WHITE PAPER

Reverse Mode Application of Sine Amplitude Converters

Written by: David Bourner

Abstract

The power electronics industry is seeing the re-emergence of DC high voltage distribution in place of AC systems of power transmission within advanced machines and installations [1]. A modular DC-DC converter is available in a number of different package and power formats that can form a bridge from low voltage systems to ones that run at levels in the 400 - 1000 V range. Experiments and feasibility studies [1,4] point the way to new product variants of both the BCM (bus converter module) and VTM (voltage transformation module) engines – both of which manifest mature SAC (sine amplitude converter) technology. Efforts are now focused on qualifying parts for bidirectional power flow use. Three operational topology variants are described. Early experimental objectives and outcomes are outlined in the article, along with pertinent techniques that can be used to overcome new challenges implied in this novel deployment of SAC parts. Examples of applications drawing on the technique are outlined in the final part of this article.

1. Descriptions of Application Spaces

1.1 Motivation

The BCM has seen gradual and significant improvements in efficiency over the past decade [1]. Concurrent to deploying the BCM in new packages is a drive toward a novel way of using the SAC engine, manifest also as the VTM. The SAC –is a resonant, ratio-metric, constant power, isolated, near-ideal DC-DC transformer topology. It can draw power into its secondary port, boosting applied secondary voltage by parameter K as high as 32 in a single step. It transfers most of the energy received in the secondary port, directly to the primary port with very little power loss. The inverse of the transformation ratio, K, a field of integer numbers, is also being expanded as new products are offered. The levels of the HV link to be supported in future products are also set to follow industry trends.

1.2 Classifying New SAC Operational Modes

This article deals in three new topology types associated with the use of SAC engines – besides forward mode, the conventional operational paradigm: These are reverse, mirror and bi-directional mode. It should be pointed out that all the SAC-based solutions may involve any number of parts arrayed in parallel for the purposes of increasing power throughput. So, any mention of a module in what follows may also imply an array of paralleled, identical devices. Figure 1 shows all the topologies and their governing equations.

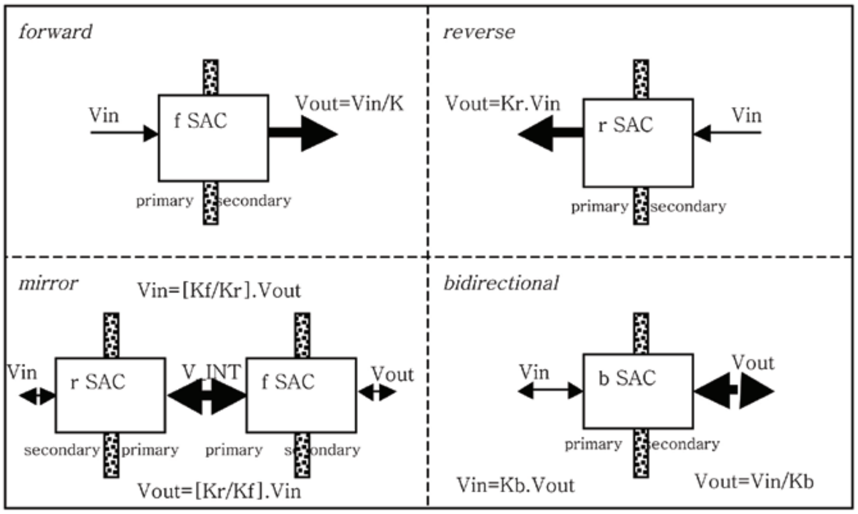


Figure 1
SAC application topology options. The SACs operate as 'f' (forward), 'r' (reverse) or 'b' (bidirectional) power converters which have isolation barriers set between their primary and secondary power ports. The grey bar represents the SAC inbuilt galvanic isolation barrier between the input and output power ports.

In reverse mode, the source is applied to the SAC secondary power port. Following start-up, the SAC delivers a voltage boosted according to the K factor associated with the particular module. This it presents to a load connected across its primary power port.

A pair of SAC engines is used in mirror mode. A source is processed with reverse-mode boost in the first SAC unit, and the other to which it is connected via the primary port interface, works in forward mode, bucking the HV rail to a level that is required in the customer's end equipment.

In bi-directional mode, a single SAC is deployed with the intent that once excited, the module is to deliver power in either the forward or reverse direction, depending on the way in which the SAC is being actively driven at a given instant in time.

2.0 Experiments and Outcomes

2.1 Establishing Reverse Mode Operation

Preliminary results were gathered from two test setups devised for steady state and transient condition assessments. A steady-state test rig, designed for a long-term testing on the bench is pictured in figure 2.

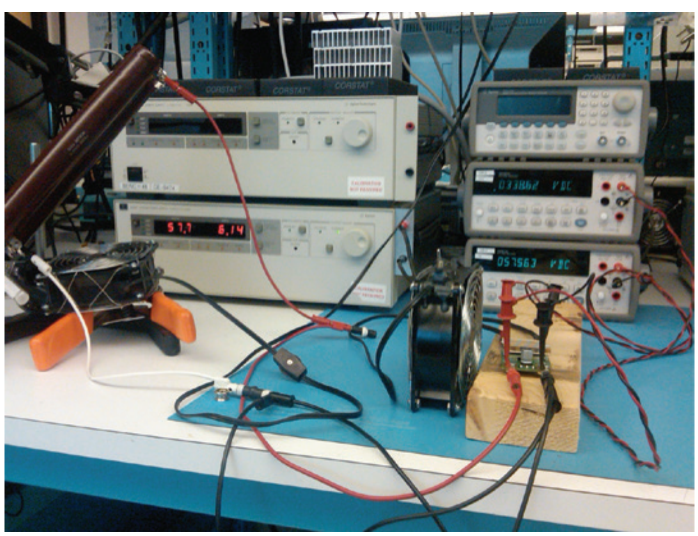


Figure 2
Reverse BCM in steady-state operation on the bench following BCM start-up

Prior to start-up, the BCM's secondary power port was back-biased - a steady voltage was applied to the secondary side of the BCM - something it tolerates without any adverse consequences. The BCM was then energized at the primary side with a unidirectional, low-current high-voltage source sufficient to bias the primary referenced controller internal to the BCM. The sources used in the experiments have large capacitor banks which can tolerate some reverse current flow prior to running a load on the primary side of the SAC. With the controller on the primary side of the part's isolation barrier, there is a need to hold off the primary load whilst starting up the BCM, and to then prevent high levels of primary current in-rush into the load, which is to be engaged only after BCM startup has been completed.

In a real application, where the secondary back bias source connected to the BCM is likely the only available power source, an auxiliary power stage would be needed to boost from the secondary side of the BCM, delivering charge at much higher potential to the primary port of the BCM, without compromising its isolation barrier.

A primary inrush test setup and result are shown in figures 3 and 4 respectively.

Figure 3
Reverse BCM Transient test setup

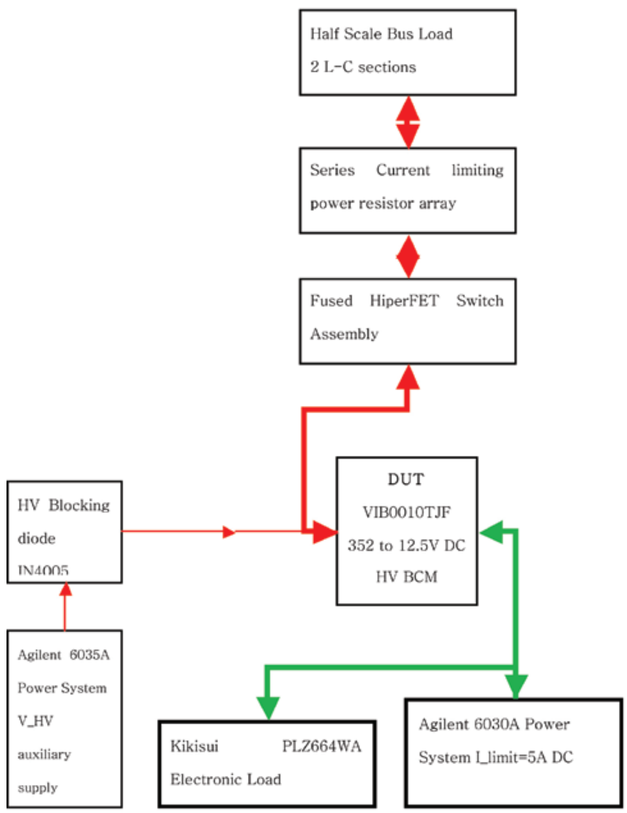
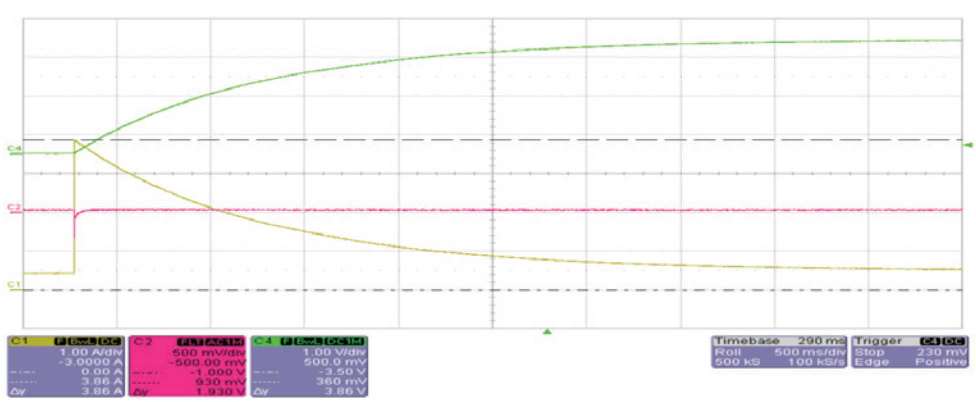


Figure 4
Transient test outcome. Green trace: boosted output with x100 attenuation, red trace: LV bus voltage; olive green trace: controlled secondary side inrush current.



2.2 Review of the Application Space

On the basis of the outcomes developed in the first experimental phase, BCM components were successfully deployed in an automotive energy harvesting and adaptive suspension system proof-of-concept, with the bidirectional BCM implementation based on learnings gleaned from the first experiments.

Since this first demonstration, customers have shared demanding applications for power transmission in tethered under-water and airborne vehicles.

These use a high voltage link, made with narrow gauge wire to pass power to the AUV or UAV at the other end of a long tether, using the mirror topology mode running from source to load. Typical power levels are in the 1-2 kW range. An airborne applications example is shown in figure 5 in a Vicor Whiteboard, a web-based tool maintained for the benefit of customers on the Vicor website. The proposed alternative being described here extends the well-tried Power Component approach which offers modularity of design, low weight, and high efficiency and power density metrics.

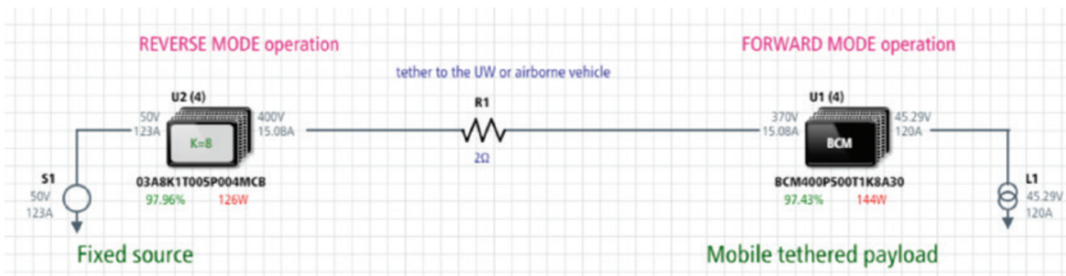


Figure 5
Airborne power transmission example uses HV link in a tether, a system that is realized with reverse and forward-mode operated BCMs. This is an example of a SAC mirror topology, albeit one that is operated with a unidirectional power flow.

3. Summary

The use of BCMs in reverse, mirror and bidirectional topologies has been described. Some preliminary results have been shown for an experimental test rig used to verify consistent operation of standard product operated in reverse mode. A couple of application spaces have been described, one in the automotive regenerative braking / active suspension arena and another for tethered UAVs to show the potential way forward with other, as yet untried, practical uses of the new SAC topologies for power processing mentioned in this report.

Table 1
Test settings, calculations corresponding to the setup shown in figure 2

Current State of Long-Term S/S Test Rig K for the MBCM270F450(F/T)M270A00 = 1/6				
V_LV (V)	57.7	LV Rail voltage setting (38-55V in Forward mode)		
V_HV (V)	338.61	HV rail voltage level in reverse mode		
R_HV (ohms)	333	Load set across MBCM's HV bus		
K'	1/5.86	Calculated Voltage Transformation Ratio		
I_HV (A)	1.06	338.61/333 =	1.017	Calculated HV load current
P_HV (W)	V_HV*I_HV	338.61*1.06=	344.31	Power in Load
I_LV		1.06 * 6 =	6.36	Calculated LV source current Set Current limit to > 7A

Table 2
Test results of DC startup action for a standard BCM

LV Rail Voltage (V DC)	HV Rail Voltages (V DC)		LV Rail Currents (A DC)		No-Load Power from LV Rail (W)
	Reverse-mode startup threshold	Active reverse mode level, K factor	Active reverse mode level	Post HV rail pre-charge completed, load connected	
11.00	306	304.97 27.72	0.408	0.455	5.01
11.75	306	325.73 27.72	0.438	0.489	5.75
12.00	306	332.66 27.72	0.446	0.497	5.96
12.50	306	346.48 27.72	0.459	0.519	6.49
13.00	306	360.28 27.71	0.485	0.536	6.97
13.50	306	374.05 27.71	0.497	0.540	7.29
14.00	306	387.87 27.71	0.519	0.561	7.85

References

[1] M Salato "The Sine Amplitude Converter™ Topology Provides Superior Efficiency and Power Density in Intermediate Bus Architecture Applications, Vicor Corporation June 2011.

[2] Vicor Company Private Document "VTM II: Theory of Operation"

[3] P Yeaman VIC Application Note AN:016 "Using BCM Bus Converters in High Power Arrays"

[4] A Patel "An Isolated Step-Up DC-DC Converter Using Series Connected Sine Amplitude Converters " APEC2015, ISBN 978-1-4799-6735-3/15

[5] D Bourner "Back-Driven Vicor Bus Converter Modules – Startup Characteristics" Vicor Internal report Sep 2012

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