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

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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
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) 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–ac 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.

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 \( T_s \), \( d = t_{on}/T_s = t_{on} f_s \), 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 Kirchhoff’s voltage and current laws as follows [21,22]:

For interval \( d \)

\[
\dot{x} = A_1 x + B_1 u
\]

and interval \( 1 – d \)

\[
\dot{x} = A_2 x + B_2 u
\]

where \( x \) = state variable vector, \( A = \) state coefficient matrix, \( u = \) source vector, \( B = \) 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

\[
\dot{x} = [A_1 d + A_2 (1-d)] x + [B_1 d + B_2 (1-d)] u
\]

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, \( i_{L1} \), and load voltage, \( v_o \), are considered as state variables. The matrix form of state equations with S1 and S3 ON \((d\)-interval) and S1 and S3 OFF \((1-d\)-interval) are expressed respectively:

\[
\dot{x} = f_x
\]

\[
i_{L1}
\]

\[
v_o
\]

\[
v_s
\]

\[
d
\]

\[
i_{IL}
\]

\[
c_{new}
\]

\[
m
\]

\[
V_{ref}
\]

\[
r
\]
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