# LOW POWER HIGH VOLTAGE STEP-DOWN CONVERTER


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**Abstract**: This article refers about problematics of DC/DC converters. Basic topologies of DC/DC converters with and without pulse transformer are mentioned in this article. There is also a focus on some IC drivers and controllers used for converters without pulse transformer. The main part of the article is reserved for the description of the step-down converter powered from voltage in excess of 100 V, which is able to work in application, where special IC controller cannot be used.



**Keywords**: Power electronics; DC/DC converters; IC drivers; step-down converter.


## 1 INTRODUCTION

DC/DC converters are used in a wide scale of applications in power electronics today. The use is advantageous due to their high efficiency and low price in mass production. There is also a reduced need of precious metals such as copper. The body of this article is divided into three parts. In the first part, basic topologies of DC/DC converters are mentioned. The second part describes some special IC controllers, which are commonly used in construction of DC/DC converters without pulse transformer. A main focus of the contribution is a simple step-down converter, which consists only of six transistors and one operational amplifier. The use of special IC controller is impossible due to higher input voltage (110 V). For that reason, own design of the converter was created. It is described in the last part of this article.

## 2 BASIC TOPOLOGIES OF DC/DC CONVERTERS

DC/DC converters are devices with DC voltage and current input and output. Converters, which contain pulse transformer, are also called switch mode power supplies. DC output is galvanically isolated from DC input by isolation pulse transformer. Switch mode power supplies can be constructed as forward converters and flyback converters. Topologies of forward converters are: single and two transistor forward converter, half-bridge push-pull converter and full-bridge push-pull converter. Flyback converters contain one transistor. Switch mode power supplies are used as battery chargers, welding inverters, PC and other equipment supplies and in similar applications [1].

Next part of the article is focused on DC/DC converters without pulse transformer. These converters are used in applications, where the galvanic isolation is not needed. For example in electrical drives with DC motors, board applications in cars, planes and as an internal part of electronic devices. Converters can be powered from battery or from rectified mains. The single-quadrant converters are the step-down converter and the step-up converter. These converters work in the first (step-down) and in the second (step-up) quadrant of the four-quadrant load diagram. This diagram is in Figure 1 and it is used in power electronics and electrical drives. In the first quadrant, current flows from supply to load, for example to motor, and the voltage on the load is positive. In the second quadrant, load (motor) works as a generator and current flows from load to supply. The voltage on the load is positive. In the third quadrant, the voltage on the load is negative and current flows from supply to load. In the fourth quadrant, load works again as a generator, the voltage on the load is negative and current flows from load to supply [2].

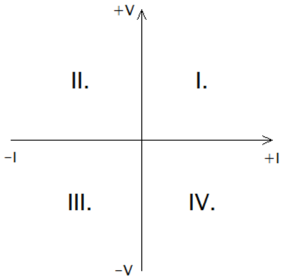


**Figure 1**: Four-quadrant load diagram [2]

Circuit diagrams of the step-down converter (on the left) and of the step-up converter (on the right) are in Figure 2.

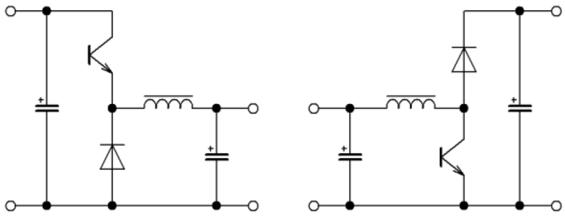

**Figure 2**: Step-down and step-up converters [2]

Two-quadrant converters are combinations of step-down and step-up converters. Two combinations are defined: Converter, which works in the first and in the second quadrant, and converter, which works in the first and in the fourth quadrant. In the first instance, there is one polarity of voltage on the output and current can flow from supply to load or back, so load is able to work as a generator in the second quadrant. In the second instance, current can flow only one way and there are both polarities of voltage on the load, which can work as a generator in the fourth quadrant. Both kinds of converters are in Figure 3. The first type is on the left, the second one on the right [2].

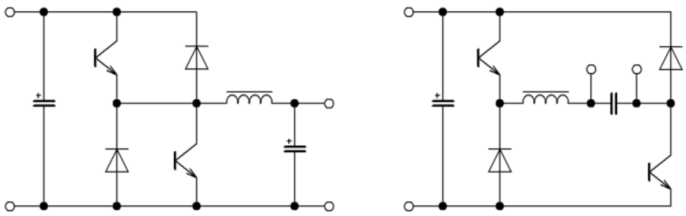

**Figure 3**: Two-quadrant converters [2]

Four-quadrant converter, known as the H-bridge or full bridge, consists of four transistors and four diodes. This converter is able to work in all quadrants (both polarities of voltage, both polarities of current). With different control signals it can also work as an one-phase AC inverter. Circuit diagram is in Figure 4 [2].

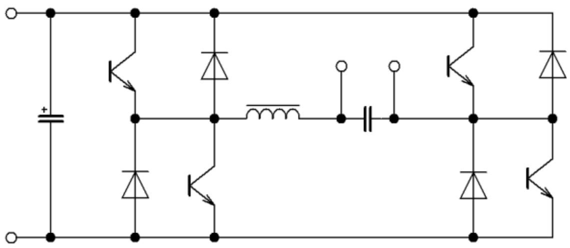

**Figure 4**: Four-quadrant converter [2]

## 3 IC DRIVERS AND CONTROLLERS FOR DC/DC CONVERTERS

Pulse width modulation (PWM) for DC converters is based on comparison of two signals: DC control signal and triangular carrier signal. These two signals are compared by comparator. On the output of the comparator there are rectangular pulses with variable width. This output signal is used for switching the transistors in converters. Comparator, triangular signal oscillator, gate driver, power MOS-FET and other supporting circuits are integrated in special ICs, which are used in construction of converters [2]. Here are some examples:

RT7259 (Figure 5) is a DC/DC converter with internal high-side power MOS-FET and gate driver for external low-side power MOS-FET. IC can be powered from 4.5 - 24 V DC and it can deliver 10 A output current. Output voltage is adjustable from 0.808 to 15 V. Switching frequency is 600 kHz. Synchronization to an external clock frequency is possible. IC is suitable for TV and monitors, set top boxes and similar applications [3].

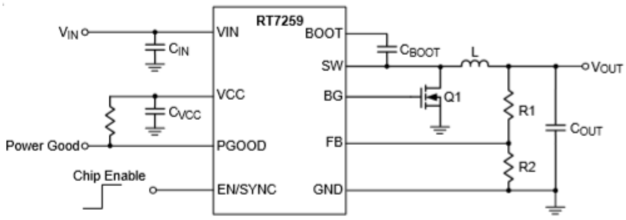


**Figure 5**: RT7259 application circuit [3]

LT3845 (Figure 6) is a step-down controller with adjustable operating frequency. The range of the frequency is adjustable from 100 kHz to 500 kHz. Operating frequency can be also synchronized to an external clock signal. Controller can be powered from a wide range of voltage from 4 V to 60 V DC. It contains two gate drivers for switching two power N MOS-FET transistors. The gate driver of the high-side MOS-FET is powered from external bootstrap capacitor. Controller is suitable for avionics, automotive, telecom and industrial applications [4].

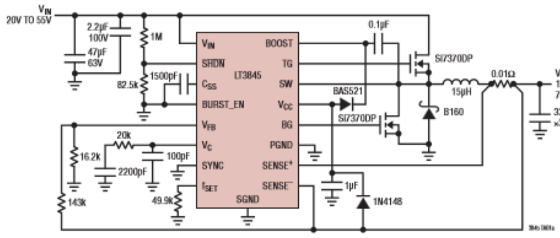


**Figure 6**: LT3845 application circuit [4]

LM2596 (Figure 7) are integrated circuits for step-down converters. There are three versions with fixed output voltage (3.3 V, 5 V and 12 V) and one version with adjustable output voltage from 1.2 V to 37 V. Maximum value of the input voltage is 40 V. Every version can deliver 3 A output current. Operating frequency is 150 kHz. LM2596 are available in 7-pin TO-220 package and in 7-pin TO-263 package for surface montage. ICs require only four external components to be able to operate. They are suitable for high-efficiency switching regulators [5].

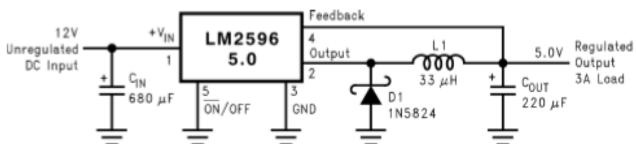


**Figure 7**: LM2596 (with fixed output voltage) application diagram [5]

## 4 STEP-DOWN CONVERTER WITH A HYSTERESIS REGULATOR

This converter was constructed to supply a special cell-electroporation device. Cell-electroporation is a modern non-invasive method of cancer treatment. Higher input voltage (110 V) and a wide range of the output voltage regulation (from 0 V to 100 V) was required. 100 V is maximum input voltage of the cell-electroporation device. Circuit diagram of the step-down converter is in Figure 8. Commonly used ICs mentioned in previous part of this article are not able to be supplied from 110 V. It is possible to use IC controller and external gate driver with transformer supplied from decreased input voltage. But there is a problem with the duty cycle of the gate driver with transformer, which cannot be higher than approximately 0.5. So the range of the output voltage regulation would be decreased. Very simple construction of the converter was also demanded. These problems have been solved by using P MOS-FET transistor and hysteresis regulator. P MOS-FET transistor does not need gate driver with transformer in this topology and IC controller is replaced by hysteresis regulator. Digital control is not used due to the simplicity of the converter.

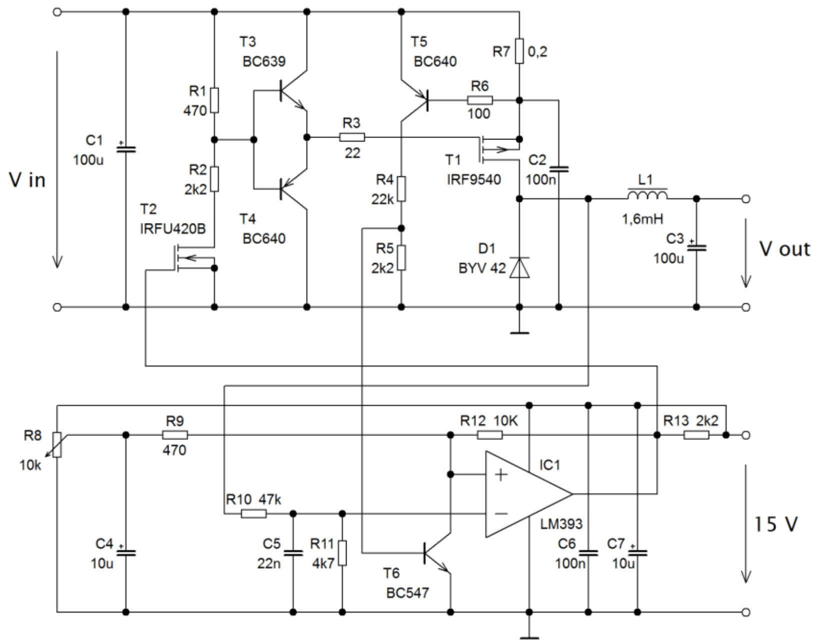


**Figure 8**: Circuit diagram of step-down converter with a hysteresis regulator

Input DC voltage (V in) 110 V is transformed from AC mains 230 V, 50 Hz by mains toroidal transformer and rectified. Output DC voltage (V out) is adjustable by potentiometer R8. The power part of the converter consists of switching P MOS-FET transistor T1, free-wheeling diode D1 and capacitor C2. Output filter contains coil L1 and capacitor C3. Transistor T1 is switched by push-pull gate driver, which consists of transistors T2, T3 and T4. R7 is a shunt resistor. Transistors T5 and T6 work as an over-current protection. Control signal is generated by IC1, which is connected as a hysteresis regulator that compares required value of the output voltage from potentiometer R8 and real value from output of the converter. When the required value of the output voltage is higher than the real value, there is + 15 V DC on the output of the regulator. Power MOS-FET T1 is switched on by gate driver (transistors T2 and T4) and the output voltage increases until it exceeds the required value. Then the output of the regulator switches to 0 V, gate driver (transistor T3) switches the power MOS-FET T1 off and the output voltage decreases. In the case of current overload, voltage drop on the shunt resistor R7 turns transistors T5 and T6 on. The required value of the output voltage is decreased by transistor T6. Hysteresis regulator IC1 and its external circuits are supplied from 15 V DC linear supply, which consists of small mains transformer, bridge rectifier, capacitors and monolithic 15 V voltage regulator. Converter was constructed on small universal PCB and then successfully tested.

## 5 CONCLUSION

This article was focused on problematics of DC/DC converters without pulse transformer. These converters are used in electrical drives, in automotive and avionics and as an internal part of various electronic devices (TVs, monitors, computers etc.). DC output is not galvanically isolated from DC input. DC/DC converters are cheap in mass production and they have high energetical efficiency.

In the first part, basic topologies of DC/DC converters were discussed. The single-quadrant converters are step-down and step-up converters, which work in one quadrant of the four-quadrant load diagram. These converters consist of one transistor and one diode. Step-down converter works in the first quadrant and step-up converter works in the second quadrant. Two-quadrant converters work in the first and in the second quadrant or in the first and in the fourth quadrant. They contain two transistors and two diodes. Four-quadrant converter (known as the H-bridge or full bridge) is able to work in all quadrants and it consists of four transistors and four diodes.

Some special IC drivers and controllers commonly used in DC/DC converters were briefly described in the second part. Mentioned ICs are powered from low voltage (up to 60 V). Output voltage is adjustable or fixed. Operating frequency is adjustable and the range of the frequency is wide (from 150 kHz to 600 kHz). ICs contain comparator, triangular signal generator, gate drivers and some of them power MOS-FET transistors. However these IC controllers are not suitable for this application, because a high input voltage (110 V DC) is required.

Step-down converter constructed to supply special cell-electroporation device was described in the third part. This converter is powered from 110 V DC. Output voltage is adjustable from 0 V to 100 V (maximum input voltage of the supplied electroporation device). Converter consists only of six transistors and one operational amplifier. Switching P MOS-FET transistor does not need gate driver with pulse transformer, so the duty cycle of the step-down converter can be varied from 0 to 1. Control signal is generated by comparator, which is used as the hysteresis regulator. Output voltage is adjusted by potentiometer. The converter is also equipped with over-current protection, which protects the power part.

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