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Design and Implementation of Parallel Connected DC-DC Buck Converters

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Abstract: In this paper, the design and implementation of parallel connected DC-DC buck converters are studied. It was proposed to develop a master-slave controller for parallel DC-DC buck converters which will enable equal sharing of load among the buck converters. The proposed control concept may lead to effective distribution of control implementation of parallel dc-dc converters which also may lead to redundancy. The advantages of this scheme are its simplicity in design, good voltage regulation, flexibility and rapid transient response to reduce the impact of very high frequency dynamics due to parasitic on the closed loop system. The effect of this current sharing scheme is to "Regulate the system output voltage".

Keywords*:* Parallel connected DC-DC buck converter, master slave control, current sharing

I. INTRODUCTION

The dc-dc buck converter is the simplest power converter circuit used for power management and voltage regulator applications. In this project, Parallel dc-dc converters were analyzed, to study their output. Parallel DC-DC Converters are largely used in telecommunication power supplies, since a Parallel DC-DC converter helps in providing an uninterrupted service. They operate under closed-loop feedback control to regulate output voltage, equalize the currents in the individual converters. A parallel DC-DC converter provides smooth acceleration control, high efficiency and fast dynamic response. To achieve the above advantages, three current sharing mechanisms are used namely, voltage mode control, current mode control and master-slave control. The control concepts are proposed to provide sharing of load currents between parallel connected converters. To control the switch, Pulse width modulation (PWM) is the most frequently used control method. A saw-tooth signal is compared with a control signal to produce a series of pulses that control the states of the power electronic switches. The controlled system provides a more accurate and faster current limit under over load condition

II. PARALLEL CONNECTED BUCK

The parallel connection of switch mode converter is a well known strategy. It involves phase shifting of two or more buck converters connected in parallel and operating at the same switching frequency. Two buck converters are connected in parallel feeding a common resistive load as shown in fig.1. Converters are connected in parallel to equalize the load currents in the individual converters. The two converters are working at the same switching frequency so as to reduce the current ripple, conduction losses, Lower switching frequency for each phase to fast transient response.

As per Fig 1, we use a parallel scheme, where switch S_1 and inductance L_1 are for converter1 while S_2 and L_2 for converter2. The switches and diodes conduct in complementary fashion. If switch S_1 conducts, then diode D_1 will not conduct and vice versa.

The circuit operates as below, the inductor current flows continuously over one switching period. The switch is either on or off according to the switching function q and this results in two circuit states. The first sub-circuit state is when the switch is turned on, diode is reverse biased and inductor current flows through the switch, the second sub-circuit state is when the Switch is turned off and current freewheels through the diode.

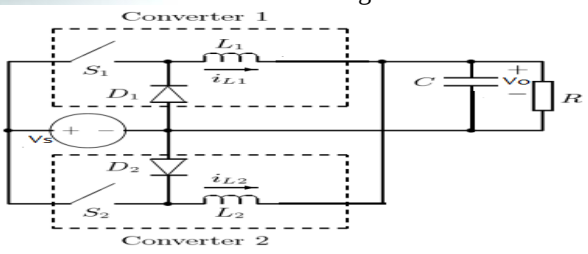

Fig. 1 Block diagram of parallel connected buck converter

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A.Modes of Operations

Based on the continuity of inductor current flow the dc-dc converters can be classified into two different modes of operation that are (a) Continuous conduction mode (CCM) and (b) Discontinuous conduction mode (DCM). According to the requirement a converter can be designed in any mode of operation. For this study the circuit has been designed to operate on CCM or DCM based on the Load provided to the Circuit.

Continuous conduction mode

During the switching period, when the inductor current flow is continuous of charge and discharge it is called Continuous Conduction Mode (CCM) of operation shown in fig 2(a). The converter operating in CCM delivers larger current and the converter operating in DCM delivers lesser current compare to CCM. In CCM, each switching cycle T_S consists of two parts that is D_1T_S and D_2T_S ($D_1+D_2=1$).During D_1T_S inductor current increases linearly and then in D_2T_2 Sit ramps down that is decreases linearly.

Discontinuous Conduction Mode

When the inductor current staying at zero and has a interval of time with no charge and discharge then it is said to be functioning in Discontinuous Conduction Mode (DCM) operation and the waveform of inductor current is illustrated in fig 2(b). At lighter load currents, the converter operates in DCM. The regulated output voltage in DCM does not have a linear relationship with the input voltage as in CCM. In DCM, each switching cycle is divided into of three parts that is D_1T_S, D_2T_S and D_3T_S ($D_1+D_2+D_3= 1$). During the third mode i.e. in D_3T_S, inductor current stays at zero.

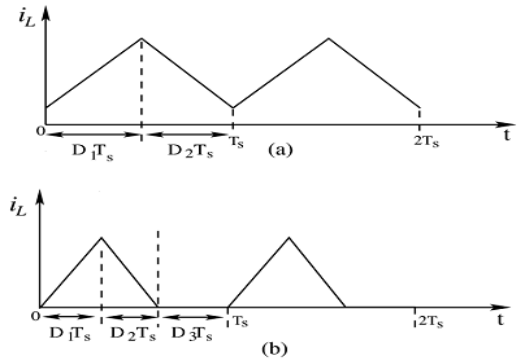

Fig.2 inductor current waveform of (a) CMC, (b) DCM

III. PARALLEL BUCK WITH VMC

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In Voltage mode control (VMC) the Output voltage of the Convertor is again fed back to an error amplifier and compared with a reference voltage fed externally. The difference in Voltage is passed through a Control Unit and fed to a comparator. The Ramp Signal and the voltage difference fed produce the Pulse to control the Switch. Since only the output voltage from the converter is used to produce the pulse this method is called voltage Mode Controller.

The parallel buck converter based on voltage mode control is shown in fig 3; it consists of a capacitor C, controlled switch S_w (MOSFET) diode D, an inductor L, and a load resistance R.

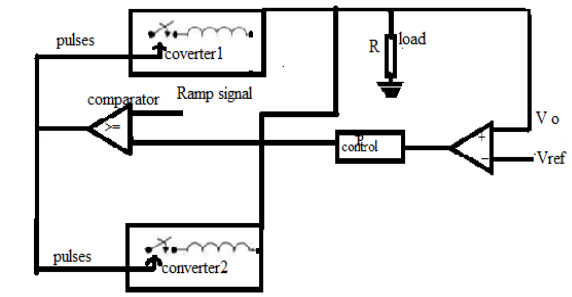

Fig.3 Block diagram of VMC

The analog PWM feedback logic controls the switching action. This is achieved by obtaining a control voltage Vcon as function of the output voltage V_o and a reference signal V_{ref} in the form, Where K_p is the gain of proportional controller .An externally generated saw-tooth voltage defined as V_{ramp} is used to determine the switching instants.

$$V_{ramp(t)}=V_L+(V_U-V_L)*F*(t/T_S) \qquad (1)$$

where Ts is the time period and V_U and V_L are upper and lower threshold voltages respectively. Here F(x)denotes the fractional part of (x),In voltage mode control, the controlled voltage V_{con} is then compared with the periodic saw-tooth wave V_{ramp}, to generate the switching signal q [1, 0] is described by

$$\text{If} \quad V_{ramp} < V_{con} \qquad q = 1$$
$$V_{ramp} > V_{con} \qquad q = 0$$

The inductor current increases while the switch S_w is on i.e q=1 and falls while the switch S is off i.e. q=0.

IV. PARALLEL BUCK WITH CMC

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There are two feedback loops in the Current-mode controlled dc-dc converter, a current feedback loop and a voltage feedback loop. The inductor current is used as a feedback states.

Both the inductor currents and the output voltage controlled by this scheme. The control strategy is designed such that the inductor current I_{L1} ,I_{L2}currents follows the sinusoidal line voltage. An analog multiplier generates the current programming signal by multiplying the rectified line voltage with the output of the voltage error amplifier. This modulation makes the current programming signal follow the shape of input voltage.

The signal acts as a reference current. It is compared with the switch current in a PWM comparator. The resulting pulses drive a MOSFET

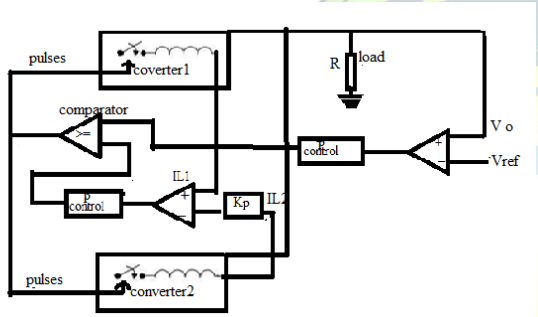

Fig. 4 Block diagram of CMC

The control input signal is proportional to reference current i_{ref}. The reference current i_{ref} is a function of output of the controller to regulate the output voltage. The control voltage can be defined as,

$$V_{con}=V_{offset}- K_v(V_o- V_{ref}) - K_i(i_1-m\, i_2) \quad (2)$$

V. PARALLEL BUCK WITH MSC

For the purpose of load current sharing Master slave control method is employed. To ensure the voltage regulation one converter is chosen as the master converter and the other as slave converter which is keeping the output current to be same as the master's by regulating their voltage reference through current sharing control loops. The output voltage loop acts as the reference for the current loop all the slave modules have the same controller structure and receive the current reference from the master module.

This method achieves current sharing by modifying the sensed current signal, hence no additional current sensing circuit is needed. The stability analysis of the entire parallel system is similar to the stability of an individual dc-dc buck converter.

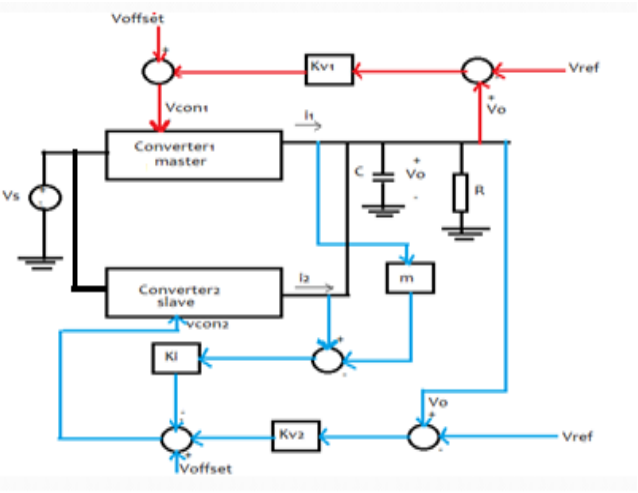

Fig. 5 Block diagram of MSC

In the master-slave control, the two converters, converter 1 and 2 are controlled via a simple pulse-width modulation (PWM) scheme, in which a control voltage V_{con} is compared with a saw tooth signal to generate a pulse-width modulated signal that drives the switch. The relationship between control voltage and PWM output is shown in fig 3. The saw tooth signal of the PWM generator is given by

$$V_{ramp} = V_L + (V_U - V_L)t \bmod /T \quad (3)$$

For Converter 1, the control voltage is derived from a voltage feedback loop, i.e.

$$V_{con1} = V_{offset} - K_{v1}(V_0 - V_{ref}) \quad (4)$$

Where V_{offset} is a dc offset voltage that gives the steady-state duty cycle, V_{ref} is the reference voltage, and K_{v1} is the voltage feedback gain for converter 1.

For converter 2, an additional current error signal, which is proportional to the weighted difference of the output currents of the two converters, determines the control voltage.

The control voltage for converter 2 is

$$V_{con2}=V_{offset}-K_{v2}(V_0 - V_{ref}) - K_i(i_2 - mi_1) \quad (5)$$

where K_{v2} is the voltage feedback gain of converter 2, K_i is the current feedback gain, and m is a current weighting factor. When m=1, we expect equal current sharing

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VI. RESULTS

The simulation results of parallel buck converter and the component values used in simulation circuit are shown in table 1

TABLE 1: Parameters of the Parallel Buck Converters

Parameters		Values
Source voltage	Vs	12V
Output voltage	Vo	5.5V
Inductor	L	14.58µH
Capacitor	C	200µF
Resistor	R	50Ω
Ripple voltage	ΔV	2% of Vo
Ripple current	ΔI	8% of Io
Switching frequency	F	25KHz
Power rating	P	560Mw

A . SIMULATION RESULTS Of voltage Control Mode

Waveform of gate pulses

The switches will conduct when gate pulses given to both the converters. The gate pulses for switches are shown in fig 6.

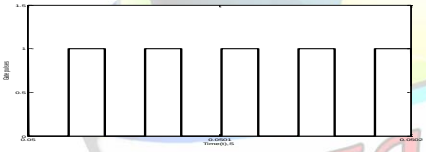

Fig. 6 gate pulses

Waveforms of inductor currents

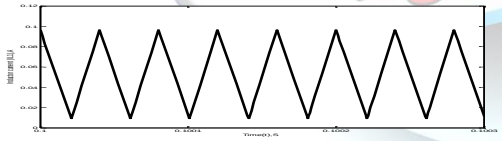

Fig .7a waveform of inductor current(I_{L1})

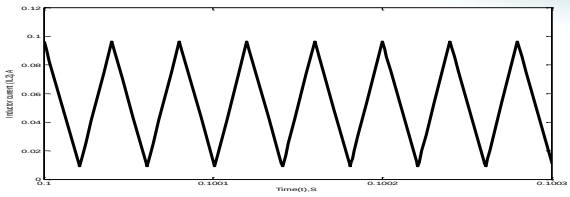

Fig.7b waveform of inductor current (I_{L2})

The inductor currents is equal for both converters as shown in fig 7a & 7b the inductor current is 0.1Amps

Waveform of output voltage

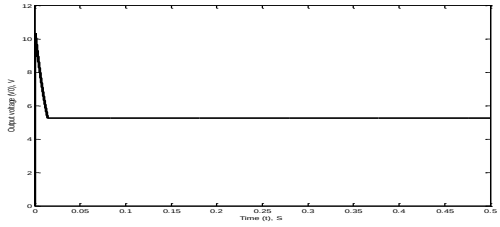

Fig.8 waveform of output voltage

For the buck converters the output voltage is less than the input voltage. The output voltage obtained is 5.2volts dc supply and the output voltage waveform is shown in fig 8.

B. Simulation Results of Current control Mode

Waveform of gate pulses

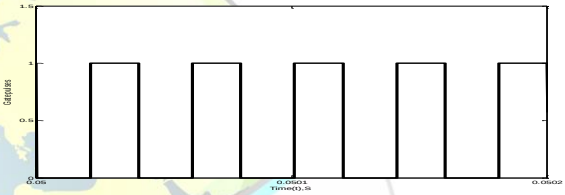

Fig.9.wave forms of gate pulses

Wave forms of inductor current

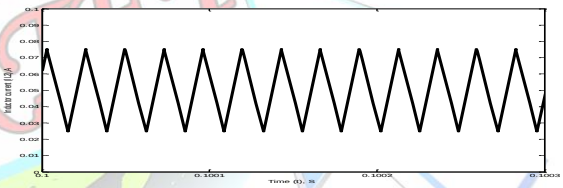

Fig.10a. waveform of inductor current (I_{L1})

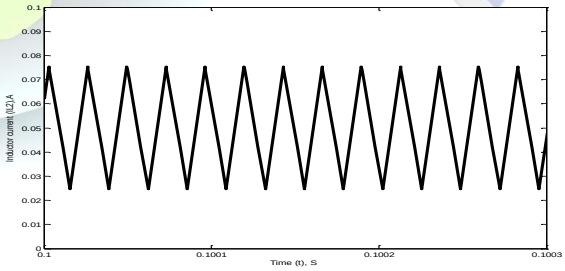

Fig.10a. waveform of inductor current (I_{L2})

The inductor currents is equal for both converters as shown in fig 10a &10b the inductor current is 0.08Amps.

Waveforms of output voltage

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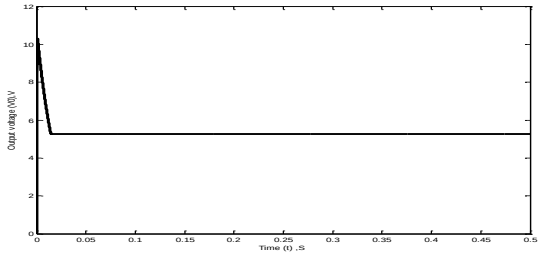

Fig.11.Waveforms of output voltage

For the buck converters the input voltage is 12 volts. The output voltage obtained is 5.2volts dc supply and the output voltage waveform is shown in fig 11.

C. Simulation Results Of Master Slave Control

Waveform of gate pulses

For the buck converters the input voltage is l2volts. The output voltage obtained is 5.0 volts dc supply and pulses loaded to master-slave is shown in fig.12a & 12b

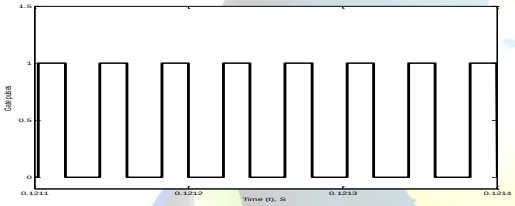

Fig.12a. Gate pulses of the master

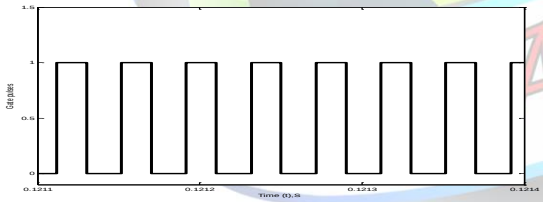

Fig.12b. Gate pulses of the slave

The switches will conduct when gate pulses given to the slave converter. The gate pulses for switches are shown.fig.12b

Waveforms of inductor currents

The inductor currents are equal for both converters; the waveforms are shown in fig 13a & 13b

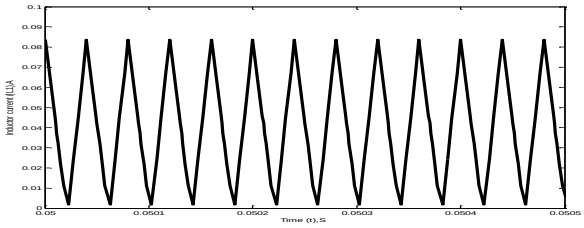

Fig.13a.waveform of the Inductor current (I_{L1}) of master converter

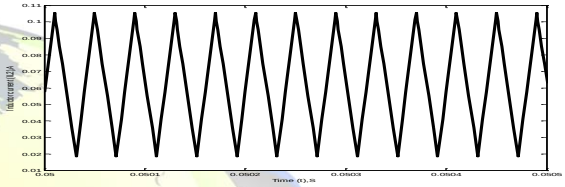

Fig.13b .waveform of the Inductor current (I_{L2}) of slave Converter

Waveform of output voltage

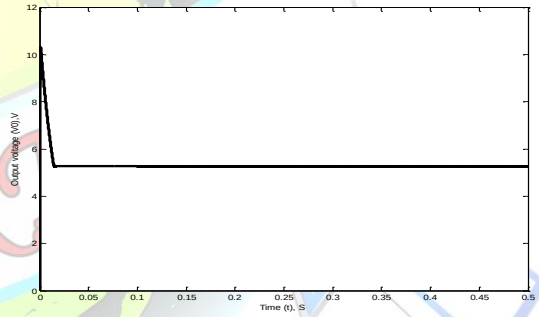

Fig .14.waveform of the output voltage

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COMPARISON OF THREE CONTROL MODES

Current mode control	Voltage mode control	Master-slave control
The circuit analysis is difficult because it has two feedback loops.	it has single feedback loop making design and circuit analysis easier	it has two feedback loops so that the circuit design and analysis is difficult compare to cmc
It provides a more accurate and faster current limit under overload conditions	It is a very slow system, as the respond is much longer of switching cycles.	It provides a good voltage regulation and more accuracy .
the inductor current does not change quickly when the input voltage changes, so the supply has good line transient performance.	low-impedance power output providing better cross-regulation for multiple-output supplies.	Reduce the ripple content in the inductor current and fast transient response.
a current mode-controlled converter is more reliable .	It is less in reliability, stability, or performance when several converters in parallel supply with one load	It has more reliability, stability and redundancy
It is very unstable when duty ratio exceeds 0.5 in the peak current mode- control.	It can work over a wide range of duty cycles	If, the master converter is failed then the entire system will shutdown

VII. CONCLUSION

Even though VMC is having simple design it can work over a wide range of duty cycles but it has less stability and reliability. Due to stability and reliability the CMC provides more accurate and faster current limit under overload conditions but it becomes unstable when the duty ratio exceeds 0.5. Due to more stability and reliability MSC provides good voltage regulation and more accuracy due to which it reduces the ripple content in the inductor current and also it has faster transient response. The parallel connected buck converter using a master-slave approach control strategy implemented. When the buck converters are connected in parallel, the current is shared based onthe current sharing ratio and the output voltage is regulated.

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