

ПРИБОРЫ И УСТРОЙСТВА СИЛОВОЙ ЭНЕРГЕТИКИ

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CHOICE OF THE MOSFET DRIVERS FOR THE CONVERTER UTILIZED AS DIMMABLE LED DRIVER

This paper represents one of the development stages of the converter (light-emitting diode driver) operating in amplitude mode light regulation. The principles of construction of the MOSFET driver circuits for the schematic with two n-channel MOSFET transistors are described. Also the schematic where high side transistor is substituted with p-channel transistor is considered. Utilization of the p-channel transistor allows eliminating necessity of using of isolated power supply for the driver of the high side transistor. In the last two sections of the article the losses in driver circuits are considered. This allows evaluating the scope of application for all considered approaches. From point of view of transistor driver losses it is preferable to use schematic with p-channel transistor at lower input voltages (in range of 12...30V) and higher switching frequencies.

Keywords: DC-DC power converters, electrical ballasts, switched-mode power supply, driver circuits.

Данная статья представляет собой описание одного из этапов разработки преобразователя (драйвера светодиодов), работающего по новым принципам в режиме амплитудного регулирования. Описаны принципы построения драйверов силовых транзисторов для схемы, в которой оба ключа являются n-канальными полевыми транзисторами. Рассмотрена так же схема, в которой один из полевых транзисторов заменен на p-канальный. Использование p-канального транзистора позволяет избавиться от использования гальванически развязанного блока питания для драйвера транзистора верхнего плеча. В последней части статьи приведены расчеты потерь драйверов транзисторов, что позволяет судить о целесообразности использования того или иного подхода в зависимости от конфигурации преобразователя и области его применения. С точки зрения потерь схему с p-канальным транзистором выгоднее использовать при низком входном напряжении (порядка 12...25В) и при более высоких частотах преобразователя.

Ключевые слова: DC-DC преобразователь, электронный балласт, импульсный преобразователь, цепи MOSFET драйверов.

Introduction

At the moment, there is rapid development of lighting equipment and devices in the direction of „smart” lighting due to improvements in quality and efficacy of white LEDs [2]. Adjustment of the amount of produced light (dimming) is one of the most important tools to reduce the overall power consumption of the „smart” lighting system [6].

Light regulation techniques of LED lamps can be divided in two main groups: 1) pulse mode light regulation (pulse width regulation PWM); 2) fluent light regulation (amplitude mode current regulation). This article presents description of one of the stages of development of the converter (LED driver) that operates by new principles in amplitude mode current regulation, as the amplitude mode provides better performance of the lighting system in most of the control range [1],[5]. The properties of the transistor control circuits (drivers) are considered in this paper.

Brief description of features of converter

LEDs are current consumers. It means the LED driver for „smart” lighting system should be controllable current source and the converter considered here is such a current source. General description of the converter is given in [4], [7].

Actually, the considered converter is not-inverting buck-boost converter the hallmark of which is a special control technique of the transistors. The signals of the transistors can overlap each other (Fig. 1 b). In general case it means the necessity of independent control for each transistor.

Implementation methods for control circuits of the power transistors

This circuit (Fig. 1) contains the high side transistor Q1 and the low side transistor Q2, which are located on different branches of the bridge. This leads to certain difficulties in organization of the MOSFET driver circuits. In general case the power supply systems of both drivers should be independent from each

other. Besides, at least one of drivers must be galvanically isolated from the control circuit. However isolation of both channels is desired.

The standard solutions of the problems described above (use of isolation transformer for decoupling of transistor signals or MOSFET drivers with bootstrap capacitor) are not suitable for this converter because of special control technique of the transistors (the value of duty cycle d of the control signal at certain operation point of the converter can reach 100 %).

Utilization of a galvanically isolated power supply for the MOSFET driver solves the problems described above. Both switches of the converter for the considered case are n-channel field effect transistors (FETs). For this approach it is necessary to use separate small power pulse mode converter with isolation transformer (the general case is shown in Fig. 1 a). A ready-made small power (1W) isolated DC-DC power supplies can be used for this purpose. Such a power supplies are widely represented on the market. The second option is to use application specific integrated circuits (ASICs) to build isolated power supply for drivers. The benefit in this case is the possibility to provide isolated supply for both drivers by one auxiliary power supply. The main drawbacks are higher initial costs as well as more complicated overall system.

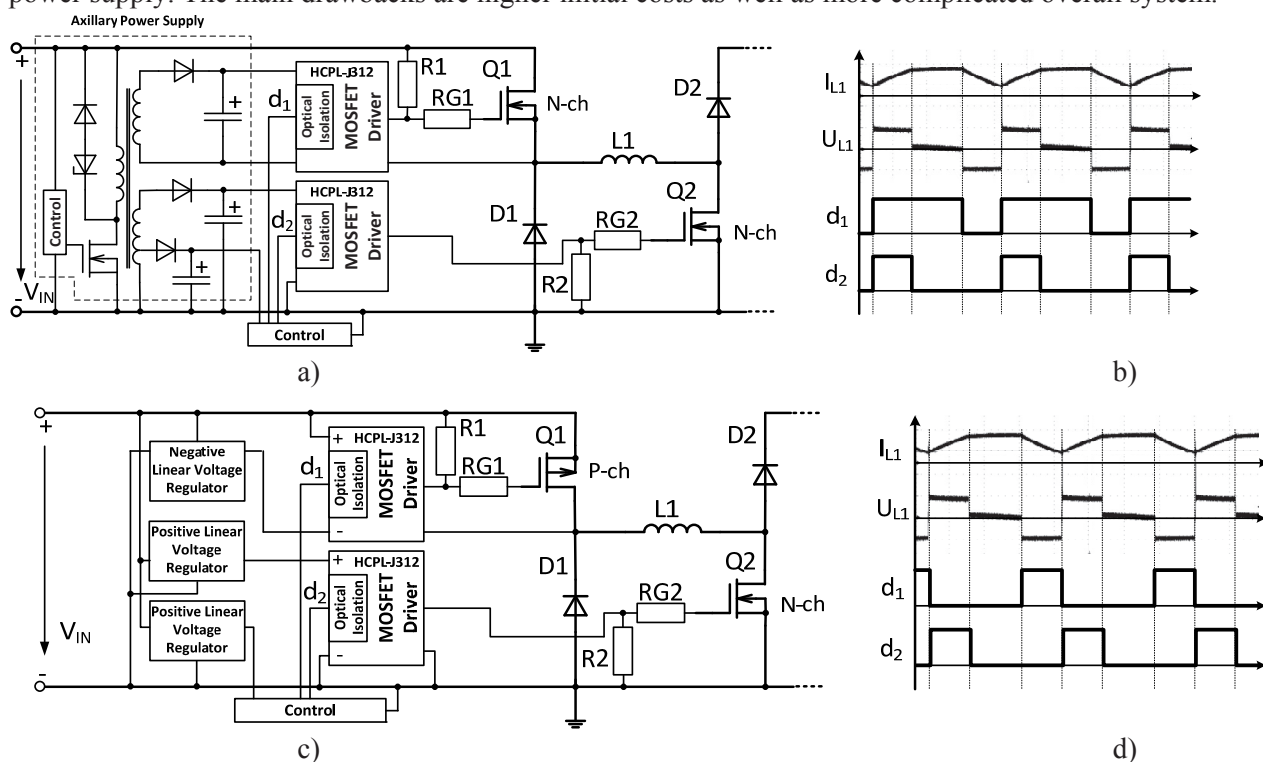


Fig. 1

For the clarity of operation principles the current and the voltage waveforms of the inductor L_1 , as well as control signals of the transistors for this configuration of driver circuits are shown in Fig. 1. b.

Utilization of n-channel field effect transistors. The substitution of high side n-channel FET by p-channel FET allows to get rid from obligatory using of auxiliary isolated power supply. The supply of p-channel FET driver can be implemented on negative linear voltage regulators, as it shown in Fig. 1 c. The current and the voltage waveforms of the inductor L_1 , as well as control signals of the transistors for this configuration of driver circuits are shown in Fig. 1 d. In this case the logic of the control signal d_1 of P-FET will be inverted. It is worth to mention, that there are higher power losses on linear voltage regulators with the increase of input voltage in comparison with small power isolated DC-DC converters (isolated auxiliary supplies).

Power losses in control circuits of power transistors are caused by necessary energy to recharge MOSFET gate capacitance. In general case the capacitance of the gate is variable which is affected by voltage applied to transistor U_{DS} (drain-to-source voltage) as shown in Fig. 2 a. Fig. 2 b shows dependency of total charge of the gate from the voltage applied to the gate U_{GS} (gate-to-source voltage) and the voltage applied to transistor U_{DS} . The value of the total gate charge is most commonly used for the calculation of power losses in the control circuit of MOSFET transistors.

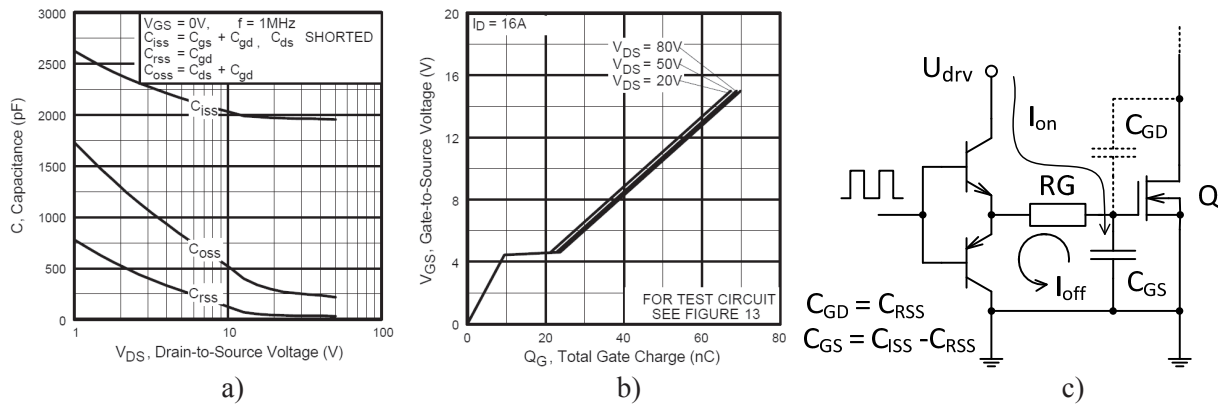


Fig. 2

The energy E_c stored in gate capacitance can be expressed by equation

$$E_c = \frac{C_{GS} \cdot U_{drv}^2}{2} = \frac{1}{2} \cdot Q_g \cdot U_{drv}, \quad (1)$$

where U_{drv} is supply voltage of MOSFET driver, C_{GS} is gate-to-source capacitance, Q_g is the total charge of the gate of transistor. Stored energy dissipates in particular transistor driver elements: mainly in gate resistor R_G , which limits driver current, as well as in gate driver (on low side transistor of output stage of driver, as shown in Fig. 2 c). The losses in named elements during discharge process (switch off process of power transistor) of stored gate charge can be found from the equation

$$\frac{1}{2} \Delta P_{drv} = \frac{f_{sw} \cdot C_{GS} \cdot U_{drv}^2}{2} = \frac{1}{2} f_{sw} \cdot Q_g \cdot U_{drv}, \quad (2)$$

where f_{sw} is switching frequency of the converter. This expression does not include power losses in gate resistor and high side transistor of output stage of driver during charging process of gate capacitance C_{GS} (switch on process of power transistor). Approximate estimation of overall power losses in control circuit ΔP_{drv} of one transistor can be done by expression

$$\Delta P_{drv} = f_{sw} \cdot C_{GS} \cdot U_{drv}^2 = f_{sw} \cdot Q_g \cdot U_{drv}, \quad (3)$$

for which the value of total charge of gate can be found in the datasheet of considered transistor for appropriate operation conditions. It is worth to mention that the product of switching frequency and total gate charge $f_{sw} \cdot Q_g$ gives the average current consumed by driver [3].

The analysis of currently available transistors. The next step is the estimation of overall power losses in transistor control circuits taking into account the efficiency of power supply system of this control circuit. The increase of input voltage and output power of the LED driver leads to increase of power losses in transistor control circuits. Mainly it happens because of necessity to use higher power transistor (total gate charge increases for transistors with lower drain-to-source on resistance R_{DS} . This relationship is clearly evident in case of P-FETs designed for higher operation voltages $V_{DS} = 150 \dots 200V$ as shown in Fig. 3 a. Power regression characterizes this relationship in the best way. Fig. 3 a summarizes the data about N-FETs and

P-FETs currently available in electronic catalogues (in the range of 2...6A of operation currents at 25 °C ambient temperature). Also the total gate charge increases at higher drain-to-source applied voltages (Fig. 2 b).

Fig. 3 b shows the relationship between total gate charge Q_g and drain-to-source voltage V_{DS} for both transistors types. In the same way the relationship between drain-to-source on state resistance R_{DSon} and drain-to-source voltage V_{DS} is shown in Fig. 3 b. In case of P-FETs logarithmic regression characterizes this relationship in the best way. For N-FETs linear regression is better choice.

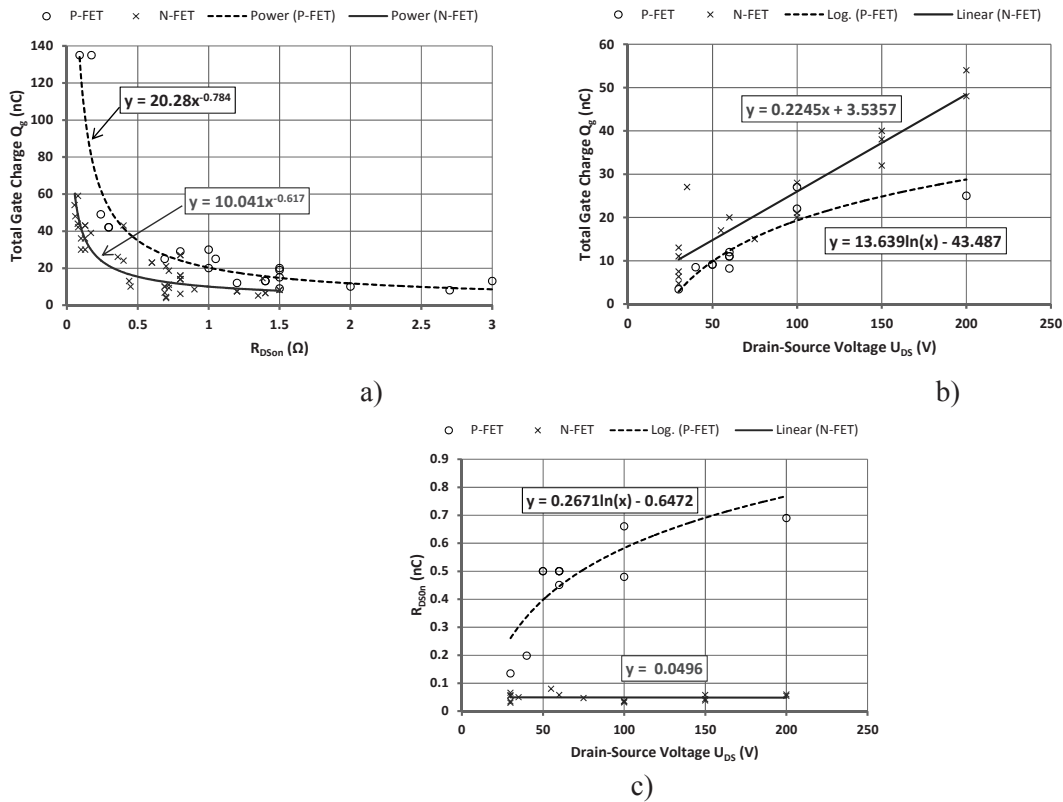


Fig. 3

Taking into account these functions (Fig. 3 b and c) and (3) it is possible to find losses in transistor control circuits in whole range of considered operation voltages. If the power supply of MOSFET drivers is linear regulator, then total power losses of one transistor driver circuit can be found from the equation

$$\Delta P_{drv.linear} = f_{sw} \cdot Q_g \cdot U_{in} \tag{4}$$

where V_{in} is input voltage of LED driver. In case of galvanically isolated power supply of MOSFET driver the losses can be found from the expression

$$\Delta P_{drv.isolated} = (f_{sw} \cdot Q_g \cdot U_{drv}) / \eta \tag{5}$$

where η is efficiency of isolated power supply, which in general case also depends on input voltage. The common relationship between efficiency and input voltage for isolated small power supplies (1W) is shown in Fig. 4.

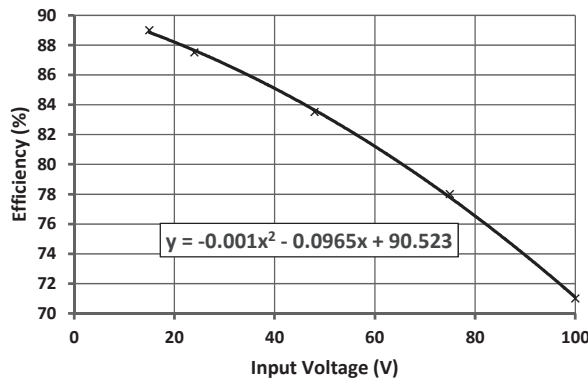


Fig. 4

For proper evaluation also it is necessary to take into account transistor conduction losses which appears due to transistor on state resistance (Fig. 3 c). Conduction losses of the transistor can be calculated using equation

$$\Delta P_{Q.cond} = R_{DSon} \cdot I_{d.RMS}^2 = R_{DSon} \cdot I_{d.pk}^2 \cdot d \tag{6}$$

where $I_{d,RMS}$ is root mean square (RMS) value of the current which flows through transistor, $I_{d,pk}$ is peak value of current in transistor, d is the duty cycle of the control signal for the transistor. It is seen from this expression that conduction losses will depend on duty ration, thus also on average current and illumination level. To make proper evaluation it is necessary to make calculations for all transistors at one operation point (in this case $d = 0.9$ value was chosen). Losses in the control circuits of MOSFETs are independent from duty cycle in range of $0 < d < 1$ values excepting two points ($d = 0$ и $d = 1$) with no losses (theoretically). Knowing all parameters discussed above it is possible to calculate power losses associated with different approaches of the organization of control circuits of MOSFETs. The relationships of power losses in control circuits as well as conduction losses (for one transistor) at different operation conditions are shown in Fig. 5.

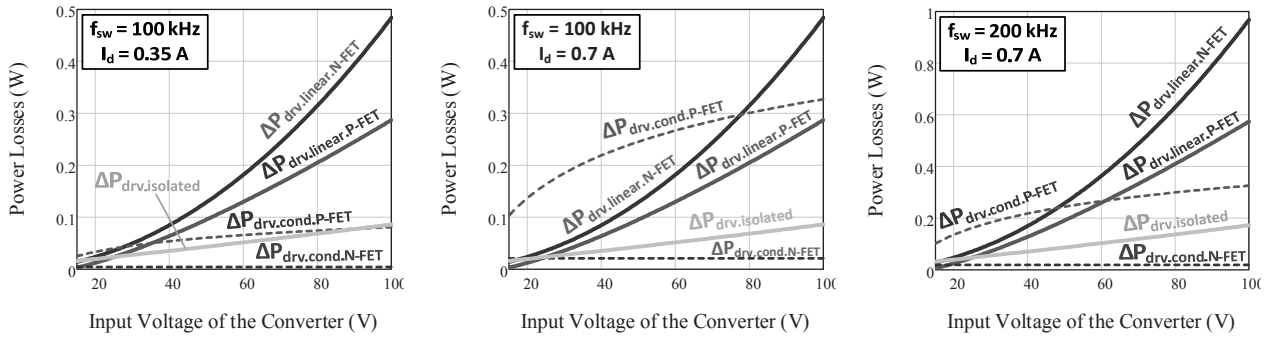


Fig.5

The distribution of power losses of MOSFET drivers as well as conduction losses are well represented in Fig. 5. However from this picture (absolute values of power losses) it is difficult to compare different approaches in organization of control circuits. For more objective comparison it is necessary to associate absolute power losses to the output power of the converter. The power circuit of the considered converter contains two transistors, so Fig. 6 shows the relative losses (in percent from output power) in control circuits for three different approaches:

- 1) Utilization of P-FET as a high side switch and N-FET as low side switch with linear voltage regulators as a power supply of MOSFET driver (P-FET + N-FET).
- 2) Utilization of N-FET as a high side switch with isolated power supply and N-FET as low side switch with linear voltage regulators as a power supply (Linear + Isolated).
- 3) Utilization of N-FETs as a high side and low side switches with isolated power supplies (2 x Isolated).

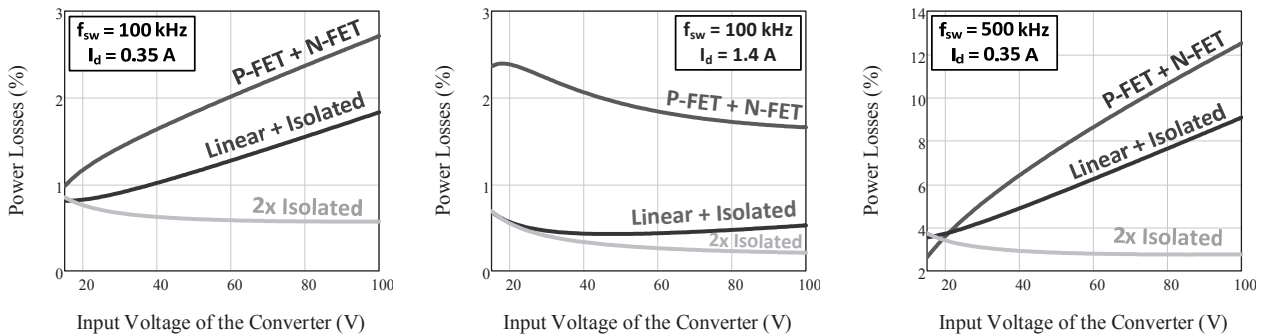


Fig.6

It is seen from Fig. 6 that from point of view of power losses the last one approach is the most effective. Utilization of P-FET as a high side switch seems to be reasonable only at low input voltages of LED driver and low output power (Fig. 6). However, this configuration performs better at higher switching frequencies, thus is better for weight and size crucial applications. Also it is necessary to take into account economic aspects (initial costs for different approaches), as the initial costs in case of linear regulator are lower approximately 10 times than in case of isolated power supply.

Conclusion

In this paper several approaches of organization of MOSFET gate drivers control circuits were considered: utilization of isolated power supply for MOSFET drivers and the substitution of N-FET by P-

FET with linear voltage regulator as a driver power supply. The estimation of power losses in MOSFET driver shows that the utilization of P-FET is profitable at low input voltages of the converter. Also this configuration gives benefits at higher switching frequencies (Fig. 6), thus may be utilized for minimization of size and weight of converter (at low input voltage). At higher input voltages the utilization of isolated power supply MOSFET driver is preferable.

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ВИБІР ДРАЙВЕРІВ СИЛОВИХ ТРАНЗИСТОРІВ В ПЕРЕТВОРЮВАЧАХ, ВИКОРИСТОВУВАНИХ В ЯКОСТІ КЕРОВАНИХ ДРАЙВЕРІВ СВІТЛОДІОДІВ

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Дана стаття являє собою опис одного з етапів розробки перетворювача (драйвера світлодіодів), що працює за новими принципами в режимі амплітудного регулювання струму. Описано принципи побудови драйверів силових транзисторів для схеми, в якій обидва ключа є n-канальні польові транзистори. Розглянута так само схема, в якій один з польових транзисторів замінений на р-канальний. Використання р-канального транзистора дозволяє позбутися від використання гальванічно розв'язаного блоку живлення для драйвера транзистора верхнього плеча. В останній частині статті наведено розрахунки втрат драйверів транзисторів, що дозволяє судити про доцільність використання того чи іншого підходу в залежності від конфігурації перетворювача і області його застосування. З точки зору втрат схему з р-канальним транзистором вигідніше використовувати при низькій вхідній напрузі (порядку 12 ... 25В). З точки зору втрат схему з n-канальним транзистором вигідніше використовувати при низькій вхідній напрузі (порядку 12 ... 25В) і при більш високих частотах перетворювача.

Ключові слова: DC-DC перетворювач, електронний баласт, імпульсний перетворювач, схеми MOSFET драйверів.