Marching in time

How to ensure converters connected in parallel work together. By Kai Johnstad.

While a single dc/dc converter is always preferable, there are many instances when two or more converters are needed to meet a military system's power requirements. In such applications, these converters may be connected in parallel to generate the requisite power. In other cases, where an application needs to be robust, fault tolerant or N+1 redundant power supplies are used.

In critical military applications, where power supply failure can be catastrophic, fault tolerant power supplies use N+1 similar converters to provide a high level of reliability. Through redundancy, fault tolerant systems ensure there is at least one module more than the minimum number required to carry the load in case of converter failure.

If the dc/dc converters in an array are operating from the same feed, they are typically collocated to gain the benefit of shared thermal and shielding features, while saving real estate. Although, these converters may be of the same type, switching frequency mismatches will occur unless the dc/dc converters selected permit synchronisation.

Slight variations or mismatches in non synchronous dc/dc converters operating in parallel from the same input bus voltage generate small differences in their operating frequencies. This results in undesired beat frequencies in the input current to the array. As a result, ac ripple current circulating in the input section of the converters is increased. While converters offering a synchronisation method will avoid beat frequencies – there are no operating frequency mismatches – there is a restricted choice 'off the shelf', which can lead to lower overall system efficiency and power density. By implementing simple input filters, the input ripple currents of an array of unsynchronised converters can be suppressed significantly, along with beat frequency components, allowing unsynchronised converters to be considered.

Beat frequencies
To demonstrate this problem and the impact of input filtering, we can consider rf transmitters or microwave radio links, which require substantial power. For example, a system requiring an output power of 2.1kW from a MIL-STD-704E supply connects eight 270W bus converters in parallel to form a high power dc/dc array. For simplicity, we will look at two high input voltage 270W Sine Amplitude Bus converters connected in parallel – providing a total output of 540W.

Even though Sine Amplitude Bus Converters switch at fixed multi megaHertz frequencies, part to part variations in members of this family result in each converter operating at a slightly different switching frequency. The interaction between the switching noise of each dc/dc converter in the array creates the undesired beat frequencies, at multiples of the differences between their operating frequencies.

The impact is most notable in the ripple current circulating amongst the array’s dc/dc
converters. The ripple currents of the switching frequencies add up to generate an amplitude modulation of the overall ripple current envelope of the converters. For instance, in the parallel dc/dc converter array described earlier and shown in figure 1, a pair of interconnected bus converters with nominal switching frequency of 1.7MHz might have actual switching frequencies of 1700kHz and 1702.7kHz. The 2.7kHz difference between the two means the total input current will have a much lower frequency component to the apparent ripple.

During periods when the ripple amplitudes are at their highest, the copper losses in the interconnect wiring between the converters are higher than they need to be – while the circulating ac ripple current is not being used by the dc/dc converters, it is still flowing through conductors with finite resistance.

High additive ripple currents can also stress input bypassing capacitors and system noise can be increased, depending on the board layout. In some cases, these circulating currents can interfere constructively with sufficient amplitude to lead to the converters demonstrating unpredictable behaviour – for example, erroneous detection of an overcurrent condition inside a module.

The problem is demonstrated using the parallel array shown in fig 1. For the initial measurement, the input inductors L1 and L2 are not included and there is no input filtering beyond the input bypass capacitors C1 and C2.

Because of the asynchronous switching of the two modules in the array, their ac input ripple current frequencies are also different. With a common input and no inductive filtering, the ac ripple currents mix and generate ripple with modulated amplitude based on the lower beat frequency as discussed above.

This array was built from two bus converters operating at 270V in and 45V out. The nominal fundamental operating frequency for this converter model is 1.7MHz. The input ripple current to one of the modules was measured and the time domain plot of the resulting performance is shown in fig 2a. For the bus converter array used in this measurement, the total input current was about 2.1A dc for full load operation.

**Suppressing the beats**
With fairly simple input filtering, the unwanted ac ripple currents circulating between unsynchronised converters in an array can be controlled. The input inductors (L1 and L2 in fig 1) are incorporated to serve as additional input filters. In this experimental setup, the 0.4µH inductors were placed in series with the +In leg of each bus converter in the array. The input inductors increase the impedance between the input stage of one converter and the other converters in the array at the switching frequency. In this case, the impedance of the inductors is roughly 4Ω at 1.7MHz fundamental switching frequency of the bus converters. This impedance reduces the high frequency ac circulating currents in the system.

The performance after adding the input inductors is shown in fig 2b. Overall ripple amplitude is reduced and there is a corresponding reduction in the lower frequency modulation of the ripple current envelope. As a result, with input filter inductors, the amplitude of the input ripple current drops from 84.4mA p-p to less than 14.3mA p-p.

It was observed that the circulating ac ripple current at the input of an array of non-synchronised dc/dc converters can be substantially higher if no filtering is employed at the common input bus of this array of parallel converters. In fact, ac ripple current can be substantial compared to the dc input current. However, by using simple input filtering, the ac input ripple can be curtailed significantly. Because the bus converters used in this example operate at higher fundamental switching frequencies (more than 1MHz), smaller filtering components with lower losses were employed, compared to those required for lower switching frequency converters. This can be advantageous for systems where overall space, weight, and efficiency are at a premium.

From the results shown in fig 2, it can be seen that input filtering plays an important role in curbing the influence of beat frequencies when arrays of switching dc/dc converters are connected in parallel. With the use of simple input filter inductors, the amplitude of the ac input ripple current in one of the bus converters, in an array of two high input voltage bus converters was reduced by more than 80%.

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