

# Bidirectional Ac/Dc Converter with Reduced Switching Losses using Feed Forward Control

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**Abstract:** The main objective of this project is to provide power transfer between AC and DC grids. The proposed converter presents four switches with few switching sequence to operate either in rectifier or inverter mode and reduces the switching sequence. The number of switching's of proposed converter is one-fourth that of conventional unipolar PWM and bipolar PWM. The proposed feed-forward control is developed for better performance in rectifier mode and inverter mode. This new PWM method is preferred in renewable energy system for bidirectional power flow using single phase full bridge converter to accomplish good ac current shaping and dc voltage regulation.

**Keywords:** Bidirectional AC/DC converter, Total Harmonic Distortion (THD), Feed forward control.

## I. INTRODUCTION:

In recent years, development of static conversion techniques has gained attention, because of the growing demand for industrial motor drives. The single phase AC/DC converter is widely used in these applications. AC/DC PWM converters are used as interface in a grid tied system, for providing power factor correction, low distortion line current, high quality dc output voltage and bidirectional power flow capability. Several PWM strategies have been utilized in a single phase AC/DC converter such as Bipolar Pulse Width Modulation (BPWM), Unipolar Pulse Width Modulation (UPWM), Hybrid Pulse Width Modulation (HPWM) and hysteresis switching. UPWM has a smaller ripple in the DC side current and lower AC side harmonic content compared to BPWM. The switching frequency in the AC voltage is double in UPWM. The HPWM uses two out of four switches at high frequency and utilizes the remaining switches at the low frequency to reduce the switching frequency and to achieve better quality output, but still the switching loss in the HPWM is same as that of unipolar PWM. The hysteresis switching method utilizes hysteresis in comparison with the actual voltage and current with reference. Although the hysteresis switching method has the advantages of simplicity and robustness, the converters switching frequency depends largely on the load parameters and consequently the harmonic ripples are not optimal.

To have effective utilization of the distributed energy resources (DERs) and retain power system stability the bidirectional AC/DC converter is important. The block diagram of bidirectional AC/DC converter using feed-forward control scheme for reducing switching losses is shown in figure 1.2.

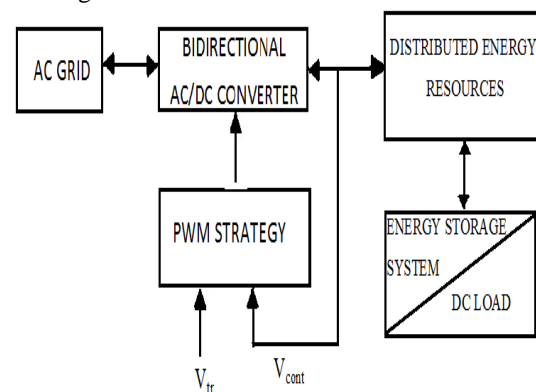


Fig. 1.2 Block diagram of a bidirectional AC/DC converter using feed-forward control.

The energy from the DC Bus can be easily transferred into AC grid through the bidirectional AC/DC converter when DERs have enough power; otherwise the bidirectional AC/DC converter can simultaneously and quickly change the power flow direction from AC grid to DC grid and gives enough power to the DC load and energy storage system. PWM converters are used for modular system design and system reconfiguration.

## II. PROPOSED SYSTEM:

A single-phase bidirectional AC/DC converter is used as the interface between the AC grid system and DERs to maintain good dc voltage regulation and ac current shaping. The topology of the single phase bidirectional AC/DC converter is shown in fig. 2.1. This topology allows bidirectional power flow between DERs and AC grid system.

In single phase bridge converter to achieve bidirectional power flow in renewable system a PWM strategy may be applied to accomplish voltage regulation in DC side and current shaping in AC side.

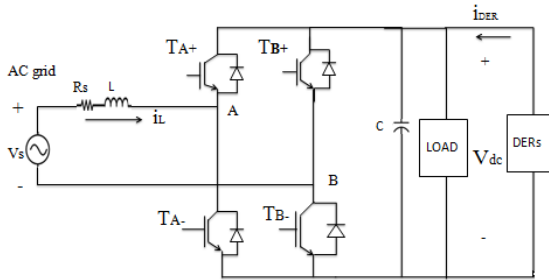


Fig 2.1 A bidirectional single-phase AC/DC converter in the renewable energy system

Generally, BPWM and UPWM strategies are often utilized in a single phase AC/DC converter but now a simplified PWM strategy is proposed. This proposed simplified PWM only changes the switching statuses of active switch. In these proposed simplified PWM to achieve both charging and discharging of the ac side inductor current there is change of only one active switch status in switching period. Therefore, the proposed PWM strategy reduces the switching losses and provides high conversion efficiency. The switching statuses of the proposed PWM are listed in Table 1 and 2 for rectifier mode and inverter mode operation, respectively.

	status	TA+	TA-	TB+	TB-	
Vs>0	A	OFF	OFF	ON	OFF	VL>0
	B	OFF	ON	OFF	OFF	
	E	OFF	OFF	OFF	OFF	VL<0
Vs<0	C	ON	OFF	OFF	OFF	VL<0
	D	OFF	OFF	OFF	ON	
	E	OFF	OFF	OFF	OFF	VL>0

Table1 Rectifier mode switching combination

	status	TA+	TA-	TB+	TB-	
Vs>0	F	ON	OFF	OFF	OFF	VL>0
	G	OFF	OFF	OFF	ON	
	H	ON	OFF	OFF	ON	VL<0
Vs<0	I	OFF	ON	OFF	OFF	VL<0
	J	OFF	OFF	ON	OFF	
	K	OFF	ON	ON	OFF	VL>0

Table 2 inverter mode switching combination

For explanation of how the proposed PWM works, consider the single phase bidirectional AC/DC converter system as shown in fig 2.1 and assuming that AC grid system has the internal impedance which is highly inductive which is represented by L. Considering the equivalent series resistance (ESR) of inductor is negligible.

The switching combination of the proposed PWM operated in the rectifier mode is listed in Table 1. In positive half cycle of ac grid voltage source i.e. when Vs>0, the switching of switches is as status A and status B as listed in Table 1. In status A switch TB+ is turned on and inductor current path is Vs - L - DA+ - TB+ - Vs and in status B switch TA- is turned on and inductor current path is Vs - L - TA- - DB- - Vs. Using Kirchoff's voltage law the voltage relationship is:

$$Vs - L \frac{d}{dt} i = 0$$

While Vs>0, in both status (status A and status B) the inductor current is increasing and the voltage across the inductor is Vs. Therefore in both this conditions (status A and status B) the inductor current is in charging state. In both this cases load voltage is greater than zero (VL>0).

In positive half cycle when all switches are turned off that is when the converter is in status E. In this status as all switches are turned off the inductor current takes the path of Vs - L - DA+ - DB+ - Vs. Using Kirchoff's voltage law the voltage relationship is:

$$Vs - L \frac{d}{dt} i - Vdc = 0$$

The inductor voltage is Vs - Vdc and the inductor current decreases. Therefore, in this case the inductor is in discharging state. In this case load voltage is less than zero (VL<0).

Considering the negative half cycle of the ac grid voltage source i.e. when Vs<0, the switching of switches is as status C and status D in Table 1. In status C switch TA+ is turned on and inductor current path is Vs - L - TA+ - DB+ - Vs and in status D switch TB- is turned on and inductor current path is Vs - L - DA- - TB- - Vs. Using Kirchoff's voltage law the voltage relationship is:

$$Vs - L \frac{d}{dt} i = 0$$

While Vs<0, in both status (status C and status D) the inductor current is decreasing and the voltage across the inductor is Vs. Therefore in both this conditions (status C and status D) the inductor current is discharging state. In both this cases load voltage is less than zero (VL<0).

In negative half cycle when all switches are turned off that is when the converter is in status E. In this status as all switches are turned off the inductor current takes the path of Vs - L - DA- - DB+ - Vs. Using Kirchoff's voltage law the voltage relationship is:

$$Vs - L \frac{d}{dt} i + Vdc = 0$$

The inductor voltage is Vs+ Vdc, and the inductor current increase. Therefore, in the case the inductor is in charging state. In this case load voltage is greater than zero (VL>0).

As a summary, in positive half cycle of ac grid voltage source Vs>0, both status A and status B the inductor current increases and status E the inductor current decreases to achieve ac current shaping and dc voltage regulation. While in negative half cycle of ac grid voltage Vs<0, both status C and status D the inductor current decreases and status E the inductor current increases to accomplish ac current shaping and dc voltage regulation. Regardless whether the ac grid voltage source is operating in the positive half cycle Vs>0 or negative half cycle Vs<0, the converter inductor current can be increased or decreased properly in the proposed PWM operation in rectifier mode.

As a summary, in positive half cycle of c grid voltage Vs>0, both status F and status G the inductor current increases and in status H the inductor current decreases to achieve ac current shaping and dc voltage regulation. While in negative half cycle of ac grid voltage Vs<0, both status I and status J the inductor current

decreases and in status K the inductor current increases to accomplish ac current shaping and dc voltage regulation. Regardless whether the ac grid voltage source is operating in the positive half cycle  $V_s > 0$  or negative half cycle  $V_s < 0$ , the converter inductor current can be increased or decreased properly in the proposed PWM operation in inverter mode.

In a single phase AC/DC PWM converter the ac grid line voltage can be increased or decreased in both rectifier and inverter mode to achieve bidirectional power flow and proper line current shaping and voltage regulation in the proposed simplified PWM strategy.

### III. FEED-FORWARD CONTROL SCHEME

The proposed feed forward control scheme applied to single phase bidirectional AC/DC converter is shown in Fig 3.1

The proposed feed forward control scheme is obtained by added duty ratio feed forward control for the dual loop control system. For a convenient explanation the converter operated in the rectifier mode is considered first. The rectifier mode switching combination is listed in Table 1. One can choose Operation status A and status E during the condition  $V_s > 0$ , status C and status E during  $V_s < 0$ . It should be noted that selection of status A or status B can be selected for increasing inductor current, and status C or status D can be selected for decreasing inductor current.

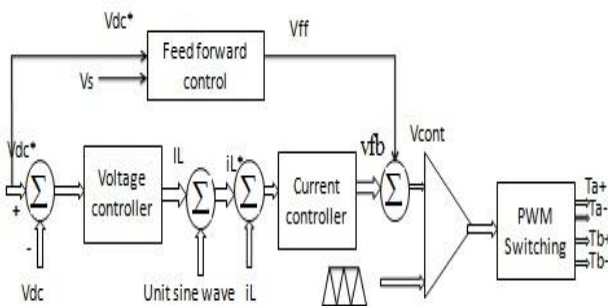


Fig 3.1 The proposed control scheme for the proposed PWM strategy.

To drive the state-space averaged equation for the proposed PWM strategy the duty ratio  $D_{on}$  is defined as  $D_{on} = t_{on}/T$ , where  $t_{on}$  is the time duration when switch is turned ON, ie.  $S_{on} = 1$ , and  $T$  is the time period of the triangular waveform. The 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  $V_s > 0$ , the switching duty ratio of status A is defined as  $D_{on}$  and that 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 as follows

$$V_s - (1 - D_{on}) V_{dc} = 0$$

When converter is operated in the steady state, the DC voltage is equal to the desired command  $V_{dc} = V_{dc}^*$ , above equation can be expressed in the following form

$$D_{on} = (1 - V_s / V_{dc}^*)$$

While the ac grid voltage source is operating in the negative half cycle  $V_s < 0$ , the duty ratios corresponding to

status E and status C are  $D_{on}$  and  $D_{off}$ , respectively. By introducing the state space averaged technique and volt-second balance theory the state space averaged equation is derived as follows

$$V_s + D_{on} V_{dc} = 0$$

Similarly while the converter is operated in the steady state the output voltage is equal to the desired command  $V_{dc} = V_{dc}^*$ , above equation can be expressed in the form

$$D_{on} = -V_s / V_{dc}^*$$

According to the PWM properties the switching duty ratio can be expressed in the terms of the control signal and peak value of the triangular waveform.

$$D_{on} = V'_{cont} / V'_{tri}$$

The switching duty ratio in both conditions  $V_s > 0$  and  $V_s < 0$  are derived

$$V'_{cont} = \begin{cases} \left(1 - \frac{V_s}{V_{dc}^*}\right) V'_{tri}, & \text{if } V_s > 0 \\ -\frac{V_s}{V_{dc}^*} V'_{tri}, & \text{if } V_s < 0 \end{cases}$$

Consider that the converter is operated in the inverter mode with the switching combination listed in Table 2. One can choose status F or status G and status H for increasing and decreasing the inductor current, respectively, during the condition  $V_s > 0$ , and status I or status J and status K for decreasing and increasing the inductor, respectively, during the condition  $V_s < 0$ . While converter is operated in the inverter mode, the control signal  $v'_{cont}$  can be obtained in similar manner in the rectifier mode. The control signal  $V'_{cont}$  operated in the inverter mode is as follows

$$V'_{cont} = \begin{cases} \left(1 - \frac{V_s}{V_{dc}^*}\right) V'_{tri}, & \text{if } V_s > 0 \\ -\frac{V_s}{V_{dc}^*} V'_{tri}, & \text{if } V_s < 0 \end{cases}$$

Because the controls signal  $v'_{cont}$  is proportional to  $D_{on}$ . The control signal  $V'_{cont}$  can be obtained by adding the duty ratio feed forward control signal  $V_{ff}$  to the dual loop feedback control signal  $V_{fb}$ . The feed forward control signal  $V_{ff}$  can enhance the control ability to provide fast output voltage response as well as improve current shaping.

### IV. SIMULATION CIRCUITS AND RESULT

To verify the validity of the proposed simplified PWM strategy and the feed-forward control scheme, the well-known software MATLAB 2013a was adopted to carry out the simulation process. The complete simulation can be divided into three parts namely basic circuit, feed forward control and gate signal control as shown in figure 4.1, 4.2 and 4.3 respectively.

Parameters	Values
Grid voltage $V_{in}$	110sinwtV
Inductance L	1.65mH
Capacitance C	1400µF
Dc voltage(for inverter mode)	300V
Load	150Ω
Switching frequency	50Hz

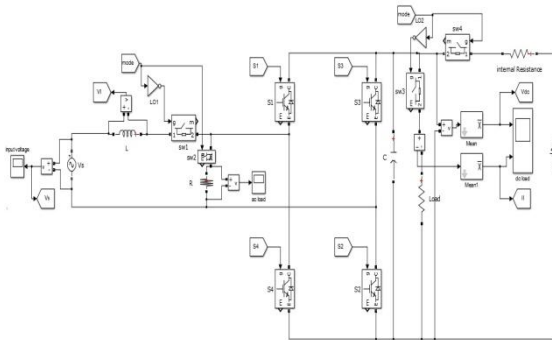


Fig. 4.1 Basic circuit of the proposed circuit

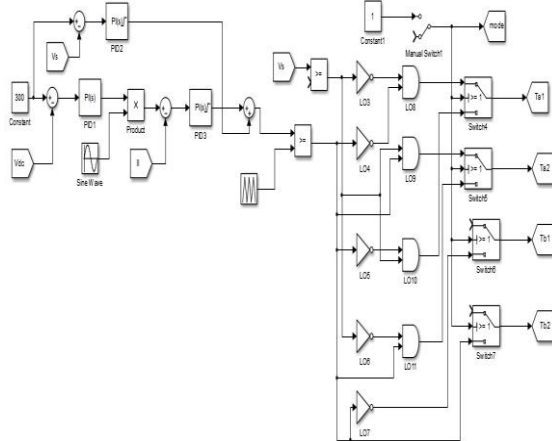


Fig. 4.2 Feed forward control for proposed circuit.

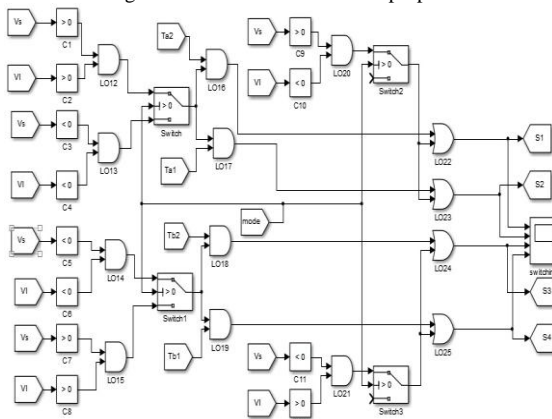


Fig. 4.3 Gate signal for the proposed circuit.

Input AC sinusoidal voltage of 110V is given to the system as grid voltage as shown in fig.4.4.

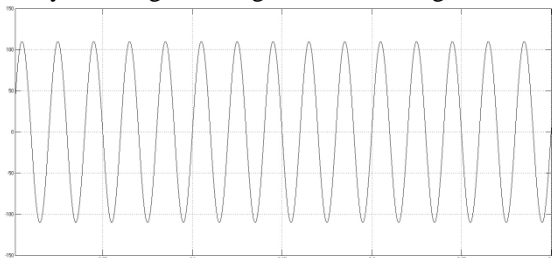


Fig. 4.4 Grid voltage (AC voltage)

The mode from inverter to rectifier can be changed according to the availability of DER voltage. The circuit is operated for 1min in which rectifier mode operation is from 0 to 0.4s and 0.78 to 1min and inverter mode operation from 0.4 to 0.78s

The circuit is operated in rectifier mode from time period 0 to 0.4s and 0.78s to 1 min in this period the ac grid

voltage is converted to dc voltage of 280V as shown in fig 4.5 at this period the ac load is disconnected and is zero as shown in fig 4.6. While in the inverter mode the dc voltage of 300v is converted to ac voltage of pulses as shown in the Fig 4.6 from time period 0.4s to 0.78s.

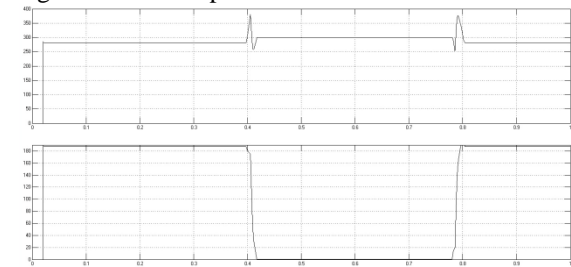


Fig 4.5 DC load voltage and current waveforms

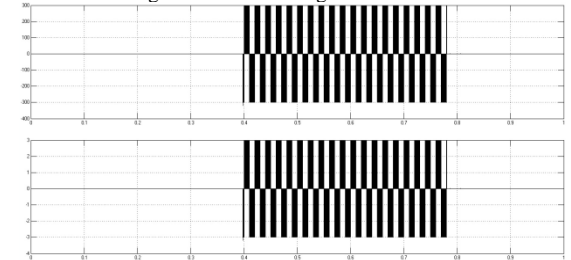


Fig 4.6 AC load voltage and current waveforms

In the Fig 4.7 we can observe that only one switch is on at a time.

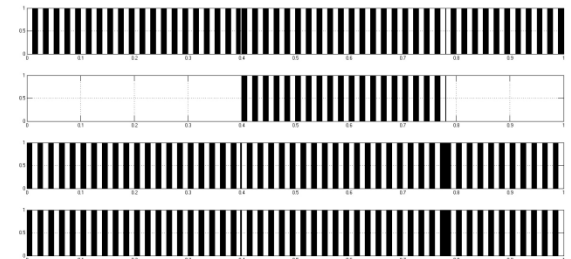


Fig 4.7 Switching sequences of IGBT switches

## V. CONCLUSION

In this paper a novel bidirectional AC/DC converter with a feed-forward control scheme is first presented. The proposed PWM strategy requires changing of one active switch status in the switching period instead of changing four active switch statuses as required in the unipolar and bipolar PWM strategy. The efficiency of an 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 both the rectifier and inverter operating modes. In addition, the proposed simplified PWM operated in the inverter mode has larger available fundamental output voltage  $V_{AB}$  than both BPWM and UPWM. The simulation results validity of the proposed PWM strategy and control scheme.

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