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Synchronization control of single-phase full bridge photovoltaic grid-connected inverter

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ABSTRACT

In this paper, the single-phase full bridge photovoltaic (PV) grid-connected inverter is introduced. Based on the working principle and circuit theory, the corresponding dimensionless mathematical model with 8-dimensions piecewise smooth state equation is established. An improved unidirectional correlation method for synchronizing the inverter to the utility grid is proposed. Analysis shows that the presented control scheme is effective and can synchronize the output current of PV inverter with the phase and frequency of utility grid by selecting appropriate correlation factor, disregarding the dynamics behavior of inverter.

1. Introduction

The rapid trend of industrialization and increased interest in environmental issues has recently to consider the use of renewable energy sources such as fuel cell, wind and solar energy (photovoltaic generation) [1,2]. Photovoltaic (PV) arrays provide electrical energy directly from sunlight. As a renewable and green power source, PV generation is recently becoming increasingly important because of the owning merits of requiring little maintenance, not being polluting, incurring no fuel costs, and emitting no noise [3].

Commonly, PV power systems need to be connected to the utility at distribution voltage levels to form a grid connected system through inverters [2,4]. Grid-connected inverter is the crucial interface of PV system and grid-system, so the dynamics and steady operation of inverter is critically important in PV generation system [5,6]. As we known the fact that the grid-connected inverter has the characteristics of complicated nonlinearity since the electrical devices are time-varying and exhibits increased switching frequency, which affects the quality of the power supply [7]. Although there are lots of works on analyzing the dynamics of DC–DC converters [8–11], there has been relatively little research on DC–AC inverters. Hao et al. [12] investigated the bifurcation and chaos in sliding mode controlled first-order H-bridge inverter based on pulse width modulation. Liu et al. [13] studied the nonlinear phenomena in dual buck full-bridge inverter, showing that the correct choice of circuit parameters of dual buck full-bridge inverter is very important for its stable operation. Hu et al. [14] analyzed the fast-scale bifurcation of a single-phase SPWM inverter under peak current mode control.

Grid-connected inverter should be able to transfer efficiently the maximum amount of PV energy to the utility grid. In order to accomplish the transformation, the output current from inverter is required to be delivered in phase (and frequency) with the utility voltage of the power grid. However, due to the complexity of circuit structure of inverter it is impossible to have a sinusoidal output current. So, to respond with the quality of power supply by which distributed generation units are connected to the utility grid, various current control strategies were proposed recently. There exist two kind of current control strategy: linear controllers based on open loop voltage type PWM (pulse-width-modulation) and nonlinear controllers based on closed loop current type PWM [15,16]. In linear current controller, the PWM generation and current error compensation is separated based on space vector PWM (SVPWM), and a sinusoidal waveform yields with an excellent steady-state response and low current ripples [17]. However, for the linear current controller, a previous linearization step is required to compensate steady-state error, which constitutes an approximation of complex nonlinear dynamics behavior of the inverter. These difficulties have motivated researchers of both power electronics and control community to proceed with a different approach of nonlinear control than linear control scheme. In the nonlinear control techniques, hysteresis current control is often used for 3-phase grid-connected voltage source inverter system. The controller unit compensates the current error and produce PWM signals with appropriate dynamic response. However, the current is controlled separately by a control delay and the zero voltage vectors cannot be generated, thus leading to large current ripples with harmonic distortion [18]. In Ref. [19], the authors pre-

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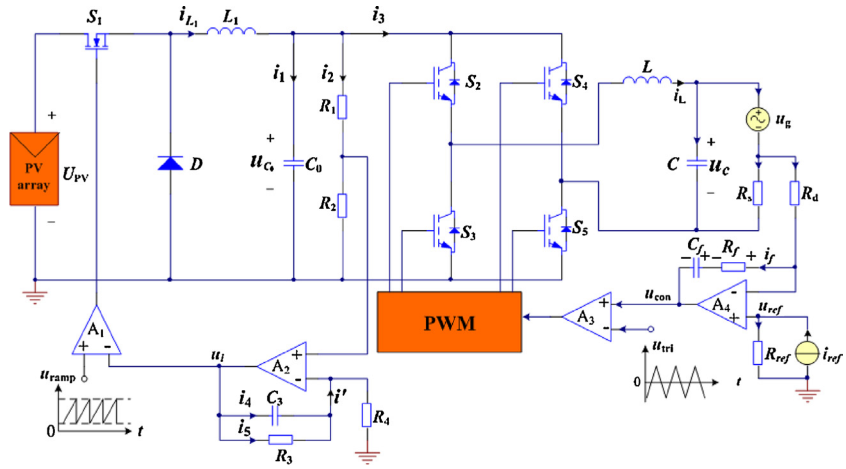

Fig. 1. Schematic of single-phase full bridge photovoltaic grid-connected inverter.

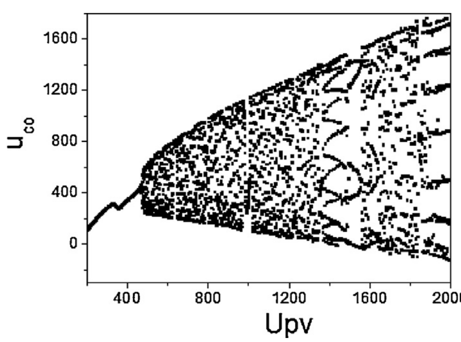

Fig. 2. Bifurcation diagram of PV inverter versus U_{pv}.

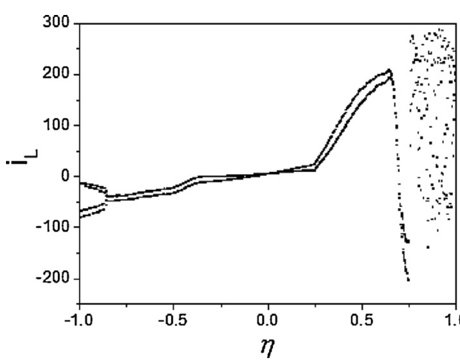

Fig. 3. Bifurcation diagram of system (6) with $U_{pv} = 300$ vs. η.

sented a Lyapunov-based nonlinear controller for a single-stage full-bridge grid-connected power inverter. In Ref. [1], a nonlinear and adaptive control scheme is introduced for a single-phase single-stage grid-connected PV inverter. The proposed controller could provide an approving closed-loop behavior without neglecting the nonlinear electrical characteristics of the system and deal with the system uncertainty that depends on the solar irradiance. The disadvantage of nonlinear controllers for PV inverter that may be encountered in practical implementation is the dependency on system's parameters and computational complexity.

It is known that chaotic systems have complex dynamical behavior and intrinsic randomness, this randomness can weaken even eliminate the correlation of system state variables. Therefore, to turn the system variables in order, one can strengthen the correlation of system variables. The correlation control is a linear feedback control technology and can be executed only by choosing and coupling some state variables of dynamical system [20]. This control scheme does not change the system parameters, so it may be useful even for these engineering systems in which we cannot directly access any of its parameters.

In this paper, the single-phase full bridge photovoltaic (PV) grid-connected inverter is introduced. Based on the circuit theory of Kirchhoff, the corresponding dimensionless mathematical model with 8-dimensions piecewise smooth state equation is setup. Analysis shows that this circuit system displays complicated nonlinear dynamics and can even produce chaotic behavior under certain parameter conditions. An improved unidirectional correlation method for synchronizing the inverter to the utility grid is proposed. Compared to the existing control schemes [1,15–19], the presented unidirectional correlation scheme is simpler and independent on system's parameters, thus it can be realized in engineering more convenient. Simulation analysis further shows that the presented control scheme is effective and can synchronize the output current of grid-connected inverter with the phase and frequency of utility grid by selecting appropriate correlation factor.

2. Circuit of PV grid-connected inverter

As a bridge building a connection between the PV array and utility grid, PV inverter performs an important function of delivering the output current of PV array in phase (and frequency) with the utility voltage of the power grid. The circuit model of single-phase full bridge photovoltaic grid-connected inverter is introduced here, as displayed in Fig. 1. In which, the output voltage of PV array and utility voltage U_g serve as the input and active load of inverter, respectively. The main circuit includes DC/DC converter, DC/AC converter, filter circuit and control circuit.

DC/DC converter adopts voltage-programmed Buck circuit, with u_{C_0} being the output voltage, u_i the control voltage, u_{ramp} the sawtooth voltage. For the PWM control, switch S_1 turns off when $u_{ramp} < u_i$, turns on when $u_{ramp} > u_i$.

The input voltage of DC/AC converter is u_{C_0}, which is delivered in phase and frequency with the utility, through full bridge inverter circuit and filter circuit. The current in grid is compared to the reference current i_{ref}, the resulted error signal passes through amplifier A_4, and one gets the control voltage u_{con}. The PWM control signal of S_2–S_5 is achieved when the triangular wave u_{tri} is modulated by u_{con}. The switch logic of S_2–S_5 is denoted as $S_{2,5} = S$, $S_{3,4} = \bar{S}$ with

$$S = \begin{cases} 0, & u_{tri} > u_{con} \\ 1, & u_{tri} < u_{con} \end{cases} \tag{1}$$