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Synchrnonous and Asynchronous Switching of Parallel Connected Converters

ABSTRACT

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Boost converters are used to step up the input voltage given to them. They belong to the class of switched mode power supply. DC-DC boost converters are connected parallel as they provide a lot of advantages including achievement of higher power demands, more flexibility etc. But control issues arise during such connection. Some of them include rise of circulating current between converters, regulation of output voltage, voltage stress and undesirable load sharing. This paper investigates the reasons for the rise of circulating current in parallel connected boost converters. The results and observations from the simulation are presented to verify the effects of parallel connection of boost converters on load sharing and circulating current.

Key words: *Boost converters; switched mode power supply; power demands; Load sharing; circulating current; voltage regulation.*

1. INTRODUCTION

Renewable energy sources such as solar energy, wind energy, hydel energy, etc. and energy storage devices like batteries, super capacitors etc, connected together in a power grid play a vital role in energy production and management. The increase in load demand and reduction in the usage of non- renewable source of energy makes such systems more necessary in today's energy production [1]. These sources are integrated into an ac or dc grid using power electronic devices. They provide high flexibility in power conversion level and management. A dc microgrid can be used for this and it utilises a DC bus. The sources in a microgrid are usually small i.e. less than 500 kW [2].

When converters are connected in parallel, they provide large number of advantages. But certain control issues also arise. Some of the issues include the rise of circulating current, variation in the output voltages of the converters connected in parallel, voltage stress, load sharing problems etc. [3]-[5] Circulating current is the current that arises due to the difference in the output currents of the converter system connected in parallel. There are various reasons for the formation of circulating current in a parallel connected converter system. Some of them include variation in input voltages, delay in the current control and voltage loops, load parametric variations and asynchronous switching of the converter switches. The current unbalance can result in thermal and device stress thus affecting the device stability. The effect of asynchronous switching on the formation of circulating current is addressed in this paper [6]-[10].

2. PARALLEL OPERATION OF BOOST CONVERTERS CONNECTED IN PARALLEL

Boost converters are connected in parallel in order to meet high power demands. Based on the switching of the converters the operation is divided into two types of modes. They are synchronous and asynchronous switching mode of operation.[11]-[12]. During synchronous switching, both the switches in a converter system will be turned on or off at the same time. There is no delay in switching action. Thus, the duty signal given to the parallel connected system will be synchronous in nature.

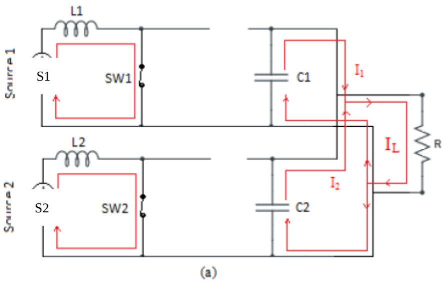


Fig 1(a)- Parallel connected converters with switches closed

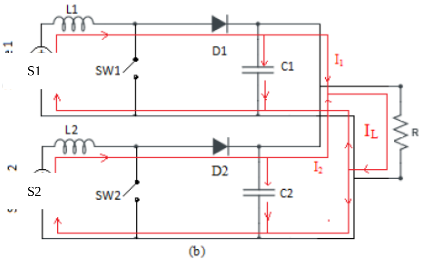


Fig 1(b)- Parallel connected converters with switches opened

Fig 1(a) shows the working of parallel connected converter system when both switches S1 and S2 are kept closed. During this mode, the diodes D1 and D2 are reverse biased. The capacitance voltage will come across the load. Fig 1(b) shows when the switches S1 and S2 are kept opened. The capacitances will charge and the load current is provided directly by the individual sources.

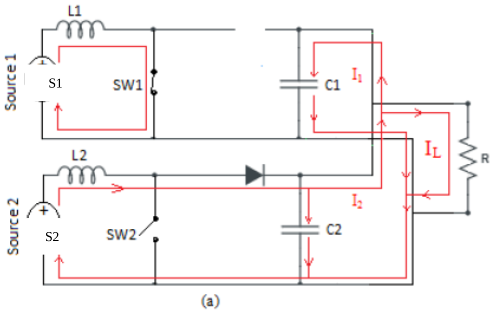


Fig 2(a)- Parallel connected converters with one switch opened and other closed.

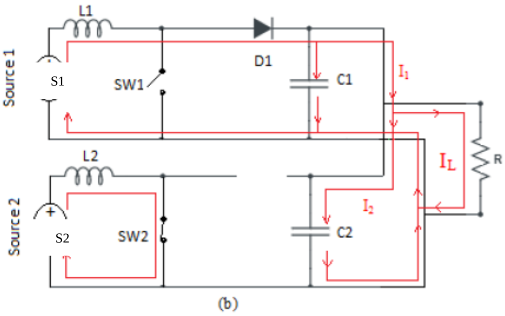


Fig 2(b)- Parallel connected converters with one switch opened and other closed.

Fig 2(a) and Fig 2(b) shows the asynchronous switching of parallel connected boost converters. Here either one of the switches will be closed at a time. S1 is closed [illegible] is kept opened. Now diode D1 is reverse biased and op [illegible] (5) ode D2 is forward biased and closed. This leads to flow of circulating current from converter 2 to charge the capacitor. In Fig 2 (b), S2 is closed and S1 is kept opened. Diode D2 is reverse biased and opened, diode D1 is forward biased and closed. This results in charging the capacitor. The circulating current might be forced by converter 1.

ANALYSIS OF CIRCULATING CURRENT

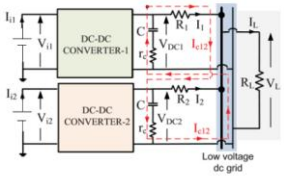


Fig 3(a)- DC-DC boost converters

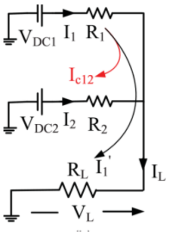


Fig 3(b)-Steady state equivalent circuit

Fig. 3(a) shows two DC-DC boost converters connected in parallel, that use battery as the source. The boost converters are connected to a common DC microgrid. The Fig 3(b) shows the steady state equivalent circuit of the parallel connected converter system.[13]. In the given Fig.3(b), V_{DC1},V_{DC2} , $I_1, I_2$and R_1, R_2 represent output voltages, output currents, and cable resistances of converter 1 and converter 2, respectively. If the output voltages V_{DC1}>V_{DC2}, then I_{C12} is the circulating current flowing from Converter 1 to Converter 2 and $I_1{}'$ represent the load component from the Converter 1.

Analysis of circulating current rising from parallel connected converters is done by using Kirchhoff's voltage law (KVL) in Fig 3(b)

$$V_{DC1} - I_1R_1 - I_LR_L = 0 \qquad (1)$$

$$V_{DC2} - I_2R_2 - I_LR_L = 0 \qquad (2)$$

The expression for output currents of both converters, I_1 and I_2 can be derived from (1) and (2) and is given as:

$$I_1 = \frac{(R_2 + R_L)V_{DC1} - R_LV_{DC2}}{R_1R_2 + R_1R_L + R_2R_L} \qquad (3)$$

$$I_2 = \frac{(R_1 + R_L)V_{DC2} - R_LV_{DC1}}{R_1R_2 + R_1R_L + R_2R_L} \qquad (4)$$

The circulating current can be expressed as:

$$I_{C12} = -I_{C21} = \frac{V_{DC1}-V_{DC2}}{R_1+R_2}$$

$$= \frac{I_1-I_2}{2} \quad (\text{if } R_1 = R_2)$$

$$= \frac{I_1R_1-I_2R_2}{R_1+R_2} \quad (\text{if} \quad R_1 \neq R_2)$$

If the cable resistances are neglected then the circulating current can be expressed as:

$$\sum_{j=2}^{n} \frac{I_1 - I_j}{\text{n}} \qquad (6)$$

4. CLOSED LOOP CONTROL OF PARALLEL CONNECTED

In order to reduce the circulating current flowing through the converter system, voltage control and current control can be done. Various controllers can be used in closed loop control for parallel connected converters. Some of them are Proportional controller, Integral controller, Derivative controller, PID controller, Fuzzy logic controller etc.

PI controllers are widely used as they enhance the stability and performance of the system. Two types of feedback such as voltage feedback and current feedback can be used for the closed loop control of parallel connected converters. Thus, PI controllers can be used for closed loop control of parallel connected converters [14].

5. OPERATION OF PARALLEL CONNECTED BOOST CONVERTERS AND FORMATION OF CIRCULATING CURRENT

The variation in the value of circulating current during different modes of switching of boost converters can be studied. Here boost converters are connected in parallel. Synchronous and asynchronous switching mode of operation is studied. When the duty ratio of the signals send to the switches of the converters is same, then switches operate at the same time leading to synchronous switching. When the switches of the converters operate with a delay then asynchronous switching occurs. A delay in the feedback control loops will result in asynchronous duty ratio. The switches of the parallel connected converters do not switch on at the same time. This leads to variation in load sharing, thus leading to the formation of circulating current. These two modes are studied in the following section.

6. RESULTS AND DISCUSSION

In the following section, the results obtained from the MATLAB simulation and hardware implementation of the system is discussed.

Table I: Simulation Parameters

Parameters	Converter 1	Converter 2
Input voltage(V)	23	23
Switching frequency (KHz)	25	25
Inductance(L)	0.023712	0.011856
Capacitance(F)	0.000086667	0.000173333
Power(W)	96	192

Table I shows the simulation parameters of the parallel connected boost converter system.

A. SIMULATION DIAGRAM AND RESULTS

Parallel connection of boost converters was simulated and waveforms were obtained.

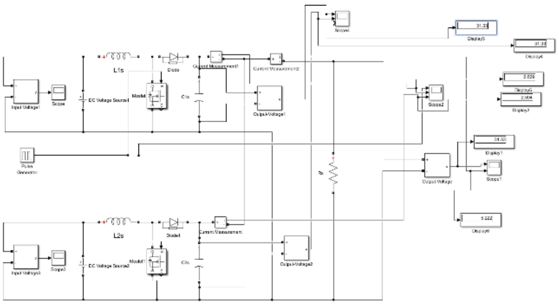


Fig 4 -Synchronous switching of converters

Here Fig 4 shows synchronous switching of the parallel connected converters. The converters of power rating 96W and 192W are connected in parallel. The pulses of 25KHz frequency generated from the PWM generator are given to the switches at the same time. The duty ratio of the converter is synchronous in nature. An input voltage of 23V is given and the switching frequency is 25KHz. The variation in the output current due to parallel operation of the converters is noted. Also, the formation of circulating current is studied.

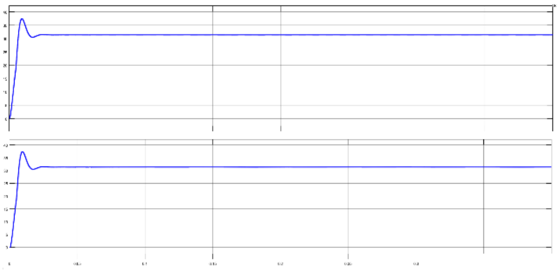


Fig 5 -Output voltages of each converter

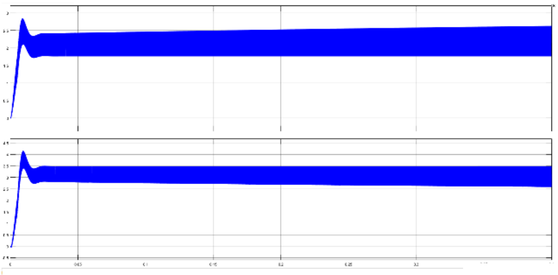


Fig 6 - Output currents of each converter

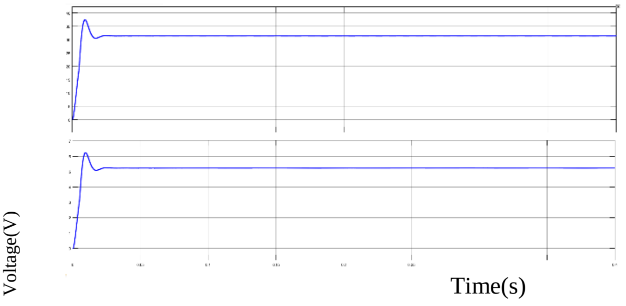


Fig 7 - The total output voltage and total output current

The figures above show the simulation r nverters connected in parallel. The Fig 5 shows the output voltages of each converter, with first graph showing the output voltage of first converter, second graph showing the output voltage of second converter. Fig 6 shows output currents of converters with first graph showing the output current of first converter, s ıd graph showing that of second converter. Fig 7 shows t otal output voltage and total output current of the parallel c erter system respectively. The variation in the output c nt and the value of the circulating current is noted.

T e II: Comparison of Output Voltages and Output Current

Parameters	Converter 1	Converter 2
Input voltage(V)	23V	23V
Output voltage(V)	47.52	47.36
Output current(A)	2.813	4.02

In table II, the output voltages and output current are tabulated. Total output current is obtained as 6.833A. From equation (5) the circulating current is obtained as 2.311A.

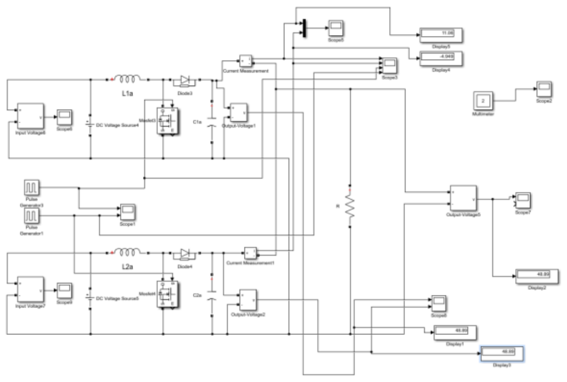


Fig 8- Parallel connected converter with asynchronous mode of switching.

Parallel connection of boost converters was simulated and waveforms were obtained as shown in Fig 8. The pulses from the PWM generator are given to the switches at the same time. The duty ratio of the converter is synchronous. An input voltage of 23V is given and the switching frequency is 25KHz. The variation in the output current is noted. Also, the formation of circulating current is studied.

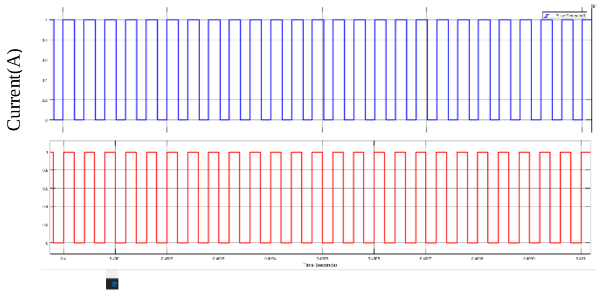


Fig 9 – Pulse signals send to the converters

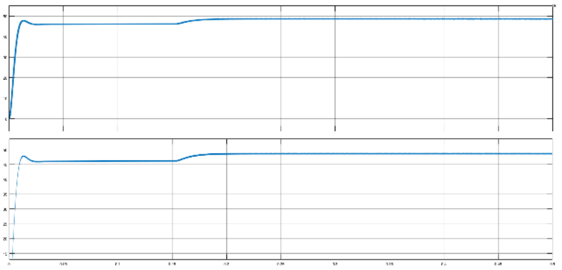
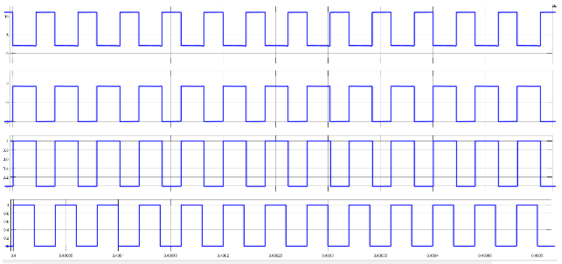


Fig 10- Output voltages of the converter:



g 11- Output currents of the converter and pulses send to the converters

e figures above show the simulation results of converters c ected in parallel. The Fig 9 shows the pulse signals send t ch converter, with first graph showing the pulse signal s to the first converter, second graph showing pulse signal s to the second converter. Fig 10 shows output voltages of converters with first graph showing the output voltage of first converter, second graph showing that of second converter. Fig 11 shows the output currents of the converter and pulses send to the converters respectively.

TABLE III: Comparison of Output Voltages and Output Currents

Parameters	Converter 1	Converter 2
Input voltage(V)	23V	23V
Output voltage(V)	48.79	48.85
Output current(A)	2.02	4.09

In table III, the output voltages and output current are tabulated. Total output current is obtained as 6.112A. From equation (5) the circulating current is obtained as 2.565A. Thus, from the tables it is clear that during asynchronous switching the circulating current increases.

7. CONCLUSION

The parallel connection of boost converters was studied in simulation platform. It was observed that circulating current arises during the operation of parallel connected converters. The value of circulating current is more during asynchronous mode of operation compared to synchronous mode of operation. Further, the PI controllers can be used in order to enhance the performance of such systems thus reducing the value of circulating current. Various other controllers other than PI controllers can be used for such purposes.

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