LED Power Supply Topologies

Topologies for Optimizing Efficiency, EMC and Time to Market

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Abstract
No load energy consumption of electronics is becoming more and more important. In many cases there is a conflict between high efficiency and low emission. For instance, a design for low emission that uses snubber circuits increases the no-load consumption and lowers the efficiency. The right power supply topology can save a lot of time during certification and EMC optimization of the product. An overview about the latest power supply technologies will be given and solutions will be proposed about how to develop low emission and high efficiency LED drivers simultaneously.

Potential
The future for the lighting technology belongs to the LED. McKinsey & Company predicted in its recent study on the development of the LED market for 2015 a worldwide volume of one billion units. The possibilities in using the LED technology are wide. For example the potential to save energy is very large. Through the use of digital LED drivers and power supplies there are suddenly many opportunities to the manufacturers to design individual lights. “Smart Lightning” is getting more into the focus. To remote control LED lights is possible trough different platforms like internet or tablets. LED drivers can be configured individually. LED lights can be networked in a grid. Communication among the LED lights enables further energy savings potential. The brightness can be individually matched to the customers need.
Professional LED lighting development requires an interdisciplinary approach that pays attention to all influencing factors. The complete system includes not only the mechanical design, but also the optic and the LED drivers. The later should be matched to the LED for optimal performance. To cool the LED is another challenge.
One success factor is the high efficiency of the LED compared to conventional light sources. Due to this high efficiency attention must be paid to develop low loss end efficient LED drivers. With today’s technology, LED power supplies with active power factor correction and efficiency >94% are possible.
In many cases, LED lights are dimmed via bus systems such as DALI. Thus, the efficiency in the partial-load operating range should be considered. If the light is turned off, standby mode, the power consumption should be at least lower than 0.5W. Solutions < 100mW are possible. Points not to be underestimated are the requirements for electrical safety and electromagnetic compatibility (EMC). In the latter, to comply with the harmonics according to EN 61000-3-2 can be challenging. Also the conducted and the radiated emission can cause problems and costs. Costs may result by a late market entry or not optimally designed devices.

Topology

For the best possible efficiency, soft switching power supply topologies are used. The switching of the main transistors is always at a moment with nearly zero current or voltage (ZCS, ZVS). Due to the zero voltage or current switching the switching losses are reduced greatly. Another effect is that those power supplies can be operated with higher switching frequencies. The magnetic components, PFC choke or transformer can be smaller. For further improvement the current in the transistors and magnetic components should be as small as possible. With the same power level the voltage must be increased. Due to the soft switching of the main transistors we don't have higher switching losses. The lower current will reduce the conducted losses. Thus, for example the power loss in the output rectifier of a 48V power supply can be greatly reduced compared to a 24V version.

Flyback Converter

If we can touch the LED itself, the power supply needs a galvanic isolation. For the power level below 50W, the most common used technology is the flyback converter. For cost reasons, normally they are not operated in a resonant mode. This means, the transistor is not turned on during zero current or voltage. The result: Decreasing efficiency and higher conducted and radiated emission due to the hard switching of the transistor. A possible solution to improve that situation is the use of quasi-resonant switching flyback converters. Here the transistor is turned on when the drain-source voltage reaches a minimum (see Fig. 1). With the right timing switching losses can be reduced. There is also an improvement of the EMC.

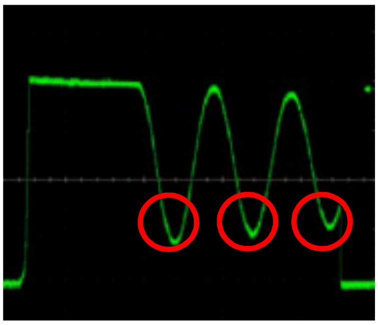

Fig. 1: Valley points

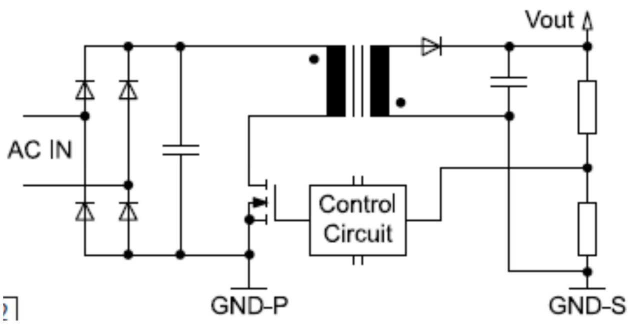

Fig. 2: Flyback Converter

EMC in Flyback Converters

When turning of the primary transistor, voltage peaks due to stored energy in the leakage inductance are generated. The emission due to this voltage peaks are typical common mode emission. To suppress common mode emission in the megahertz range is not always that easy and cheap. A cheap solution could be a snubber circuit on the primary side. The disadvantage is that the snubbed circuit converts the peak voltage to heat. Normally the snubber circuit is also generating heat during no load or stand by (STBY) operation. If the total power consumption during this operating mode should be lower than 500mW, this can be a real problem. If we reduce the snubber, the emissions will rise. Negal Engineering is solving this problem with some type of "dynamic snubber circuits". This means the snubber is only active during operation when we are producing a high level of common mode noise. During STBY the snubber is reduced or even removed.

Power Factor

To ensure the required quality in our power grid, we must fulfil the limit according to EN 61000-3-2 category C for lighting equipment. A cheap solution to comply with the limits is the use of a "single stage flyback converter". In this topology next to the rectifier no longer electrolytic capacitors are used. The current in the flyback transformer follows the rectified AC voltage and is sinusoidal. The disadvantage of this principle is the increased output current ripple of 100Hz, respectively 120Hz. In many cases, however, this is tolerable because the human eye does not perceive this ripple in the LED light.

Is the increased output ripple not tolerable, i.e. in LED street lights, two-stage converter are used. Either with a buck converter at the output or with an active boost converter on the AC input side.

LLC Converter

For output power above 50W (wide input range) resonant converter are increasingly used. From these topologies the LLC converter is currently the most popular topology (Fig. 2).

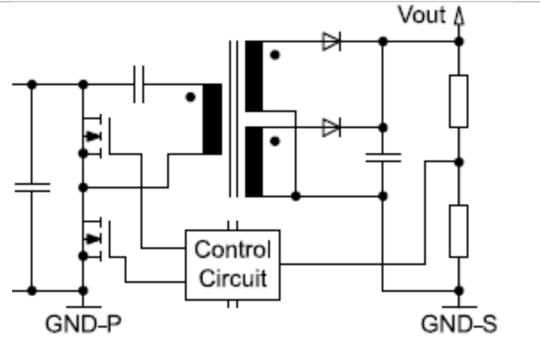

Fig. 3: LLC Converter

The LLC converter is a circuit technology that has long been known. Recent research and developments during the last years have made this topology available for industrial use. The LLC converter prevents "hard" switching in the power stage. In this topology, an inductor is used to reload the voltage of the output capacitance from the transistors. The transistor is turned on as soon as the drain source voltage is nearly zero. This switching condition generates very few switching losses. Due to the resonant switching the EMC disturbance is markedly reduced.

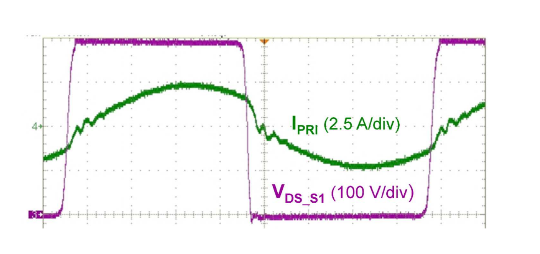

Fig. 4: Drain-Voltage (violet), Primary Current (green)

In Fig. 4 we can see that the transistor (violet) turns on if there is only the voltage of the body diode present and thus the voltage is almost zero. The series inductance for the resonant switching is normally integrated in the transformer. Therefor nearly no additional cost is caused. This "integrated" inductance is possible when the primary and secondary windings are arranged next to each other. The energy of the resonance inductor is stored in the air gap. The only drawback is that one has to develop normally a custom made bobbin. The regulation of the output voltage or current in the LLC converter is achieved by changing the frequency. The changing frequency results in a different quality of the LC circuit and thus results in a different system gain. An optimal controller setting is not easy to find because the resonant circuit cannot be tuned as desired. A further disadvantage of this topology is that a constant DC-Bus voltage is required. For this an active PFC input boost stage is required. For class C lightning power supplies, a PFC is anyway necessary to comply with limits for harmonic currents.

Power Factor

EMC is one of the major challenges in switching power supplies and LED drivers development. In addition to the immunity, it is primarily the emission from the power supply which often causes problems. An understanding of the disturbance variables is beneficial. In the lower frequency range, we can distinguish between the harmonics according EN 61000-3-2 and the conducted emission through the power line cable. It can sometimes be a challenge to comply with EN 61000-3-2 when developing dimmable LED drivers.

Harmonic	[% of fundamental]
N3	30 λ
N5	10 λ
N7	7 λ
N9	5 λ
N11-N39	3 λ

Table 1: EN 61000-3-2

As is apparent from table 1, the limit of the third harmonic strongly depends on the power factor λ (lambda). This means the lower the power factor the lower the current we can have to stay within the limits. At a power factor of 1, the third harmonic can be 30% of the fundamental. At a power factor of 0.5 only 15%. If we have for example a power supply which is dimmed to 10% of its full load, it makes a strong difference whether the power factor is 1 or even 0.5.
How can we influence the power factor in this part load operation?

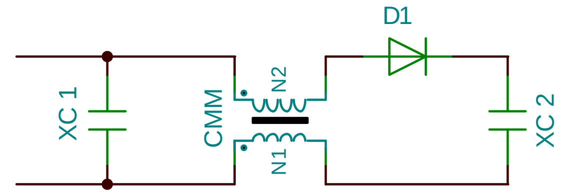

Fig. 5: Input Circuit Power Supply

Fig. 5 shows the input part of an off-line power supply. XC1 and XC2 are used to suppress the differential mode interference. The leakage inductance of the common mode inductor L forms a LC low-pass with the XC1 capacitor to filter the differential mode current. There is a disadvantage with the capacitor XC1. There is a reactive current flowing through this capacitor. The result is a worse power factor.

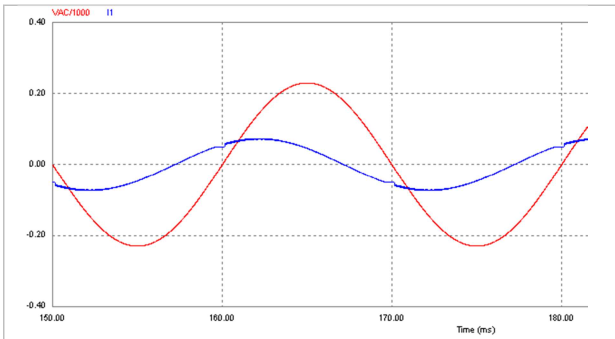

Fig. 6a: XC1 = 680n PF = 0.6

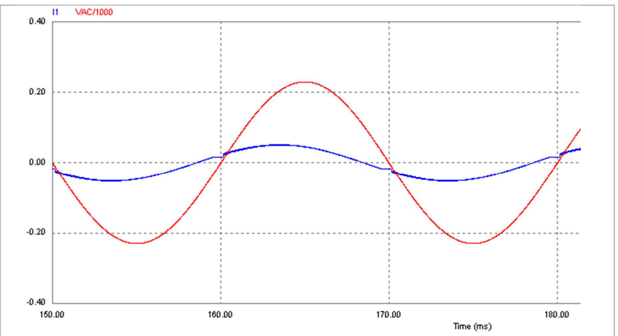

Fig. 6b: XC2 = 220n PF = 0.9

Fig. 6a and 6b shows the simulated power factor of an AC adapter with 5W output power. The phase shift between the voltage (red) and the current (blue) is related to the power factor. The power factor can be improved by using a smaller capacitor XC1. But this would reduce the filter performance for differential mode currents.

Harmonic Distortion

Harmonics are distortions of the line current. These are caused by charging of the DC-link capacitors or capacitors next to the input rectifier. In our example this is XC2. Distortions can only be reduced by reducing the value of these capacitors. But the XC2 capacitor forms a central element to suppress the conducted differential mode (DM) interference. Another possibility would be to increase the filter inductors. However, this incurs additional costs and requires additional volume.

Conducted Emissions

The LED driver must comply with the limits of EN 55015. Primarily the frequency range from 150 kHz to 30MHz must be considered. The type of interference which occurs in this frequency range can be divided into the two types: Common mode (CM) and differential mode (DM). The DM interferences are mainly responsible for the disturbance in the frequency range up to 1MHz. The switching frequency of a PFC input stage or the flyback converter lies normally in the range between 40 kHz and 130 kHz. Therefore the first harmonic lies already in the critical frequency range. The ripple current of for example the PFC input stage causes voltage drop across the ESR of the XC2 capacitor. This voltage drop is measured across the LISN as the differential interference voltage. As mentioned above, LC filters are used to reduce these voltages. For higher output power and with low input voltages, this filter can be expensive and large.

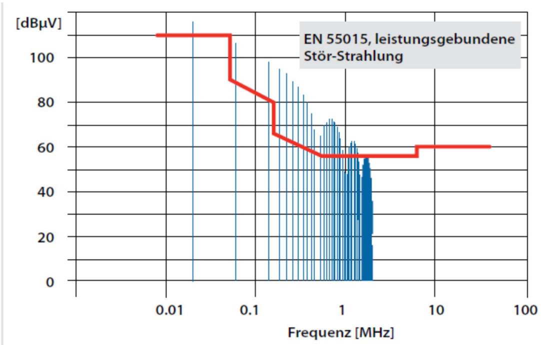

Fig 7: Limits for conducted emissions for lighting equipment

Active Power Factor Correction

With the use of the LLC topology for LED drivers with very high efficiency, a constant DC-Bus voltage is required. For that purpose boost converters are used. To stay within the limits for harmonic distortions, an active PFC is a great advantage. Thus a two-stage power supply with active power factor correction and downstream galvanic isolation is the right choice. Different topologies can be used for the PFC. For example this could be a continuous conduction (CCM) mode PFC. For an efficient CCM PFC with low EMC interference, normally silicon carbide boost diodes are used. In addition, the CCM PFC is a “hard” switching topology. This means, the efficiency compared to other solutions is lower. For output power until several hundreds of watts, the transition mode PFC is a good choice. Here the transistor is turned on when the inductor current reaches zero (Fig. 8). Due to this, very high efficiency can be achieved. A disadvantage is the relatively high peak current. It is precisely this ripple current that cause the differential interference which must be filtered.

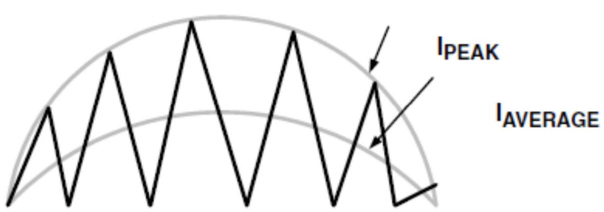

Fig. 8: Transition Mode PFC Wave Form

Zero Ripple Current PFC

A major limitation of the transition mode power factor correction is the high ripple current, as mentioned above. It would be a real advantage if one can reduce this ripple current without using bigger

PFC inductors. There is such a technique: It is called "ripple steering". This technique can theoretically reduce the ripple current in boost inductors to zero. If we manage to reduce the ripple current to the line side, the EMC filter capacitors and inductors can be reduced greatly or even be removed. Reducing the X input filter capacitors brings additional benefits to the application. X capacitors as discussed under "Harmonic Distortion" cause considerable reactive current flowing through the input filter. This reactive current is source of additional loss which can be in the range of 100mW depending on the line input voltage. Also the discharge resistors placed in parallel to the X capacitors for safety can be higher. The overall power consumption during no load operation in digital controlled LED drivers is reduced. Also the power factor is reduced which makes it more difficult to comply with EN 61000-3-2 during light load.

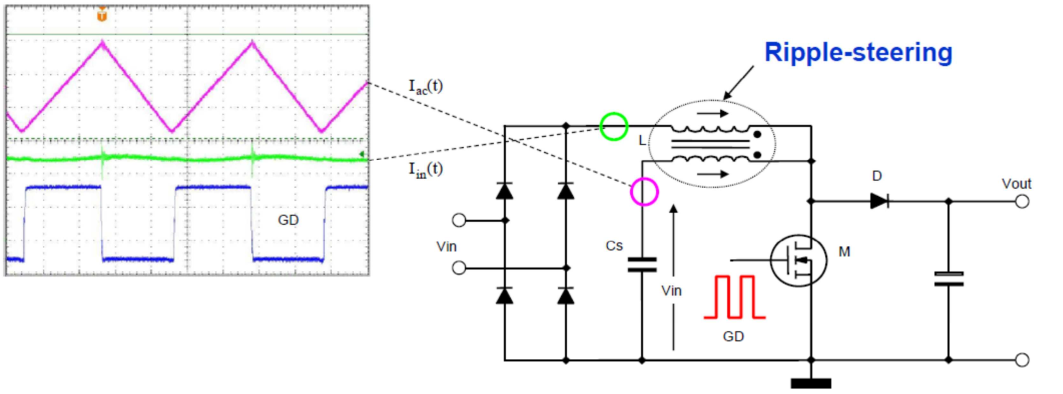

Fig. 9: Ripple Steering Boost Converter

Figure 9 shows the principle schematic of a zero ripple boost converter. To achieve a zero ripple input current a second winding must be used on the PFC inductor and an additional capacitor. The green trace above shows the greatly reduced input ripple current. With this technique one has a lot of advantages compared to the standard PFC topologies. The challenge in using this technology lies in the proper inductor design and in the understanding of the fundamentals of magnetic flux compensation. Negal Engineering has now brought this technology ready for the market for their customised LED drivers and power supplies.

Conclusions

Time to market is the most important part today, in the dynamic world of LED lightning. To choose the „right "power supply topology is the key factor to the best "customized" solution. All parameters like EMC, efficiency, cost and time to market should be considered. With the right strategy and the knowledge about different power supply topologies one can save a lot of time and money until the product will enter the market.

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