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Control of Bubbling Phenomenon in Bipolar SPWM Inverters

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Abstract: Significant growth in the adoption of electric cars and non-conventional energy sources in the electrical grid has led to an increase in the use of power electronic converters, in particular, the power inverter system which is responsible for regulating electrical energy to the user. However, in some cases its performance has been affected by a phenomenon known as bubbling, which consists on a significant distortion of the output waveforms by phase restricted high frequency oscillations. As a consequence, in this paper we propose to vary the frequency of the SPWM to control the bubbling phenomenon reported in the buck-inverter systems [1]-[4]. Our proposed strategy was successfully applied to these inverters with a very relevant advantage, it does not require any physical or structural change to the system configuration, only an appropriate tuning of the ramp frequency signal. This process was performed by using a bifurcation perspective and detecting the frequency values for which the bubbling phenomenon and other nonlinear dynamics of the systems are suppressed.

Keywords: power inverter, bipolar SPWM, bubbling phenomenon.

1. Introduction

Power inverters (DC/AC converter) controlled by different bipolar sinusoidal pulse width modulation (SPWM) strategies have shown high frequency and low amplitude oscillations embedded in the output sinusoidal signals, either in one part or in several parts of these waveforms, and also coexisting with different nonlinear dynamics [1]. This problem has been called bubbling phenomenon, and it increases the total harmonic distortion (TDH) in the output signals (output voltage $V_{out}(t) ≔ V_C$ and output current $I_{out}(t) ≔$ current flowing through the load resistance) causing not only a significant distortion to their waveforms, but also a low quality electrical service to the user. Hence, in this paper we present a modification in the control scheme of the system, which consists on changing the switching frequency. This technique was proved in several full-bridge single phase buck-inverter systems with bipolar SPWM [1]-[4]; however, for the sake of brevity, here we only show the results applied to a particular buck-inverter system, which was broadly analyzed in [1].

Fig. 1(a) shows a schematic diagram of the circuit used in this paper. L=0,1 H and C=1 μF compose the LC filter, R_L=100 Ω and R=10,6 Ω are the load and parasitic resistances, respectively. E_0=8,6 V, β=1 is the sensor gain, $V_{ref}(t)=5\cos(200\pi t)$ is the reference signal and α=16,59 is the gain of the proportional control. The bipolar ramp is given by $V_{ramp}(t)=10\left(t/T_{ramp}-\lfloor t/T_{ramp}\rfloor-1/2\right)$, with T_{ramp} being the period of the ramp, and $\lfloor t/T_{ramp}\rfloor$ defines the floor function. S/H is a zero order hold and it is synchronized with $V_{ramp}(t)$. Switches *S₁*, *S₂*, *S₃* and *S₄* are controlled by channels *E* and *D*. The dynamical system is defined by the ordinary differential equations $\dot{x}=Ax \pm Bu$, where $x=[V_C \quad I_L]^T$ and $u=1$. A and B are given in Eq. (1). V_C is the voltage across the capacitor and I_L is the current flowing through the inductor. All parameter values as in [1].

$$A = \begin{bmatrix} -1/(CR_L) & 1/C \\ -1/L & -R/L \end{bmatrix}, \quad B = \begin{bmatrix} 1 \\ E_0/L \end{bmatrix} \tag{1}$$

2. Results and Discussion

Previous analysis confirmed that the bubbling phenomenon is influenced by the switching frequency of the system; therefore, our proposed strategy to suppress the undesired bubbling phenomenon consists on changing the frequency of the ramp signal $\boldsymbol{f_{ramp}}$. The results obtained by varying $\boldsymbol{f_{ramp}}$ in the system are shown in Figs. 1(b) and 1(c). From 10 kHz onwards the bubbling phenomenon ceases, and 1T-periodic orbits are obtained (black dots). For f_{ramp}<10 kHz, the bubbling phenomenon continues appearing and the TDH increases. Considering the f_{ramp} values for which the bubbling does not appear, a frequency f_{ramp}=20 kHz is selected and the behavior of the output temporal signals is shown in Fig. 1(c).

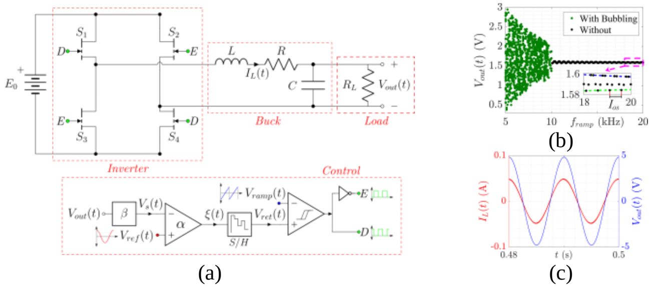

Fig. 1. (a) Single-phase full-bridge buck-inverter with bipolar SPWM. (b) Bifurcation diagram varying the frequency $f_{ramp} \in [5, 20]$ kHz. (c) Temporal output signals with f_{ramp}=20 kHz.

3. Concluding Remark

Our proposed strategy is able to efficiently and effectively find a frequency where nonlinear dynamics and bubbling phenomenon are eliminated for any power inverter system. Here, a very high frequency is not selected (f_{ramp}=20 kHz, Fig. 1(c)), and with this, it is possible to obtain a stable, very well formed and without distortion output signals. Even more, for this particular case for f_{ramp}>10 kHz, the bubbling phenomenon is avoided. On the other hand, our results let us confirm that the bubbling phenomenon is influenced by the switching frequency of the inverter systems.

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