

## Optimal Implementation of Bi-Directional Strategy for AC/DC Converters Using A PWM Technique

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### Abstract

In this paper, a Bi-directional converter using a new PWM technique is proposed; the main objective of this work is to provide power transfer between the AC and DC grids. Proposed converter presents four switches with few switching sequence to operate either in inverter or converter mode. If  $V_{ac}$  is greater than  $V_{dc}$  then the proposed scheme functions as converter and if  $V_{dc}$  is greater than  $V_{ac}$  then it works as an inverter. Comparison between various PWM techniques and new PWM is compared theoretically. Proposed new PWM is preferred in renewable energy resource system. To achieve bidirectional power flows in the 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. A new simplified PWM strategy is proposed in this project. Because it reduces the switching sequence of the rectifier and the inverter. PWM, Bi-directional, renewable, inverter.

### I. INTRODUCTION

The single phase AC/DC PWM converter is widely used in many applications such as adjustable-speed drives, switch mode power supplies, and uninterrupted power supplies. Recently, due to the development of renewable resources, the single-phase ac/dc PWM converters are usually employed as utility interface in the grid-tied system. The energy from DC Bus can be easily transferred to the AC grid when distribution energy resources (DERs) have enough power. On the other hand, when the power of DERs does not have enough energy to provide electricity to the load in the DC Bus, the bidirectional AC/DC converters can simultaneously and quickly change the power flow direction from AC grid to DC grid and give enough power to DC load and energy storage system. Therefore, there are many advantages in the AC/DC PWM converter involving unity power factor, low distortion line currents, high quality dc output voltage with a small size filter capacitor and bi-directional power flow capability. Moreover, it is also suitable for modular system design and system reconfiguration. In this report, a novel PWM control strategy with feed-forward control scheme of a bidirectional single phase AC/DC converter.

In this paper, a novel simplified PWM strategy is presented. The proposed simplified PWM only requires one active switch to change status during the period of switching time. In contrast, the conventional PWM [1]-[3], HPWM [4]-[7] and/or

BPWM require four active switches to change statuses during the period of switching time. Based on the proposed simplified PWM strategy, a novel feed-forward control scheme is also developed so that both rectified mode and inverter mode can be operated in a good manner.

### II. EXISTING SYSTEM

AC/DC converter, converter's switches are all operated at higher frequency than the ac line frequency so that the switching harmonics can be easily removed by the filter. Therefore, the ac line current waveform can be more sinusoidal at the expense of switching losses. Until now, there are several PWM strategies utilized in a single phase ac/dc converter such as bipolar PWM, unipolar PWM, HPWM [3] and Hysteresis switching. Unipolar PWM results in a smaller ripple in the DC side current and significantly lower the AC side harmonic content compared to the bipolar PWM. Moreover, the unipolar PWM effectively double the switching frequency in the harmonic spectrum of the AC voltage waveform and the switching harmonics can easily be removed by the passive filter. The HPWM utilizes two of the four switches modulated at high frequency and utilizes the other two switches commutated at the (low) output frequency to reduce switching frequency for better quality output, but the switching loss of HPWM is still the same as that of unipolar PWM.

### III. PROPOSED SYSTEM

A bidirectional single-phase AC/DC converter is usually utilized as the interface between the distributed energy resources (DERs) and the AC grid system to deliver power flows bidirectionally and maintain good ac current shaping and dc voltage regulation as shown in Fig. 4.1. The good current shaping can avoid harmonic pollution in ac grid system and good dc voltage regulation can provide dc load with high power quality.

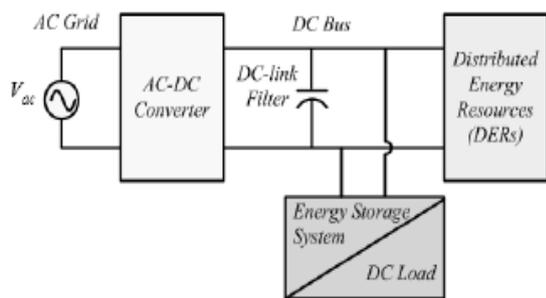


Fig 3.1 The distribution energy system

To achieve bidirectional power flows in the 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 to be utilized in a single-phase AC/DC converter. In this paper, a novel simplified PWM strategy is proposed. The switching statuses of the proposed simplified PWM are listed in Table 3.1 and Table 3.2 for rectifier mode and inverter mode operation, respectively. Both the rectifier mode and inverter mode operation of the simplified PWM strategies are explained in this section as follows.

#### Rectifier Mode

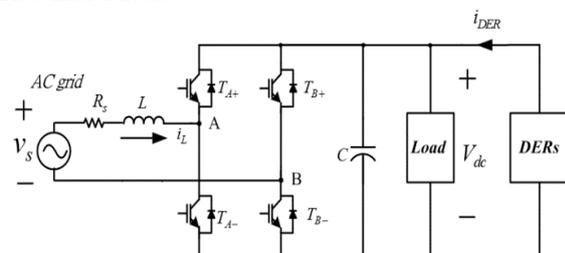


Fig 3.2 A bidirectional single-phase AC/DC converter in the renewable energy system

For a convenient explanation of how proposed simplified PWM does work, consider the single-phase system shown in Fig 3. 2, and assume the internal impedance of the AC grid system is highly inductive and therefore is represented by  $L$ . The equivalent series resistance (ESR) of  $L$  is neglected. First, consider the converter is operated in

the rectifier mode. While ac grid voltage source is during the positive half-cycle, the operation circuits of Status A and Status B listed in Table 3.1 of the proposed simplified PWM are utilized. Using Kirchhoff's voltage law in the operation circuits of Status A and Status B, the voltage relationship can be obtained as follows:

$$v_s - L \frac{d}{dt} i_L = 0$$

One can see that while  $v_s > 0$  the inductor current is increasing in the both Status A and Status B, and the across voltage of input inductor is  $v$

Table 3.1 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	$v_L > 0$
	E	OFF	OFF	OFF	OFF	$v_L < 0$
$v_s < 0$	C	ON	OFF	OFF	OFF	$v_L < 0$
	D	OFF	OFF	OFF	ON	$v_L < 0$
	E	OFF	OFF	OFF	OFF	$v_L > 0$

The cross voltage of the inductor is  $v_s - V_{dc}$ , which decreases the inductor current. Therefore, in this condition, the inductor current is in the discharging state. Next, consider the ac grid voltage source is during the negative half-cycle  $v_s < 0$  in Fig.4. 2. The operation circuits of Status C and Status D of the proposed simplified PWM are utilized. Using Kirchhoff's voltage law in the operation circuits of Status C and Status D, the voltage relationship can be obtained as follows:

$$v_s - L \frac{d}{dt} i_L = 0$$

One can see that while ac grid voltage source is during the negative half-cycle  $v_s < 0$ , the inductor current is decreasing in both Status C and Status D. The across voltage of the inductor  $L$  is  $v_s$ . Therefore, in this condition, the inductor current is in the discharging state. On the other hand, while the converter is in Status E, i.e. all the switches are turned OFF. Using Kirchhoff's voltage law in the operation circuit Status E, the voltage relationship can be obtained as follows:

$$v_s - L \frac{d}{dt} i_L + V_{dc} = 0$$

The voltage across the inductor is  $v_s + V_{dc}$ , which increases the inductor current. Therefore, in this condition, the inductor current is in the charging state. With the foregoing explanation, in summary, while ac grid voltage source is during the positive half-cycle  $v_s > 0$ , both status A and status B increase the inductor current and status E decreases the inductor current to achieve ac current shaping and dc voltage regulation. While ac grid voltage source is

during the negative half-cycle  $v_s < 0$ , both status C and status D decrease the inductor current and status E increases the inductor current to also accomplish ac current shaping and dc voltage regulation

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### Inverter Mode

The switching combination of the proposed simplified PWM operated in the inverter mode is listed in Table 4.2. When the converter is operated in the inverter mode, the actual inductor current is in the reverse direction compared to the ac grid voltage. First, consider ac grid voltage source is during the positive half-cycle  $v_s > 0$ , the input current is in the reverse direction  $i_L < 0$ . Both status F and status G give inductor  $L$  the positive voltage to charge the inductor current. On the other hand, Status H gives inductor  $L$  the negative voltage to discharge the inductor current.

**Table 3.2 Inverter Mode switching combination**

	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	
$v_s < 0$	I	OFF	ON	OFF	OFF	$v_L < 0$
	J	OFF	OFF	ON	OFF	
	K	OFF	ON	ON	OFF	

Next, while ac grid voltage source is during the negative half-cycle  $v_s < 0$ , the input current is also in the reverse direction  $i_L > 0$ . Both status I and status J give inductor  $L$  the negative voltage to discharge the inductor current. On the other hand, Status K gives inductor  $L$  the positive voltage to charge the inductor current. With foregoing understanding, no matter ac grid voltage source is during the positive half-cycle  $v_s > 0$  or during the negative half-cycle  $v_s < 0$ , the inductor current of the converter can be increased or decreased properly to achieve ac current shaping and dc voltage regulation in the proposed simplified PWM operated in the inverter mode. According to the previous discussion, the ac grid line current of a single-phase ac/dc PWM converter could be increased and decreased easily both in rectifier mode and inverter mode to achieve bidirectional power flows and proper line current shaping and voltage regulation in the proposed simplified PWM strategy.

### Comparisons of PWM Strategies

In order to understand the merits of the proposed simplified PWM strategy, the comparison for BPWM, UPWM and proposed simplified PWM strategies are conducted. For a convenient comparison, the statuses of the active switch

combination of BPWM and UPWM are listed in Table 3.3 and 3.4, respectively. It can be seen that BPWM only has two switching statuses, because if one switch,  $T_{A+}$ , is determined, then the other switches,  $T_{A-}$ ,  $T_{B+}$  and  $T_{B-}$ , are all determined, too. In the UPWM, the switching signals of ( $T_{A+}$ ,  $T_{A-}$ ) and ( $T_{B+}$  and  $T_{B-}$ ) are controlled separately by comparing carrier waveform with original and reverse control signals. Therefore, UPWM has four switching statuses listed in table 3.4.

**Table 3.3 Statuses of the active switches in Bipolar PWM**

Status	$T_{A+}$	$T_{A-}$	$T_{B+}$	$T_{B-}$
A	ON	OFF	OFF	ON
B	OFF	ON	ON	OFF
C	ON	OFF	ON	OFF
D	OFF	ON	OFF	ON

**Table 3.4 Statuses of the active switches in Unipolar PWM**

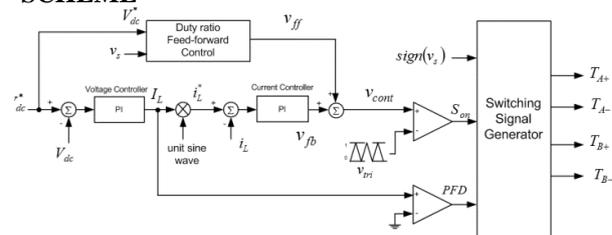
Status	$T_{A+}$	$T_{A-}$	$T_{B+}$	$T_{B-}$
A	OFF	ON	ON	OFF
B	ON	OFF	OFF	ON

In order to count the switching times of active switches for BPWM, UPWM and proposed simplified PWM, Fig. 4.3 shows the cumulated switching numbers of BPWM, UPWM, and proposed simplified PWM

**Table 3.5 Comparisons of BPWM, UPWM and Proposed simplified PWM operated in the single-phase bidirectional AC/DC converter**

	BPWM	UPWM	Simplified PWM
Switching numbers (N) in a carrier cycle	N=8	N=8	N=2
Switching Losses	Large ( $\propto N$ )	Large ( $\propto N$ )	Small ( $\propto N$ )
Total Harmonic Distortion	Large	Small	Small

### PROPOSED FEED-FORWARD CONTROL SCHEME



The operation mechanism of the proposed simplified PWM is clearly explained in the section II. However, conventional dual loop control scheme

applied to the proposed simplified PWM cannot possess good performance in a single phase bidirectional AC/DC converter. In this section, based on the proposed simplified PWM strategy, a feed-forward control scheme is also developed to provide better line current shaping and better output voltage regulation compared with the conventional dual loop control scheme. Based on the proposed simplified PWM, a novel feed forward control scheme is presented in this section. For a convenient explanation, the converter operated in the rectifier mode is first discussed. The switching combination of the rectifier mode is listed in the Table 1. One can choose operation Status A and Status E for the condition  $v_s > 0$ , Status C and Status E for the condition  $v_s < 0$ . 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 are 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  $D_{on} = t_{on} / T$ , where  $t_{on}$  is the time duration when the switch is turned on and  $T$  is the period time of triangular waveform. The duty ratio off  $D$  is defined as  $D_{off} / (D_{off} + D_{on})$ , which is the duty ratio when the switch is turned off. While ac grid voltage source is during the positive half cycle  $v_s > 0$ , the switching duty ratio of status A is defined as  $D_{on}$  and the switching duty ratio of status E is defined as  $D_{off}$ . By introducing the state-space averaged technique and volt second balance theory, the state-space averaged equation is derived. When the converter is operated in the steady state, the DC voltage is equal to the desired command. On the other hand, while ac grid voltage source is during the negative half-cycle. The duty ratios corresponding to Status E and Status C are  $D_{on}$  and  $D_{off}$ , respectively. The corresponding circuit equations of status E and status C have been obtained from equations respectively. Also, by introducing the state-space averaged.

#### IV. SIMULATION CIRCUITS AND RESULTS.

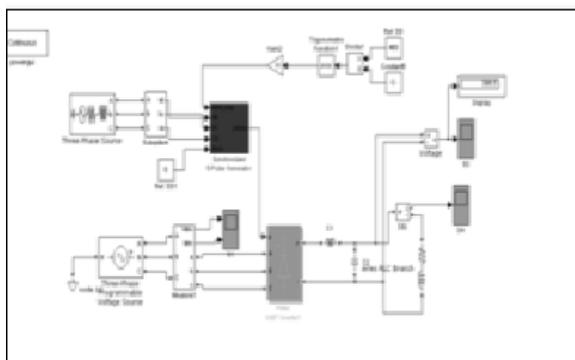


Fig 4.1 Simulation Circuit

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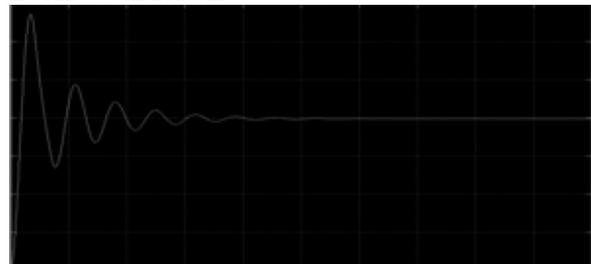
MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications. Features include:

#### 7.2 Output Waveform

Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java™, COM, and Microsoft® Excel. Development environment for managing code, files, and data. Interactive tools for iterative exploration, design, and problem solving. Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration. 2-D and 3-D graphics functions for visualizing data. Tools for building custom graphical user interfaces.

#### 4.2 Output Waveform

##### LOAD VOLTAGE



##### LOAD CURRENT



## V. CONCLUSION

In this paper, a novel simplified PWM strategy using feed forward control scheme in the bidirectional single phase AC/DC converter is first presented. The proposed simplified PWM strategy only requires changing one active switch status in the period of switching time instead of changing four active switch statuses required in the unipolar and bipolar PWM strategy. The efficiency of a AC/DC converter operated in the proposed simplified PWM strategy is higher than that in the unipolar and bipolar PWM strategy. Based on the proposed feed-forward control scheme, both AC current shaping and DC voltage regulation are achieved in the rectifier mode and inverter mode operation. Finally, the prototype system is constructed and tested. Both simulation and experimental results verify the validity of the proposed PWM strategy and control scheme.

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