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A new control scheme of a cascaded transformer type multilevel PWM inverter for a residential photovoltaic power conditioning system

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Abstract

From the viewpoint of high quality output voltage generation in a residential photovoltaic system, a multilevel inverter employing cascaded transformers can become a good substitute for the conventional pulse width modulated inverters and other multilevel counterparts. However, to obtain more sinusoidal output voltage waves, it should increase the number of switching devices and transformers resulting in a cost increase. To alleviate this problem, an efficient switching pattern is proposed and applied to a multilevel inverter equipped with two cascaded transformers, which have a series-connected secondary. Operational principle and analysis are illustrated focusing on a change of the switching pattern. High-performance of the proposed multilevel scheme embedded in a photovoltaic power conditioning system is verified by computer-aided simulations and experimental results.

Keywords: Cascaded transformer; Multilevel inverter; Photovoltaic system; Pulse-width-modulated inverter

1. Introduction

Residential photovoltaic (PV) power conditioning systems generally employ a voltage source pulse-width-modulated (PWM) inverter to convert power from dc to ac. The inverter should be equipped with features such as high quality output voltage waves, voltage and frequency within the allowable limits, less harmonic generation by the inverter in itself to avoid damage to electronic appliances, and other requirements (Rashid, 2001). From the viewpoint of high quality output voltage generation and reduction of dv/dt stress on power

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Nomenclature

a_1	turn-ratio of the first transformer (Tr.1)
a_2	turn-ratio of the first transformer (Tr.2)
I_p	solar array current (A)
k	the number of cascaded transformers
m	the number of output levels
n	output voltage level
%	the modulus operator in C-language
P_{pv}	solar power (W)
ΔP_{pv}	the slope of P_{pv}
S_{FB1}	switching function of the first inverter module
S_{FB2}	switching function of the second inverter module
V_1	terminal voltage of the first transformer, Tr.1 (V)
V_2	terminal voltage of the second transformer, Tr.2 (V)
V_{com}	command voltage (V)
V_{dc}	input dc voltage (V)
V_p	solar array voltage (V)

Abbreviations

ADCIN	analog inputs to the ADC
DSP	digital signal processor
FB	full-bridge
INT	interrupt
MPPT	maximum power point tracking
PV	photovoltaic
SPWM	sinusoidal pulse width modulation
T1UF	timer 1 underflow
CPU	central processing unit
EMI	electromagnetic interference
FFT	fast fourier transform
ISR	interrupt service routine
PWM	pulse width modulation
RF	radio frequency
T1P	timer 1 period
THD	total harmonic distortion

switching devices in residential photovoltaic systems, multilevel inverters can substitute for the conventional PWM inverters (Calais et al., 1999; Tolbert and Peng, 2000). However, to obtain more sinusoidal output voltage waveforms by means of synthesizing a great number of output levels, it should increase the number of switching devices and other components. So conventional multilevel inverters such as diode-clamped, flying capacitors, and cascaded full-bridge cells with separate dc sources are not useful for this application (Lai and Peng, 1996; Rodriguez et al., 2002). Recently, a multilevel inverter employing cascaded transformers, so called 3^k*-level inverter*, has been considered for PV applications (Thomas, 1994; Kang et al., 2003). From the viewpoint of the generation of high quality output voltage waveforms, the application to a residential PV system is encouraged since the multilevel inverter with cascaded transformers can produce high quality output voltage with good harmonic characteristics owing to a large number of output levels. It automatically has galvanic isolation between a photovoltaic system and output loads by employing cascaded transformers. It shows good performance to synthesize stepped output levels once it is equipped with at least three transformers, which have a series-connected secondary. If the number of cascaded transformers is boundless, the output voltage levels are infinite which is similar to analogue one. However, a large number of transformers can cause a cost increase, and manufacturing problems (Kang et al., 2003).

To alleviate this problem, an efficient switching pattern is proposed and applied to this kind of multilevel inverter equipped with two cascaded transformers, which have a series-connected secondary. Operational principle and analysis are illustrated focusing on a change of the switching pattern. The validity of the proposed multilevel scheme is verified by simulation and experimental results based on a residential photovoltaic power conditioning system prototype. The performance of the proposed multilevel PWM inverter is compared with conventional counterparts.

2. Proposed multilevel PWM inverter based on 3^k-level inverter

Fig. 1 shows a configuration of the proposed multilevel PWM inverter. It employs two transformers, which have a series-connected secondary as similar as that of 3^k-level inverter (here, k means the number of cascaded transformers in Table 1). Owing to the different turn-ratio of each transformer and the ability of each full-bridge to create three different voltages across the primary winding, the voltage at the ac terminal can be comprised of 3^k-levels as listed in Table 1. The advantage of this multilevel scheme is the relatively accurate replica of a sinusoidal wave accomplished with low switching frequencies (Calais et al., 1999; Kang et al., 2003).

Table 2 shows the switching function of the 3^k-level inverter. It covers each switching function up to that