

How to specify the best power supply topology

Abstract

Whatever the final application, power supply users want reasonably priced products that are small and efficient, yet have excellent EMC performance. Andrew Skinner, TDK Lambda UK's Chief Technology Officer, illustrates how the choice of power supply topology can greatly affect these key parameters.

Introduction

There are many well known circuits that fit certain applications very well, but if we want to find the best solution for a given application then we need to understand how the choice of topology may affect the key parameters of the power supply, which are cost, overall size, EMC performance and efficiency.

The importance each of these parameters varies between application and trade-offs made between each of them have a significant effect on the choice of topology. For example, a solution targeting the lowest cost may be quite different from one targeting the highest efficiency; counter-intuitively a solution targeting the highest power density (smallest size) won't necessarily achieve the lowest losses. With the development of the new TDK-Lambda EFE series, a high density AC-DC supply aimed at embedded front-end applications, an iterative design method was used to determine the best possible topology.

Key design criteria and design rules

The key design criteria set for the development of the EFE300 for instance were the overall dimensions of 5x3-inch and 1U compatible, 300W continuous power rating with 2m/s airflow and 400W peak power rating for 10 seconds, all achieved over the whole supply voltage range 90-264Vac, and curve B conducted EMC (EN55011, EN55022). Another important design objective was to design the supply following the tried and tested TDK Lambda design rules for component deratings, spacings, PCB design rules and so on.

These design rules have been proven successful by our engineers when designing earlier products and following them rigidly reminds us not to make compromises simply to achieve a small size. In addition, they are important in creating a product that can be easily manufactured and is reliable. It is always possible to squeeze more components into a small space to achieve a "high density" power supply, but components that are mechanically stressed or over-heated due to insufficient space being allowed for them will lead to reductions in overall reliability.

<p>“NV” topology Zero-voltage switching variable frequency modified LLC with self-driven synchronous rectifiers. TDK-Lambda patented.</p>	
<p>Half-bridge LLC resonant converter Zero voltage switching variable frequency converter with actively driven synchronous rectifiers (self drive is not possible)</p>	
<p>Full-bridge Current Doubler Zero voltage switching pulse-width modulation controlled converter with current-doubler rectification.</p>	
<p>Half-bridge Current Doubler Hard switched half-bridge pulse-width modulation controlled converter with current-doubler rectification.</p>	
<p>ZVZC switching DC-DC transformer plus pre-regulator Zero voltage and zero current switching resonant DC:DC “transformer” with buck pre-regulator (zero current or boundary mode controlled)</p>	
<p>ZCS Resonant Converter Zero current switching , variable frequency resonant converter</p>	
<p>Quasi-resonant converter Flyback converter operated with valley switching and actively driven synchronous rectifier</p>	

Table 1: Possible topologies

In order to choose the most appropriate topology we need to consider the attributes of possible solutions, shown in Table 1, by adopting a simple scoring process. Each topology is evaluated in two stages; firstly for switching and efficiency characteristics, shown in Table 2, and then for circuit complexity, EMC performance and other relevant factors of the target application, shown in Table 3. Each attribute is ranked, from “1” meaning bad through to “5” good, and the results of both stages are weighted together.

Topology	Primary switching		Secondary switching		Circulating VA		Efficiency	
	Turn-on	Turn-off	Turn-on	Turn-off	Low output voltage	High output voltage	Light load	Full load
NV topology self driven synchronous rectifier	ZVS	ZVS	ZVS	High di/dt	4	3	2	4
Half-bridge LLC synchronous rectifier	ZVS	ZVS	ZVS	ZCS	3	5	3	5
Full-bridge current doubler synchronous rectifier	ZVS	ZVS/hard	ZVS	High di/dt	5	3	2	5
Half-bridge current doubler synchronous rectifier	ZCS/hard	ZVS	ZVS	High di/dt	4	3	3	5
ZVZCS Resonant dc transformer plus pre-regulator	ZVS	ZVS/ZCS	ZVS	ZCS	2	4	2	4
ZCS Resonant converter -fixed on-time variable frequency	ZCS	ZVS	ZVS	ZCS	3	4	4	3
Quasi-resonant flyback synchronous rectifier with diode emulation	ZCS	ZVS	ZVS	ZCS	1	3	2	4

Table 2: Switching and efficiency characteristics

For the topologies considered, Table 2 shows the scoring for the switching- and efficiency-related characteristics. In general, a topology with soft switching and low circulating current will be preferred. The key issues for the attributes that are scored are:

Circulating VA: The amount of energy circulating within the topology that is not contributing directly to powering the load. For higher output voltages, this criterion is less of a concern due to the lower secondary-side currents involved.

Efficiency: Topologies with continuous output current and actively controlled synchronous rectifiers will be preferred, although generally this will lead to a lower circuit complexity score. With the appropriate selection of components and switching frequency, most circuits can be made highly efficient; this score is more a measure of the design effort required to achieve high efficiency.

Topology	Multiple outputs	Semi regulated outputs	Size		Complexity		EMC	Wide adjust range
			Low power	High power	Power circuit	Control		
NV topology self-driven synchronous rectifier	5	4	5	3	4	1	5	2
Half-bridge LLC synchronous rectifier	5	5	4	5	4	1	5	2
Full-bridge current doubler synchronous rectifier	2	3	1	5	3	2	5	2
half-bridge current doubler synchronous rectifier	2	3	2	5	2	4	3	5
ZVZCS Resonant dc transformer + pre-regulator	5	4	4	4	4	4	5	3
ZCS Resonant converter -fixed on-time variable frequency	5	4	4	2	5	3	4	2
Quasi-resonant flyback synchronous rectifier with diode emulation	5	5	5	1	5	5	4	3

Table 3: Key attributes relating to the circuit complexity, EMC performance and other application relevant factors of the topologies

The key attributes relating to the circuit complexity, EMC performance and other application relevant factors of the topologies is shown in Table 3. Let's take a look at the key issues for each.

Multiple outputs: A current-driven circuit without an output inductor is preferable since this simplifies the mechanical design.

Semi-regulated outputs: Where several outputs (that track one another with reasonable accuracy) are required a current driven design with a low secondary-side di/dt is preferred.

Size: Generally this is dependent on parts count within the power circuit for low power applications, and efficiency and even loss distribution, within components, at higher power.

Complexity: A topology that naturally limits current, does not place stringent timing requirements on the controller and has self-driven synchronous rectifiers will result in a better score for the power circuit.

A topology that has only low-side drive requirements and requires only a simple controller will score better for control circuit complexity.

Complexity is also a measure of cost, generally a topology that is complex and has a higher parts count will have a higher labour cost associated with its manufacture. The component costs will also be expected to be higher for a couple of reasons. Firstly, complex topologies tend to be less popular and hence controllers for them sell in lower volume, use a larger die size or require a larger package with more pins. The second reason, especially at lower power ratings, is that the topology generally requires more devices and will tend to use relatively small die thereby increasing the relative cost of the device packaging.

EMC: Topologies with zero-voltage switching (ZVS) on the primary side will have a better score since this often results in lower conducted EMC.

Wide adjustment range: Topologies that have zero-voltage switching often utilise the transformer magnetising current to assist in this. If the output voltage needs to vary over a wide range, then the magnetising current will also vary resulting in variable EMC, efficiency and component stress. Most soft-switching topologies therefore operate with a reduced output voltage range compared to hard-switching pulse-width modulated topologies.

Topology	Weighted score	Comments
NV topology self-driven synchronous rectifier	0.89	Continuous output current
Half-bridge LLC synchronous rectifier	0.86	High output filter ripple current and requires active synchronous rectifier gate-drive
Full-bridge current doubler synchronous rectifier	0.64	
half-bridge current doubler synchronous rectifier	0.63	
ZVZCS Resonant dc transformer +pre-regulator	0.85	High output filter ripple current
ZCS Resonant converter -fixed on-time variable frequency	0.75	
Quasi-resonant flyback synchronous rectifier with diode emulation	0.9	Very high output filter ripple current

Table 4: Weighted scores for TDK-Lambda EFE300

The scores are combined with weighting where the most important factors for a high density product (size and efficiency) are more heavily weighted than complexity (digital control makes the use of circuits with complex control algorithms, for example, an acceptable design choice). RFI is also given high weighting as curve B performance is a design objective. After applying these weightings, we arrive at the scores in Table 4. There are four topologies that have similar scores.

The low ripple current in the output filter of the NV topology make it the preferred choice at the power level and size of interest. In a 5x3-inch footprint, the number of output filter capacitors is limited due to PCB real estate constraints and can lead to electrolytic capacitors operating with high ripple current, which will result in more self-heating and reduced life. As the achievable operating frequency with the NV topology is relatively high, a few ceramic capacitors are used instead, resulting in a compact output filter design with enhanced life.

Conclusion

The industrial markets addressed by TDK-Lambda often require power supplies that have characteristics modified to suit the end application, such as non-standard voltages, modified loop-response, modified signals, etc. By utilising the power of digital control, these requirements are met more easily and, at the same time, the concerns associated with the more complex control algorithm of a resonant converter are alleviated since with digital control any control law can be implemented. The EFE series was therefore designed with an 8-bit microcontroller to control the resonant converter and to manage housekeeping functions.

Although there are similarly rated products available using LLC and DC-DC transformer with pre-regulator, the high reliability design rules used at TDK-Lambda don't allow the small component spacings needed to fit these topologies into a 5x3-inch format.

Choosing the right topology is vital to the success of the product and requires detailed knowledge of all the available choices. The correct choice results in a product with optimum cost, performance and reliability characteristics. Especially for high density power supplies, such as TDK Lambda's EFE series, squeezing an unsuitable topology into the available space can seriously damage your wealth!

For further information

To learn more about the EFE series, please visit:
<http://uk.tdk-lambda.com/efe>

You may also contact the author with any questions or comments at:
powersolutions@uk.tdk-lambda.com

TDK-Lambda

TDK-Lambda UK Ltd
Kingsley Avenue
Ilfracombe
Devon EX34 8ES UK
+44 (0)1271 856600
powersolutions@uk.tdk-lambda.com
www.uk.tdk-lambda.com