TJPRC: International Journal of Signal
Processing Systems (TJPRC: IJSPS)
Vol. 1, Issue 1, Jun 2017, 37-44

TRANS STELLAR
•Journal Publications •Research Consultancy

PREVENTION OF CIRCULATING CURRENT IN PARALLELED BIDIRECTIONAL AC/DC CONVERTER

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ABSTRACT

In this paper, bidirectional ac/dc converters are paralleled and circulating current is prevented. The converter used here is boost type ac/dc converter and it is controlled by novel PWM technique which reduce the switching loss, as only one switch operating per cycle. This PWM techniques combined with feed forward controller enable to get better current shaping and current sharing. This converter is connected in parallel to increase the power transfer capacity between AC grid and DERs. By connecting converters in parallel, circulating current arises and it affects the system performance. These ac, dc, self-generating and synchronous circulating currents are analysed and prevented by novel control strategy

KEYWORDS: Circulating current, PWM Strategy, AC/DC bidirectional converter, AC grid.

Received: Mar 06, 2017; **Accepted:** Mar 27, 2017; **Published:** Apr 03, 2017; **Paper Id:** TJPRC: IJSPSJUN20175

Original Article

INTRODUCTION

Renewable energy system capacity can be increased or fixed to the requirement by connecting converters in parallel, but there exist circulating current when they connected in parallel, this circulating current problem are due to the unsynchronized operation of the converters and the circulating current should be prevented as it affects overall performance of the system. Many methods employed for preventing circulating current but each method has its own drawbacks. Evolution of techniques for preventing circulating current is increasing day by day. Now a new novel technique is proposed to prevent circuiting current, which has many advantages compared to conventional methods, implementing cost also comparatively less and this converter overcome this drawback of the existing converter. With this PWM converter with novel control strategy, the circulating current can be prevented and the PWM technique used in this converter itself will eliminate the DC circulating current and the AC circulating current can be prevented by novel control strategy proposed in this paper. In addition, another two types of circulating currents namely self-generating and synchronous circulating currents are analysed and controlled. By this dc circulating current can be eliminated and ac circulating current can be prevented.

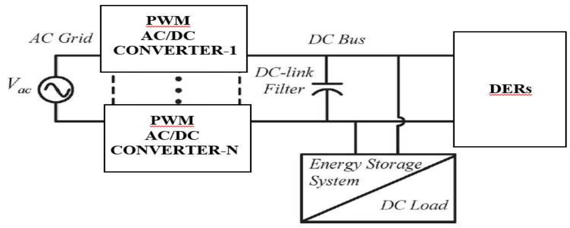

Figure 1: General Block Diagram

PRINCIPLE OF PROPOSED PWM STRATEGY

In order enable power flow in both the directions between ac grid and DERs and utilize renewable energy efficiently, high-performance converter with good current shaping and sharing is required, for which bi- directional AC/DC converter is employed. If the power sharing between the converters are neglected it will lead to distortion in line current and unbalanced load sharing. This will affect the performance of the system. Usually conventional PWM like UPWM and BPWM are employed for bi-directional power flow between AC grid and DERS, but they cause circulating current and it results to distortion in line current and unbalanced power sharing among the converters. Many literatures are proposed to eliminate circulating current, but they addressed only elimination of DC circulating currents. The novel PWM technique used here will prevent dc circulating current and novel control strategy is proposed to prevent ac circulating current. In novel control strategy the switches are forced to switch only for particular sequence in which the circulating path current can be eliminated

Table 1: Switching Status – Rectifier Mode

	Status	T_{A+}	T_{A-}	T_{B+}	T_{B-}
$V_S>0$	A	OFF	OFF	ON	OFF
	B	OFF	ON	OFF	OFF
	E	OFF	OFF	OFF	OFF
$V_S<0$	C	ON	OFF	OFF	OFF
	D	OFF	OFF	OFF	ON
	E	OFF	OFF	OFF	OFF

Table 2: Switching Status – Inverter Mode

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

The switching sequence of this PWM converter is shown in table 1 and 2. The main advantages of this PWM converter are reduced switching loss, and need of only one active switch per cycle. As the operation of switches are reduced, it obviously reduces the switching loss hence PWM technique used here is best to be employed here. This converter has the ability of power flow in both direction, hence it can be operated in all the four quadrant operation. Both rectifier and inverter operations are done, power flow from ac grid to dc bus during rectifier mode, dc bus to ac grid during inverter mode. So bidirectional power flow is achieved. The PWM converter used here has many advantages which support the renewable energy system to increase the transmission power to ac grid.

CIRCULATING CURRENT

`When converters are connected in parallel, circulating problems arrived, in this paper two converters are connected in parallel. In conventional method, circulating current will be existing such as AC, DC, self-generating and synchronous generating. DC circulating currents are eliminated by PWM technique of the converter, but ac circulating current still exist, it can be eliminated by operating the converter in particular switching sequence and forced the switches to operate only at particular switching sequence.

- DC and AC circulating currents: When parallel converters are operated by UPWM technique, there exist ac and dc circulating currents. AC circulating current loop is caused by ac grid without passing through Vdc, similarly dc current loop without passing through ac grid. This ac and dc circulating currents formed should be prevented. In this paper the proposed control scheme will eliminate dc circulating current and prevent ac circulating current.
- 2 Self generating circulating current: It is circulating current between two converters, i.e circulating current from converter 1 to converter 2. Similarly converter 2 to converter 1 and this will form a circulating current between two converters.
- Synchronising circulating current: When parallel converters operated in uniform modulation, the PWM technique used here will form circulating current. This circulating current can be prevented by this control strategy.

In this paper novel control strategy is proposed to eliminate dc current and prevent ac circulating current. Self-generating and synchronous generating circulating currents can also be suppressed by this control strategy.

PROPOSED NOVEL CONTROL STRATEGY

This control strategy is proposed to obtain better load sharing and line current distortion, to prevent circulating current, but in conventional method only dc circulating current are prevented and ac circulating currents are not considered. AC circulating current will reduce the total performance of the system. The proposed control strategy will eliminate dc circulating current and prevent ac circulating current.

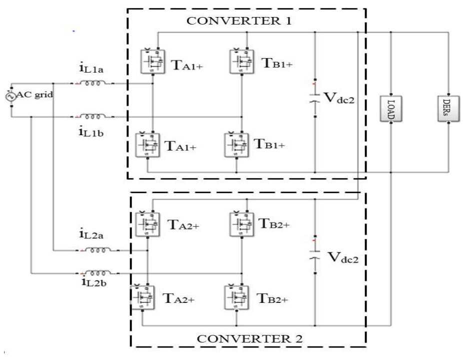

Figure 2: Paralleled Bidirectional Ac/Dc Converter

Table 3: Selected Switching Status of the Converter for Rectifier Mode

Status	T_{A+}	T_{A-}	T_{B+}	T_{B-}
B	OFF	ON	OFF	OFF
E	OFF	OFF	OFF	OFF
D	OFF	OFF	OFF	ON
E	OFF	OFF	OFF	OFF

The selected switching status of the parallel converter from table 1is given in table 3 in which x term of the converter represent the switching status of converter 1 and y term represent the switching status of converter 2. The paralleled converters are operated in status (A,A) and (A,E). The converters are in synchronous operation when the operation is in (A,A) status and exhibit circulating current, and the circulating current are called self-generating circulating current, this will create a circulating current loop between converters. The circulating current loop from converter 1 to converter 2 can be eliminated by changing the status of converters status to (A,E) but circulating current loop between converter 2 to converter 1 still exist, it cannot be controllable and it cause distortion in line current and cause power sharing between the converters.

To prevent the self-generating circulating current loop between the converter 2 to converter 1 by changing the switching status of the converters from (B,B) to (B,E). when the converters are operated in (B,B) status they form synchronous circulating current between two converters, by changing the converters status to (B,E), the circulating current from converter 1 to converter 2 is eliminated and by changing the converter 1 status to E another circulating current between converter 2 to converter 1 is also eliminated. The operation is continued till Vs<0 by operating the converter in switching status as given in the table 3. The converter operation is changed from status (D,D) to (D,E), one circulating current loop is eliminated another circulating current can be eliminated by changing the status from D to E.

Table 4: Selected Switching Status of the Converter for Inverter Mode

Status	T_{A+}	T_{A-}	T_{B+}	T_{B-}
F	ON	OFF	OFF	OFF
H	ON	OFF	OFF	ON
J	OFF	OFF	ON	OFF
K	OFF	ON	ON	OFF

The same procedure is repeated for inverter mode as shown in table 4. By this, circulating current is prevented in both rectification and inverter mode operation and good current shaping and load sharing between them is obtained by proper charging and discharging of the inductor and the line current distortion also limited.

CONTROL SCHEME

Feed-forward control scheme is applied to this PWM converter to provide better line current and voltage regulation compared to conventional dual-loop control schemes.

In dual loop control system, inner current loop and outer voltage loop will be utilized to regulate line current and output voltage. The voltage controller will generate current magnitude from the current error, the generated current magnitude will be multiplied with unit sinusoidal waveform obtained from phase locked loop to obtained reference line current. Voltage reference can be obtained from the inner loop current controller from the error between reference line current and actual line current.

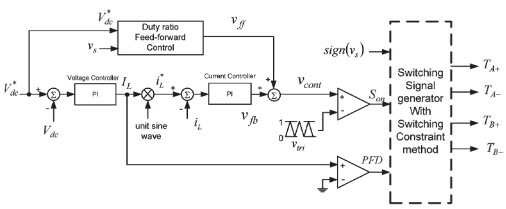

Figure 3: Feed-Forward Controller

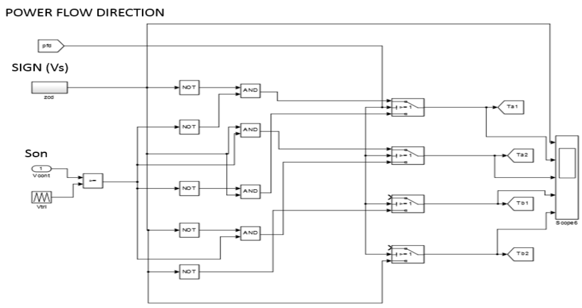

Figure 4: Construction of Switching Sequence

The duty ratio of the feed-back controller can be obtained by the derivation V_{cont}

$$v'_{\text{cont}} = \begin{cases} \left(1 - \dfrac{v_s}{V^*_{\text{dc}}}\right)\hat{V}_{\text{tri}}, & \text{if } v_s > 0 \\ -\dfrac{v_s}{V^*_{\text{dc}}}\hat{V}_{\text{tri}}, & \text{if } v_s < 0. \end{cases}$$

The feed-forward controller output and dual loop controller output are combined to get good output voltage response. The output of the controller will be the modulating signal and it will be compared with carrier signal and the pulse will be obtained. The obtained pulse will be the turn on switching pulse for the converter.

SIMULATION AND EXPERIMENTAL RESULTS

The proposed method is verified and validated in MATLAB/ Simulink environment. The proposed scheme is validated for the simulation parameter given in the table 4.

Table 5: Simulation Parameter

Parameter	Converter 1	Converter 2
Switching frequency	40kHz	40kHz
L_{xa}	0.9210mH	0.9865mH
L_{xb}	0.9278mH	0.8860mH
Capacitor	1400uF	1400uF
Load/DERs	150Ω/2.66A	
AC grid voltage Vs	230V, 50Hz	
DC link voltage Vdc	400V	

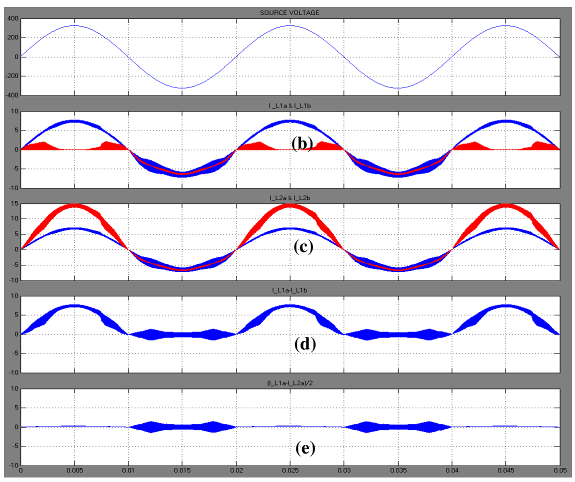

Figure 5: Simulation Results without Proposed Control Strategy for Rectifier Mode

In figure 5 (a) shows measured value of supply voltage, figure 5(b) shows line current of converter 1, figure 5(c) line current of converter 2, in figure 5(d) the difference of line current in converter 1 is shown and difference between converter 1 and converter 2 line current are shown and it will be the circulating current between the converters. In these waveforms, the line current are not in phase and the circulating current between the converters exists.

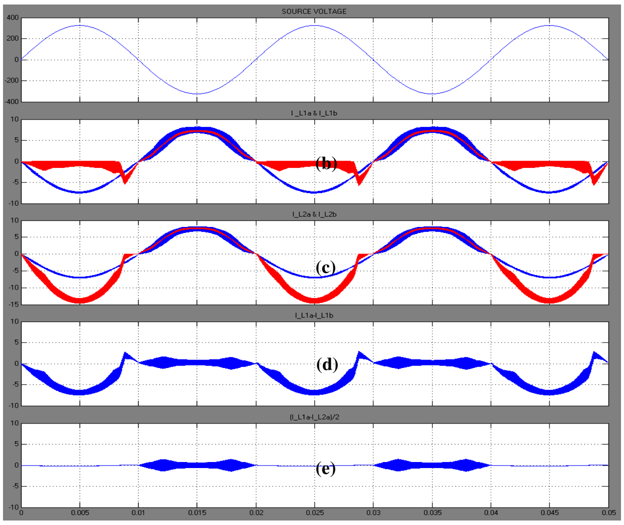

Figure 6: Simulation Results without Proposed Control Strategy Converter for Inverter Mode

Figure 6(a) shows measured value of supply voltage, figure 6(b) line current of converter 1, figure 6(c) line current of converter 2 and figure 6(d) the difference of line current in converter 1 is shown and difference between converter 1 and converter 2 line current are shown. In this waveform of without proposed control strategy, the line current are not in phase within the converter and between two converters and the circulating current exists.

(a)

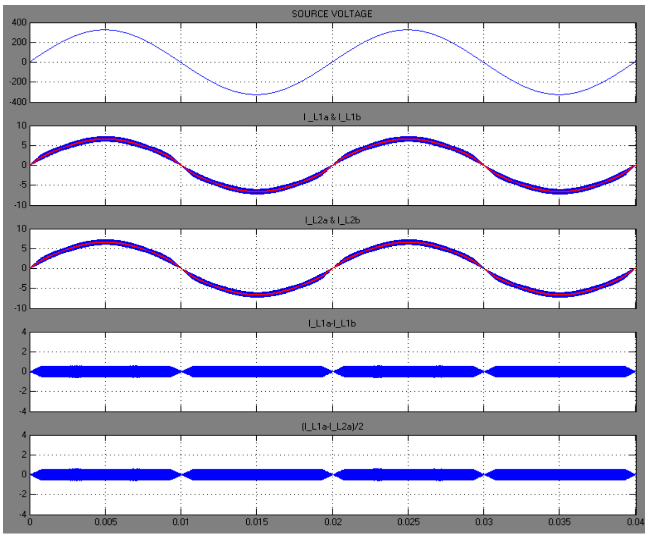

Figure 7: Simulation Results with Proposed Control Strategy for Rectifier Mode

Figure 7 (a) shows measured value of supply voltage, figure 7(b) line current of converter 1, figure 7(c) line current of converter 2, in figure 7(d) the difference of line current in converter 1 is shown and difference between converter 1 and converter 2 line current are shown and it will be the circulating current between the converters. In this waveform of proposed control strategy, the line current are in phase within the converter and between two converters and the circulating current are prevented.

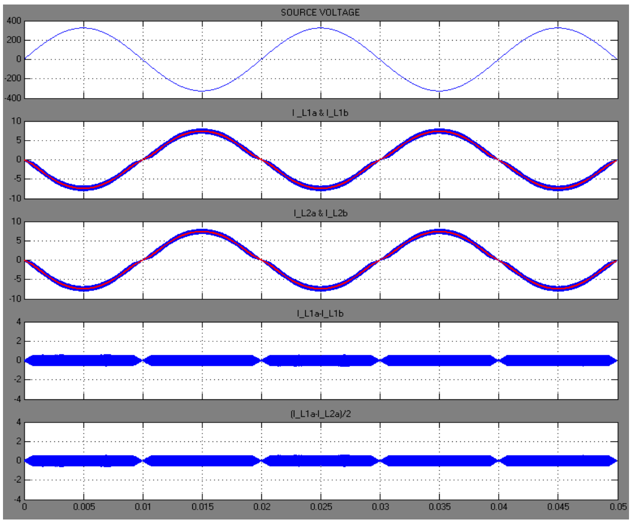

Figure 8: Simulation Results with Proposed Control Strategy for Inverter Mode

In figure 8(a) shows measured value of supply voltage, figure 8(b) line current of converter 1, figure 8(c) line current of converter two, in figure 8(d) the difference of line current in converter 1 is shown and difference between converter 1 and converter 2 line current are shown. In this waveform of proposed control strategy, the line current are in phase within the converter and between two converters and the circulating current are prevented.

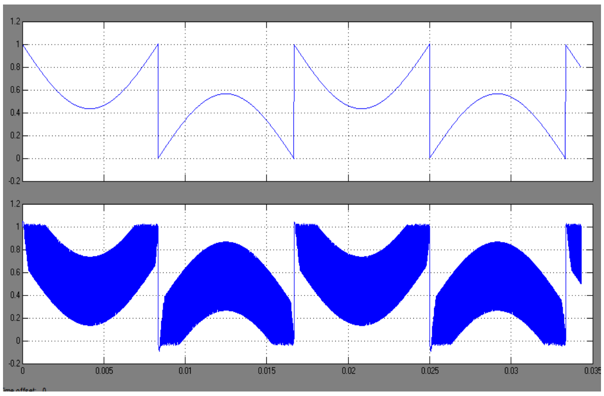

Figure 9: Output Control Signal of Feed-Forward Controller

In Figure 9 the converter output will be modulating signal, which help for better line current and voltage regulation.

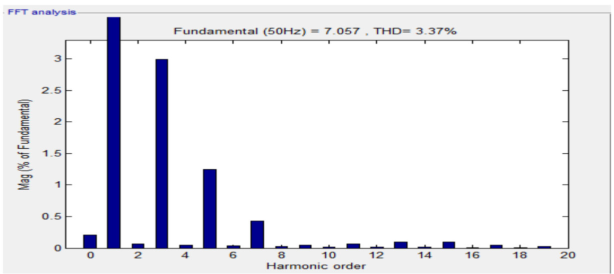

Figure 10: Line current THD of Converter 1

In figure 10 line current THD of converter 1 is measured and it is less than 5%. Hence the line current distortion is less.

CONCLUSIONS

In this paper, bidirectional AC/DC converter is analysed and the converters are paralleled. Circulating current between the converters is prevented by novel control strategy. By this control strategy the dc circulating current is eliminated and ac circulating current is prevented. Good line current and load sharing is obtained in both rectifier and inverter modes. Comparing with conventional method, in the proposed control scheme the cost of the converter is minimised.

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