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ANALYSIS OF REDUCTION IN SWITCHING LOSS WITH FEEDFORWARD CONTROL IN GRID-TIED MICRO GRID SYSTEM

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ABSTRACT
This paper proposes the simplified pulse width modulation (PWM) strategy in the bidirectional ac/dc single-phase converter with the feed-forward control scheme. In this, the number of switching of the proposed simplified PWM strategy is reduced to one-fourth to that of the unipolar & bipolar PWM. The feed-forward control scheme is used to achieve better performance of the ac/dc converter in both the rectifier & inverter mode as compared with the conventional dual-loop control scheme. The simplified PWM strategy with feed-forward control scheme has higher efficiency than that of the unipolar PWM & bipolar PWM strategies. Also, the total harmonic distortion is less in this PWM strategy. The simulation & experiments are carried out to verify the validity of the proposed PWM strategy & control scheme. The proposed simplified PWM strategy with the proposed feedforward control scheme has lower total harmonic distortion than the bipolar PWM and higher efficiency than both unipolar and bipolar PWMs. Furthermore, the proposed simplified PWM operated in the inverter mode also has larger available fundamental output voltage *VAB* than both the unipolar and bipolar PWMs. A prototype system is constructed and the control scheme is implemented using FPGA Spartan-3E XC3S250E. Both simulation and experimental results verify.

1. INTRODUCTION

In recent years, demand of electricity is increasing rapidly because of various technical inventions, awareness of its usefulness, etc. Widely used sources are the conventional sources. But now-a-days, due to the increasing use of electricity & its high cost, these conventional sources are in degradation. Hence, itbecomes a major challenge to develop commercially relevant substitute sources for generation of electrical energy. Tremendous research works are being carried out to develop feasible & pollution free powergeneration resources. Most probable renewable energy resources are solar i.e. photovoltaic, wind, biomass, hydro, fuel cells.

These renewable resources are connected to the grid through grid connected single-phase AC/DC PWM converters. Conventionally, AC/DC converters are called as rectifiers & DC/AC converters are called asinverters. These AC/DC converters are developed using thyrister& diodes in order to provide controlled& uncontrolled dc power with unidirectional & bidirectional power flow.

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The converter with approximately sinusoidal input currents & bidirectional power flow can be achieved by coupling a PWM rectifier & PWM inverter to the DC-link in a single-phase full-bridge rectifier. By using this, both the ac grid side & renewable energy resources sides are maintained properly.

As the power quality is defined by the current quality, the PWM technique is most popularly used in the voltage-source converters[19]. Poor power quality in terms of injected current harmonics causes due to the voltage distortions, poor power factor at input ac mains & slow varying rippled dc output at load end, low efficiency & large size of ac & dc filters are some of the demerits of the conventional rectifier[6]. To reduce the aforementioned problems of the conventional rectifiers, new kind of rectifiers using new solid-state self commutating devices such as MOSFETs, IGBTs, GTOs, etc. have been developed. In this paper, the single-phase PWM converter is utilized in between the ac grid system & the renewable energy sources that operates efficiently to retain the power system stability. Some of the requirements of single-phase AC/DC PWM converters are to provide the power factor correction function[4], low distortion line currents[1], highquality dc output voltage[2] & bidirectional power flow capability[8], etc. Some of the PWM strategies that have been used are bipolar PWM (BPWM), unipolar PWM (UPWM), hybrid PWM (HPWM) & Hysteresis switching[3][7]. But in the aforementioned PWM strategies, the switches are operated at higher frequencies than that of the ac line frequency with larger switching power losses.

THE single-phase ac/dc pulse width modulation (PWM) converter is widely used in many applications such as adjustable-speed drives, switch-mode power supplies, and uninterrupted power supplies. The single-phase ac/dc PWM converters [1]are usually employed as the utility interface in a grid-tied renewable resource system, as shown in Fig. 1. To utilize the distributed energy resources (DERs) efficiently and retain power system stability, the bidirectional ac/dc converter plays an important role in the renewable energy system. When DERs have enough power, the energy from the dc bus can be easily transferred into the ac grid through the bidirectional ac/dc converter. In contrast, when the DER power does not have enough energy to provide electricity to the load in the dc bus, the

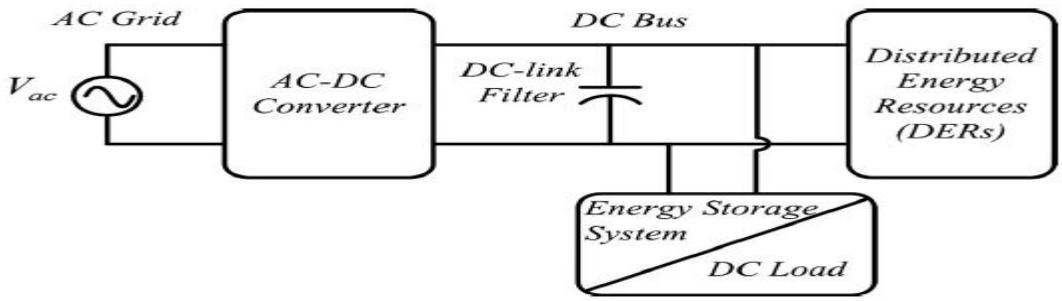

Fig. 1. Distribution energy system.

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bidirectional ac/dc converters can simultaneously and quickly change the power flow direction (PFD) from ac grid to dc grid and give enough power to the dc load and energy storage system. There are many requirements for ac/dc PWM converters as utility interface in a grid-tied system; for instance, providing power factor correction functions [4], [5], [7], low distortion line currents [1], [3], [7], high-quality dc output voltage [2], [9], and bidirectional power flow capability [8]. Moreover, PWM converters are also suitable for modular system design and system reconfiguration. In this paper, a novel PWM control strategy with feedforward control scheme of a bidirectional single-phase ac/dc converter is presented.

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2. OPERATION PRINCIPLE OF THE PROPOSED SIMPLIFIED PWM STRATEGY

A bidirectional single-phase ac/dc converter is usually utilized as the interface between DERs and the ac grid system to deliver power flows bi directionally and maintains good ac current shaping and dc voltage regulation, as shown in Fig. 2. Good current shaping can avoid harmonic pollution in an ac grid system, and good dc voltage regulation can provide a high-quality dc load.

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TABLE I
RECTIFIER MODE SWITCHING COMBINATION IN THE PROPOSED SIMPLIFIED PWM

	Status	T_{A+}	T_{A-}	T_{B+}	T_{B-}	Inductor status
$v_s>0$	A	OFF	OFF	ON	OFF	$v_L>0$
	B	OFF	ON	OFF	OFF	
	E	OFF	OFF	OFF	OFF	$v_L<0$
$v_s<0$	C	ON	OFF	OFF	OFF	$v_L<0$
	D	OFF	OFF	OFF	ON	
	E	OFF	OFF	OFF	OFF	$v_L>0$

TABLE II
INVERTER MODE SWITCHING COMBINATION IN THE PROPOSED SIMPLIFIED PWM

	Status	T_{A+}	T_{A-}	T_{B+}	T_{B-}	Inductor status
$v_s>0$	F	ON	OFF	OFF	OFF	$v_L>0$
	G	OFF	OFF	OFF	ON	
	H	ON	OFF	OFF	ON	$v_L<0$
$v_s<0$	I	OFF	ON	OFF	OFF	$v_L<0$
	J	OFF	OFF	ON	OFF	
	K	OFF	ON	ON	OFF	$v_L>0$

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To achieve bidirectional power flows in a renewable energy system, a PWM strategy may be applied for the single-phase full-bridge converter to accomplish current shaping at the ac side and voltage regulation at the dc side. Generally, BPWM and UPWM strategies are often utilized in a single-phase ac/dc converter. In this paper, a novel simplified PWM strategy is proposed. The proposed simplified PWM only changes one active switch status in the switching period to achieve both charging and discharging of the ac side inductor current. Therefore, the proposed simplified PWM strategy reduces the switching losses and also provides high conversion efficiency. The switching statuses of the proposed simplified PWM are listed in Tables I and II for rectifier mode and inverter mode operation, respectively. Both the rectifier and inverter mode operations of the simplified PWM strategies are explained in this section as follows.

3. PROPOSED FEEDFORWARD CONTROL SCHEME

The operating mechanism of the proposed simplified PWM is clearly explained in Section II. However, the conventional dual-loop control scheme applied to the proposed simplified PWM cannot produce good performance in a single-phase bidirectional ac/dc converter. In this section, based on the proposed simplified PWM strategy, a feedforward control scheme is also developed to provide better line current shaping and better output voltage regulation compared with the conventional dual-loop control scheme.

A. Conventional Dual-Loop Control Scheme

In the conventional dual-loop control scheme applied to the single-phase bidirectional ac/dc converter, the inner current loop and outer voltage loop are utilized as shown in Fig. 19, where $V*$dc is the dc voltage command, *V*dc is the actual dc voltage; $i*L$ is the ac current command, and *IL* is the actual ac current. The voltage controller calculates the voltage error and generates the current amplitude command *IL* multiplied by the unit sinusoidal waveform, obtained from the phase lock loop to generate the current command $i*L$. In general, a proportional-integral controller is adopted as the voltage controller and current controller to achieve power factor correction at the ac side and voltage regulation at the dc side.

B. Proposed Feedforward Control Scheme

Based on the proposed simplified PWM, a novel feedforward control scheme is presented in this section. For a convenient explanation, the converter operated in the rectifier mode is discussed first. The rectifier mode switching combination is listed in Table I. One can choose operation Statuses A and E during the condition $vs > 0$, and Statuses C and E during the condition $vs < 0$. It should be noted that the selection of Status A or B for increasing inductor current and Status C or D for decreasing inductor current is all allowable in the proposed simplified PWM strategy.

To derive the state-space averaged equation for the proposed simplified PWM strategy, the duty ratio *D*on is defined as on = *t*on/*T* , where *t*on is the time duration when the switch is turned ON, i.e., *S*on = 1, and *T* is the time period of triangular waveform. The

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duty ratio *D*off is defined as *D*off = 1− *D*on, which is the duty ratio when the switch is turned OFF.

While the ac grid voltage source is operating in the positive half-cycle *vs* > 0, the switching duty ratio of Status A is defined as*D*on and that of Status E is defined as*D*off . The corresponding circuit equations of Statuses A and E were obtained in (1). By introducing the state-space averaged technique and volt–second balance theory, the state-space averaged equation is derived as follows:

$$v_s - (1 - D_{\text{on}})\, V_{\text{dc}} = 0.$$

CONCLUSION

This paper presented the simplified PWM strategy with feed-forward control scheme for the bidirectional ac/dc converter. In this PWM strategy instead of using four active switch status as required in the UPWM & BPWM, only one active switch status is required in the switching period of the converter. Also efficiency of the ac/dc converter is

improved than that of the UPWM & BPWM strategies. By using simplified PWM strategy in the rectifier & inverter mode of the ac/dc converter, output voltage regulation is achieved. The THD of the proposed simplified PWM strategy is less than that of the UPWM & BPWM strategies.

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