathbf{A}_1\mathbf{x} + \mathbf{B}_1\mathbf{u} \quad (1)$$

and interval $1 - d$

$$\dot{\mathbf{x}} = \mathbf{A}_2\mathbf{x} + \mathbf{B}_2\mathbf{u} \quad (2)$$

where $\mathbf{x}$ = state variable vector, $\mathbf{A}$ = state coefficient matrix, $\mathbf{u}$ = source vector, $\mathbf{B}$ = source coefficient matrix.

Then the state-space averaging technique is applied for combining those two state equations into a single averaged state equation by using duty cycle (d) as a weighting factor. The state-space averaged equation is expressed as

$$\dot{\mathbf{x}} = [\mathbf{A}_1 d + \mathbf{A}_2(1-d)]\mathbf{x} + [\mathbf{B}_1 d + \mathbf{B}_2(1-d)]\mathrm{u} \quad (3)$$

To analyze the behavior of a dc–ac full-bridge switching converter PV grid-connected system under islanding phenomena, we can separate the overall circuit into three sections, (a) a resistive load (R) and (b) a combination of resistive, inductive and capacitive loads (RLC) and (c) a feedback current control stage.

3.1. Power stage for a resistive load

The power stage is drawn as shown in Fig. 2 with resistive load in parallel connection. An inductor current flowing through filter, i_{Lf}, and load voltage, v_o, are considered as state variables. The matrix form of state equations with S1and S3 ON (d-interval) and S1 and S3 OFF ($1 - d$ interval) are expressed respectively: