WHITE PAPER

Re-Architecting 48V Power Systems with a Novel Non-Isolated Bus Converter

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Abstract

Intermediate Bus Architectures have been popular in the telecom industry for their ability to easily accommodate a wide variety of loads from the telecom industry's common 36 – 60V distribution voltage range. [a] *A key performance metric of telecom power systems is based on the performance of the bus converter used to enable this architecture. While point-of-load converter performance is mostly driven by advances in semiconductor technologies, bus converter performance is highly dependent upon converter topology. Performance metrics impacted by bus converter topology include both power conversion efficiency* [b] *and power system stability.* [c] *The Sine Amplitude Converter bus converter topology* [d] [e] *has proven to be superior to traditional topologies* [f] *in virtually every significant performance metric, including conversion efficiency, power density, footprint, bandwidth and system stability. As telecom power-system requirements have matured, the Sine Amplitude Converter may now enable further system improvements. Specifically, grounding requirements of telecom systems are compatible with bus converters that do not require galvanic isolation.* [g] *This paper presents series-connected bus converters* [g] *optimized for use in non-isolated bus architectures (NIBA) by having primary and secondary converter stages connected in series.*

Keywords: Bus Converter, non-isolated, DC architectures, NIBA, series-connected switching stages.

Introduction

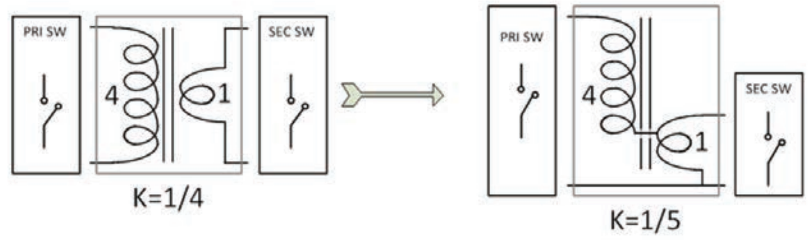
Positive-referenced DC distribution systems have been widely adopted in the telecom field, with the objective of preventing wire corrosion. [h] Phone wire material has historically been copper and it's been usually exposed to air (or worse, soil and water) at many points along its path from the telephone company central office to phone terminals. Environmental factors allow the wire to corrode: copper in the wire is converted to copper oxide or copper carbonate, a chemical reaction where copper atoms act as positively charged ions to combine with negatively charged oxygen or carbonate ions in the environment. A wire with a positive charge will actually cause negatively charged ions to migrate toward the wire, greatly accelerating corrosion. A negative charge will repel the corrosive ions, slowing down the corrosion process. Modern systems, however, present higher complexity than the simple telephone pair and often require active cathodic protection. Active techniques can be deployed on diverse plants that involve DC distribution, while active approaches are also successfully implemented in the most extreme cases, like for example submarine DC power transmission. [h] [i]

The new proposed bus converter: non-regulated and non-isolated

Bus converters have been widely used as power-conversion devices in Intermediate Bus Architecture applications. Among bus converters, fixed-ratio converters offer relatively higher efficiency reducing the heat generated on motherboards while enhancing system scalability. [k] The objective of this paper is to introduce the benefits of non-isolated fixed-ratio bus converters based on the SAC™ topology, [f] [m] without galvanic isolation.

As a starting point, converters include magnetically coupled transformers with switching stages at the input and the output of the transformer. Converter topologies incorporating zero-voltage switching (ZVS) and zero-current switching (ZCS) [f] [o] achieve higher efficiency and power density. A transformer can be configured either with, or without, galvanic isolation. Figure 1 shows a conceptual example, where a 4:1 transformer becomes a 5:1 auto-transformer by properly configuring winding connections.

Figure 1
A 4:1 transformer structure re-configured as a 5:1 auto-transformer structure, with associated switching stages



In certain applications, bus converters supply power to buck regulators feeding loads ranging from 1 to 6V. Fixed-ratio converters have historically been used, with either the 4:1 or the 5:1 ratios. From the point-of-load regulators standpoint, lower input voltages are preferable, because of higher duty cycle operation. Narrow step-down ratios help minimizing RMS current in inductors and switches for a given output voltage. Consider for example a 3.3V load in a 54V backplane distribution system. Utilizing a 5:1 bus converter instead of a 4:1 bus converter will cause the nominal input voltage to the regulator to drop from 13.5 to 10.8V, which translates in an increase in the minimum duty cycle of the buck regulator from 24 to 30%. The corresponding RMS current within the synchronous buck components decreases by at least 10%, reducing conduction and magnetic elements losses.

Design considerations

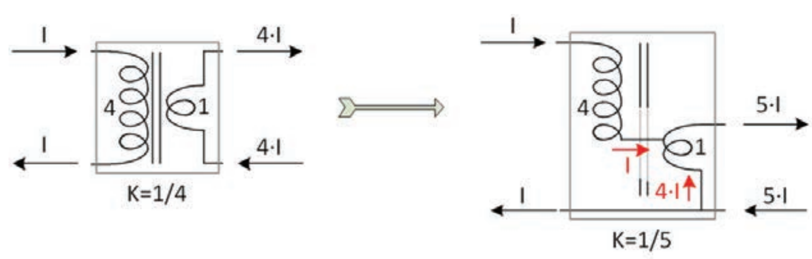
The proposed series-connected bus converter is efficiently implemented using the Sine Amplitude Converter topology. The approach offers several advantages when compared to an equivalent isolated version. Advantages include:

- Higher efficiency:
  - Reduced transformer loss
  - Reduced power semiconductors loss
- Bi-directional start up and control

Two of the key design aspects of the proposed non-isolated approach follow.

A. Aspect 1: A portion of the primary current flows to the secondary directly

Figure 2
Comparison of primary and secondary currents between a transformer and an auto-transformer



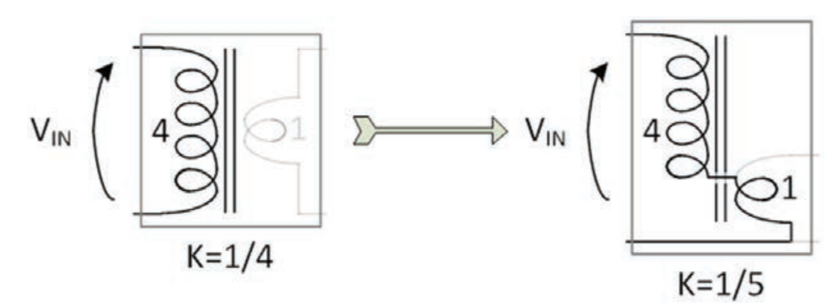
Like in classic auto-transformers, the primary current flows directly to the secondary winding, contributing to the load current. Figure 2 helps visualizing this general concept.

It is important to note that the increase in step-down ratio is obtained with reduced winding and core losses. As illustrated in Figure 2, with the same primary and secondary winding current, output current is 25% greater.

B. Aspect 2: reduced loss in the magnetic core

Transformer core losses are highly dependent on magnetic flux, in a non-linear fashion. [I] As shown in Figure 3, the proposed non-isolated structure reduces the flux density in the transformer's magnetic core by utilizing both windings (primary and secondary) to magnetize the core. To visualize this, assuming a 54V nominal input voltage for both designs, the isolated K = 1/4 will magnetize its core with 13.5V/turn; the non-isolated K = 1/5 instead will magnetize its core with 10.8V/turn.

Figure 3
Comparison of volts-per-turn on magnetizing inductance in transformer and auto-transformer design



Integrated design and characteristics comparison

Both converters have been designed and built on the Vicor ChiP™ platform. The module size is 63 x 25 x 7mm, input voltage range is 36 – 60V, fixed step-down ratio is K = 1/4 for the isolated version and the K = 1/5 for the non-isolated one, power rating is approximately 2kW for both. Figure 4 shows the packaged product and Figure 5 shows another highly integrated packaging option using the Vicor low profile VIA 4414 package (110 x 35 x 9mm) which incorporates filters, transient protections, telemetry, etc. Table 1 on Page 4 provides a side-by-side comparison of the obtained characteristics.

Figure 4
6123 ChiP NBM™ or BCM®

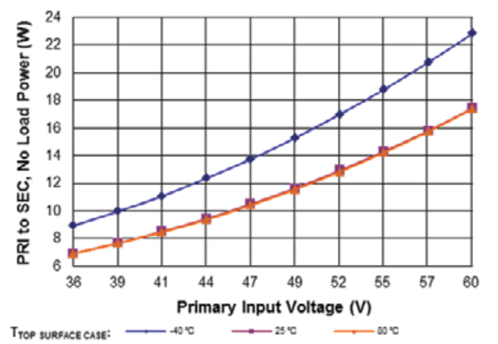
Figure 5
4414 VIA NBM or BCM

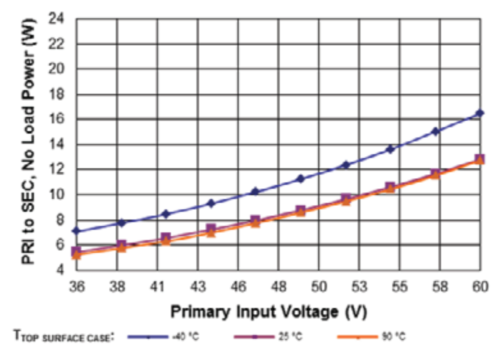
Table 1

Side-by-side characteristics comparison for the isolated (BCM®) and the non-isolated (NBM™) bus converter designs

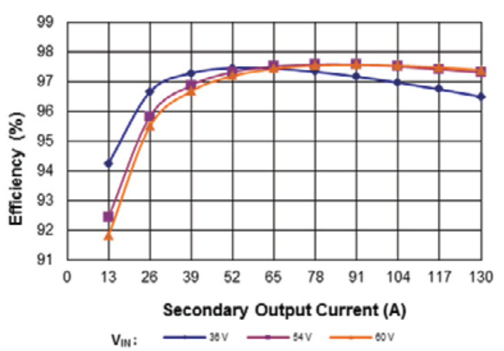
BCM K = 1/4	NBM K = 1/5

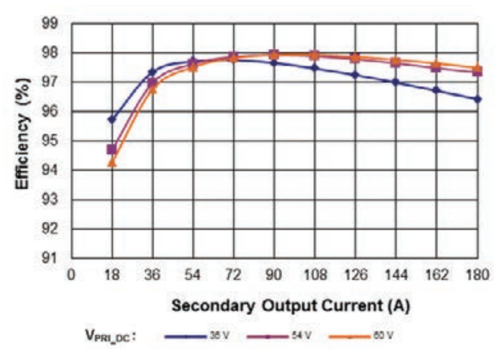
No load power dissapation vs. primary input voltage



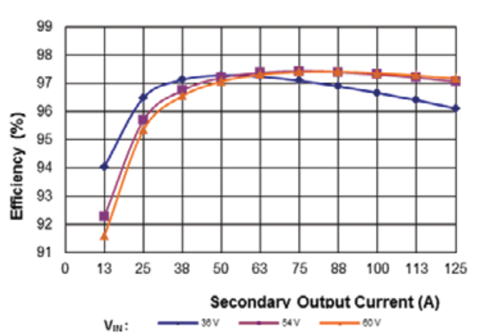


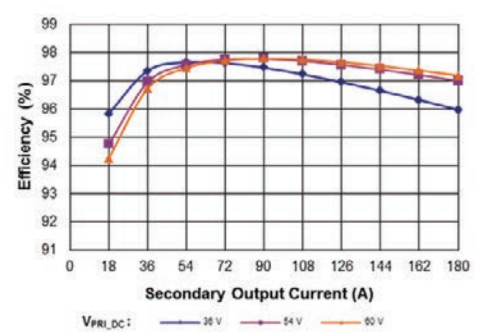
Total efficiency vs. line and load, 25°C case temperature



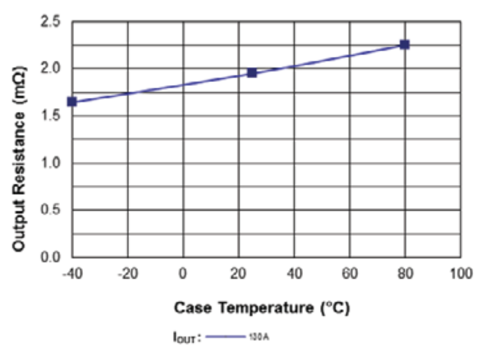


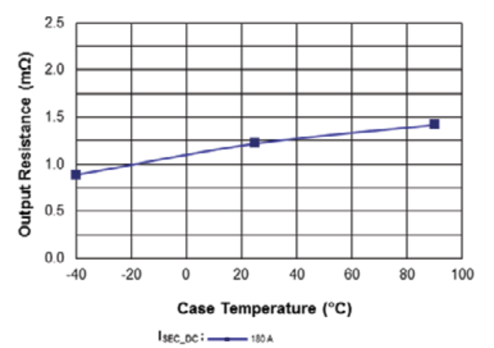
Total efficiency vs. line and load, 80°C case temperature





Bus converter output resistance vs. case temperature, maximum load





A. Positive and Negative-Referenced NIBA

NIBA in negative-referenced systems is shown in Figure 6. However, it's important to note that it is possible to address positive-referenced distribution systems (classic –48V) while retaining some of the benefits of non-isolated bus converters. Figure 7 shows such an implementation. However, the positive-referenced NIBA offers a viable retrofit option for legacy systems. It is important to note that, in this particular case, the advantages explained under "Design Considerations" aren't completely present. However, the absence of common mode noise, the higher power density and the standardization of the power architecture between new deployments and legacy systems retrofits still represent a highly-leveraged advantage.

Figure 6
Negative-referenced NIBA

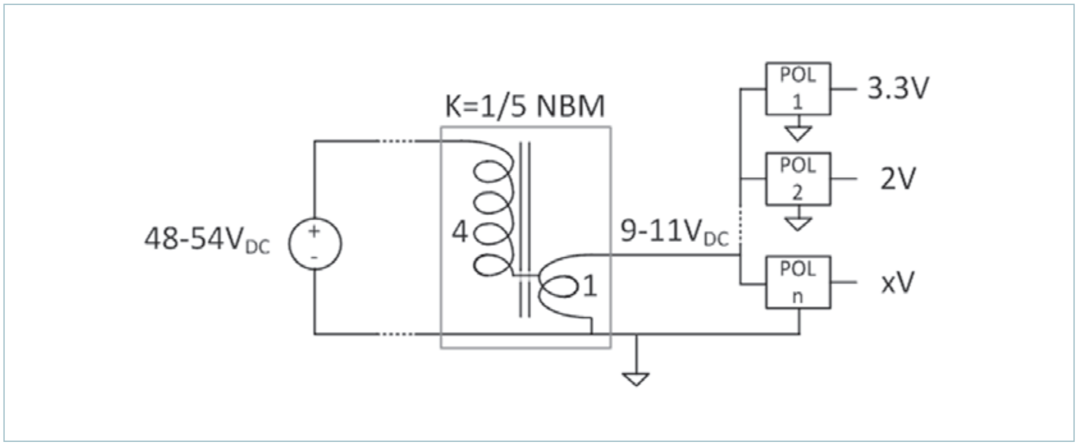
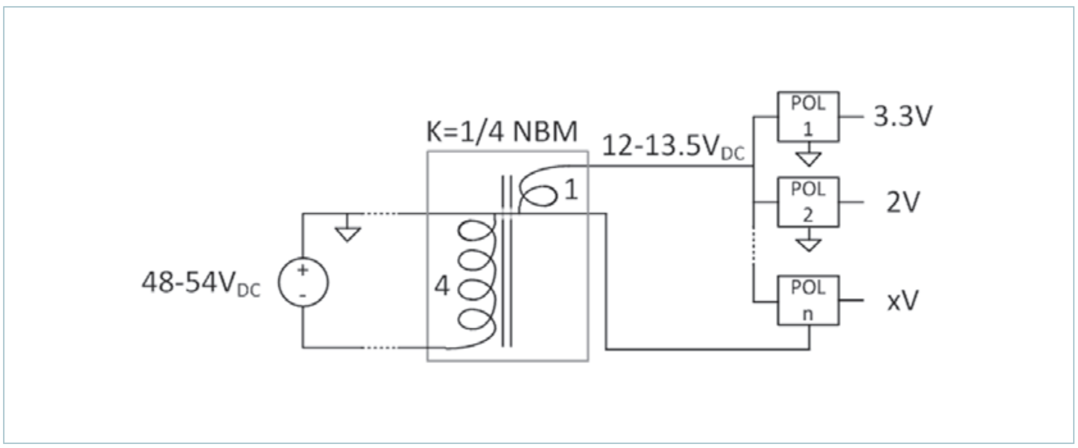


Figure 7
Positive-referenced NIBA



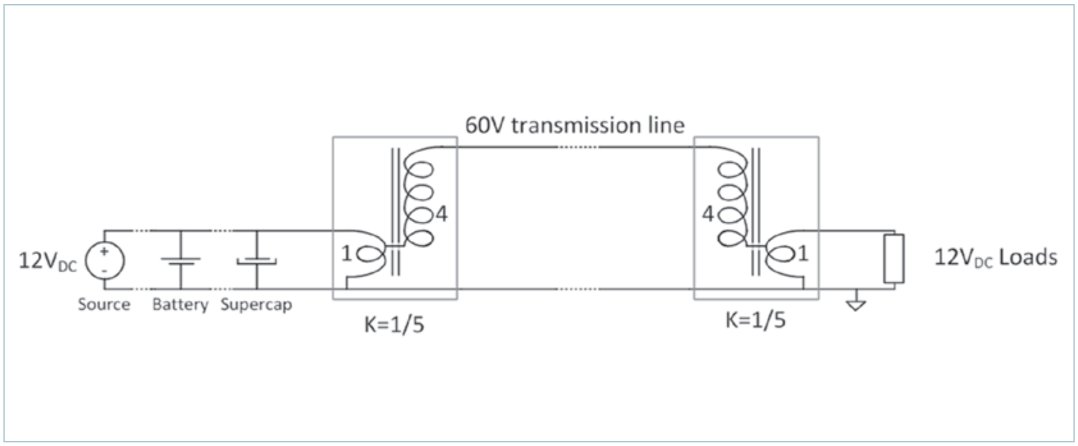
It is important to note that while the change in polarity between input and output results in the loss of some of the topology benefits (lower magnetic core losses and direct flow of input current to the output of the converter), this arrangement enables input and output switches with lower voltage ratings, therefore with higher figure of merits.

B. High-efficiency, SELV, bidirectional energy transmission

Owing to the bidirectional start up and control of the SAC™ implementation [f] [g], the proposed bus converter can be utilized to create a local, higher voltage, higher efficiency DC transmission line; for example 12V can be boosted to 60V, distributed and brought back to 12V where needed, as shown in Figure 8. This approach offers interesting options in the datacom field, where existing wiring (i.e., telephone twisted pair) can be safely utilized to transmit power. Sources, storage and loads can be easily de-localized and, at the same time, dynamically interfaced with minimal losses and passive (droop) sharing techniques.

Automotive applications can also potentially benefit from a local, higher efficiency electrical distribution system. Specifically, the capability to effectively bus 60V between electrical 12V subsystems (like, for example, super-capacitors or battery storage, alternator and distributed loads) might provide to be a convenient approach in cars and trucks with distributed low voltage electronic elements.

Figure 8
NBM™ (and NIBA) utilized for efficient energy transmission



Conclusion

An additional leap in bus converter technology can be achieved by moving the isolation function to the system level. A new family of Sine Amplitude Converter non-isolated bus converters has been described, as well as detailed performance characteristics and specific power system architectures that can fully leverage their unique characteristics.

These new bus converters naturally fit new telecom and datacom type of applications, either at equipment level or at power distribution level, with a simple, streamlined approach. Moreover, legacy deployments can be easily retrofitted, with significant advantages in terms of system density, efficiency and use of existing infrastructure.

Finally, the proposed converter provides designers with the ability to create a local, higher efficiency, safe transmission line in automotive electrical systems.

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