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D.c.-d.c. Converter Controlled by Optic Fiber Channels

The using of optic fiber is recommended in environments with intense electric and magnetic fields to send the control and measuring signals. The paper presents the structure of a simple d.c.-d.c. converter used to control the energy transfer of a large inductance coil. The closed loop control system requires two optic fiber links to send feed-back analog signal, respectively digital control signal for controlled semiconductor device. Also, the paper presents the drivers adapted to this type of control and waveform recorded during tests.

Keywords: optical link, d.c. converter, driver, semiconductor device

1. Introduction

D.c.-d.c. converters are electronic devices which control the d.c. energy transfer from one level to another. Some d.c.-d.c. converters increase the d.c. voltage level (step-up converters) and another converters decrease the d.c. voltage level (step-down converters). Therefore, the d.c.-d.c. converter is the transformer equivalent for the d.c. energy transfer from the d.c. power supply to load [1], [2], [3].

The paper shows the structure of d.c.-d.c. step-down voltage converter used to control the d.c. current level in high inductive load circuit.

This converter offers the advantage of electric isolation by fiber optic links between their control boards and power devices or modules, for safety operation.

For closed-loop control of converter two fiber optic links are necessary:

- one analog fiber optic link on the feed-back way: this link sends analog signal from current transducer output to input of control boards;

- one digital fiber optic link on the direct way: this link sends, with accuracy, the control signal from control boards to power semiconductor devices drivers.

In the second section, the general block-diagram of converter and the main control strategy in open and closed loop operation are presented.

In the third section the modules for control signal synthesis, the driver for semiconductor device and the characteristics of fiber optic links are presented.

Fourth section shows the test results and recordings of signals waveforms on direct and feed-back ways, on load and on power semiconductor device.

The final section shows the conclusions drawn from the tests.

2. Optically controlled d.c.-d.c. converter

The control system in fig.1. is a closed-loop control system for d.c. current level adjustment through inductive load. To change the d.c. current level a d.c-d.c. voltage step-down converter operates as actuator.

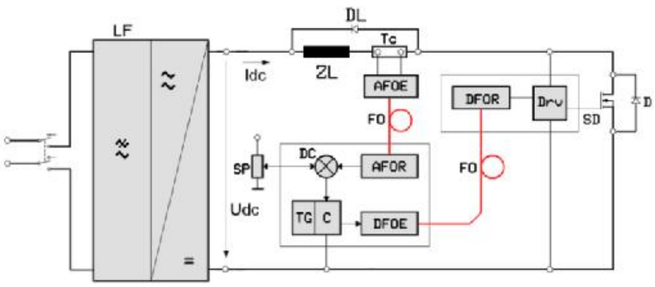

Figure 1. Block-diagram of optically controlled d.c.-d.c. converter

In many applications the remote control of convertor is necessary.

When the remote control circuits operate in high magnetic or electric fields, or in an explosive environment, or if a safer operation for employees is required, the fiber optic links can be a solution [4].

In the previous block-diagram the notations have the following significations:

- SP – set-point device for reference value I* of controlled current I;
- DC -the device for the difference between reference value I* and feed-back value, Ir, of controlled current;
- TG – triangle wave generator for PWM control signals synthesis;
- C – analog controller of PWM;
- DFOE – digital fiber optic emitter;
- DFOR – digital fiber optic receiver;
- FO – fiber optic link;
- SD – power semiconductor device;
- Drv – driver for power semiconductor device control;
- ZL – inductive load impedance;
- Tc – current transducer;
- AFOE – analog fiber optic emitter;
- AFOR – analog fiber optic receiver;

- LF – line filter;
- Udc – output d.c. voltage of a.c.-d.c. converter;
- Idc – controlled d.c. current through ZL impedance.

Triangle wave generator, TG, provides the unipolar voltage with constant amplitude A. The set-point device provides, Uref~I*, the reference value of controlled current. The PWM controller generates the control signal Ugt for semiconductor device. The time t1 is the “ON” state time and t2 is the “OFF” state time of the SD.

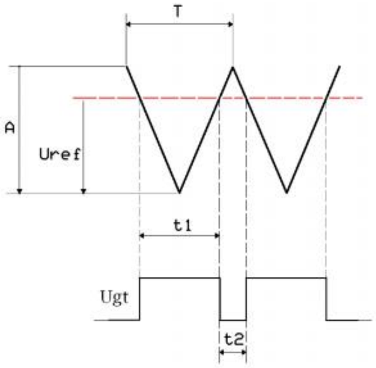

Figure 2. The control signal synthesis for power semiconductor device.

From the previous figure, we can write:

$$\frac{A}{T} = \frac{U_{ref}}{t_1} \tag{1}$$

The duty cycle, D, for Ugt control signal is:

$$D = \frac{t_1}{T} = \frac{U_{ref}}{A} \tag{2}$$

The voltage, u_L, across the coil ZL, has the same shape as the Ugt control signal. The average value, U_L, of u_L rectangular voltage is proportional to U_{ref}:

$$U_L = DU_{dc} = \frac{U_{ref}}{A} U_{dc} \tag{3}$$

The time interval T must be less than the time constant of ZL load impedance.

3. Control signals synthesis. Driver circuit for power semiconductor.

The waveform of signals from previous figure was synthesized within the circuit from fig.3. The reference voltage can be prescribed from R8 in open loop control or from a controller in closed loop control. R7 resistor shifts the level of triangular signal in positive range.

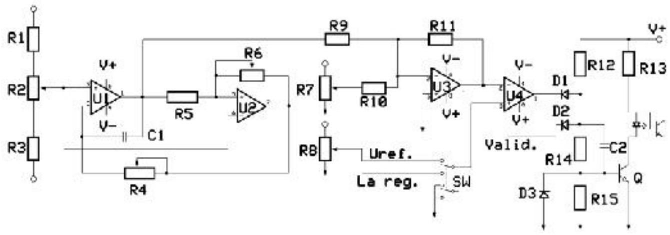

Figure 3. The circuit for control signal synthesis.

The triangular signal frequency is a function of R4, C1, R6 and R5:

$$f = \frac{1}{4R4C1}\frac{R6}{R5} \tag{4}$$

From the output of PWM controller, the control signal Ugt is sent to driver by digital fiber optic link (fig.4.).

The plastic fiber optic transmitter diode L has the maximum value of optic spectral emission at 650 nm [5]. L converts the electrical signal into optical signal. This passes through the fiber to the optic receiver FT.

It has the spectral range of photosensitivity from 600 nm to 780 nm [6]. It consists of integrated photodiode and transimpedance amplifier followed by open collector output stage.

The energy required to power the driver is taken from the d.c. line. The group R5-C2 is a low-pass filter and limiter of output current.

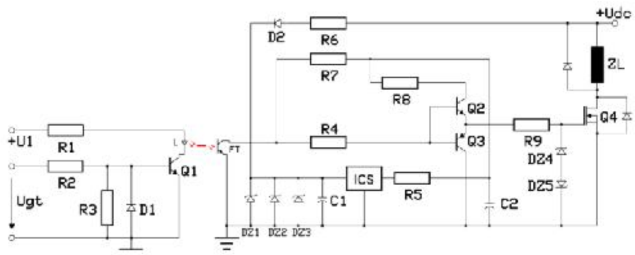

Figure 4. The driver circuit for power semiconductor device.

By moving the resistor R6 and diode D2 between anode of Zener diodes and minus terminal of d.c. supply, the control of high-side power semiconductor device is possible. Then a half-bridge or full-bridge structure can be used to bidirectional control of current through ZL.

The analog fiber optic link provides an excellent signal isolation between current transducer and PWM controller. It transfers analog signal up to several kilometers [7]. The amplitude of input signal range may be within -100 mV and +100 mV and the frequency in analog bandwidth from d.c. to 5 kHz. Between the transmitter and the receiver, the digital optical pulses are transmitted by frequency modulation method. Inside of the tracking range results a low level of the phase error between input and output analog signals.

Figure 5 shows the step response of analog fiber optic link which is characterized by: delay time td=0.1 ms, rise time tr=0.1 ms, settling time ts=0.3 ms and overshoot σ=13.3 %.

A low frequency square wave signal was applied to the input of the optical link and the behavior of output signal has been recorded using a transient states recorder.

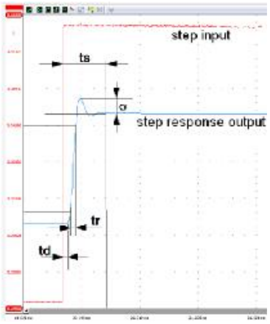

Figure 5. Step response of analog fiber optic link.

The next figure presents the amplitude of output voltage Ue versus the frequency when the input voltage has a constant amplitude. Frequency range was between 50 Hz and 10 kHz. The level of the input signal was chosen near the lower limit of the range.

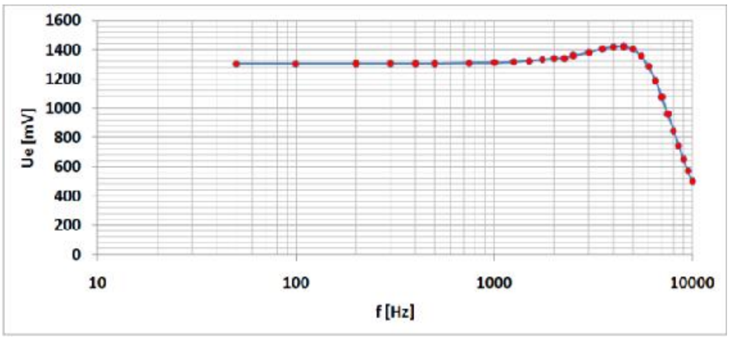

Figure 6. Output voltage amplitude-frequency characteristic of analog fiber optic link.

From 50 Hz to 2000 Hz the output voltage has a constant value and around 2500 Hz the deviation is about 7%. Because the fiber optic link operates as a closed loop control system using a phase locked loop structure, the phase difference between input signal and output signal is zero.

4. Test results and recordings.

The tests were carried out with a coil having the inductance L=955 mH and resistence R=59 Ω. The time constant of L-R load impedance results from the following formula:

$$2 = \frac{L}{R} = \frac{0,955}{59} = 16,18 \quad ms \tag{5}$$

The chosen value of the control signal frequency was f=100 Hz (T=10 ms<time constant of load impedance). The recorded waveforms of control signals are shown in fig.7. for the 50% duty cycle.

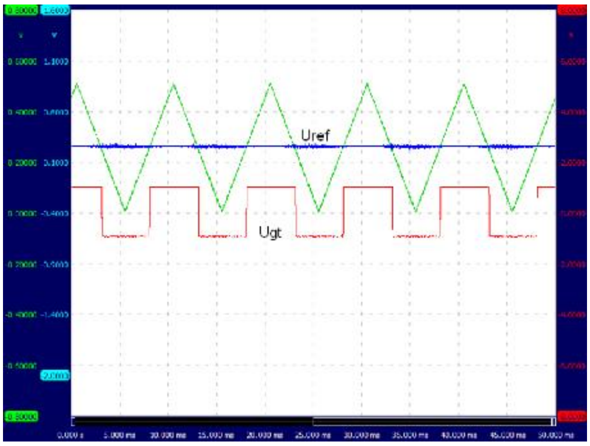

Figure 7. Waveforms of signals for control signal, Ugt, synthesis.

These signals were recorded using three test points: the output terminal of the triangle wave generator [8], the reference input and the output of integrated comparator. The triangle signal has ten volts, peak-to-peak value. The access of control signal Ugt from the output of comparator to transistor Q is possible if “valid” signal is high. The reference voltage Uref can be obtained from R8 potentiometer or from the output of the digital to analog converter led by a minicontroller (the second one is not included in this paper).

The following figure shows waveforms of the control voltage, of the current through coil and of the drain current through power semiconductor device. The signals were recorded for 80% duty cycle of the control signal Ugt. Low value resistences were used as current transducers in coil and drain circuits.

In the next figure, the control voltage, the current through coil and the drain current through power semiconductor are presented for the 80% duty cycle.

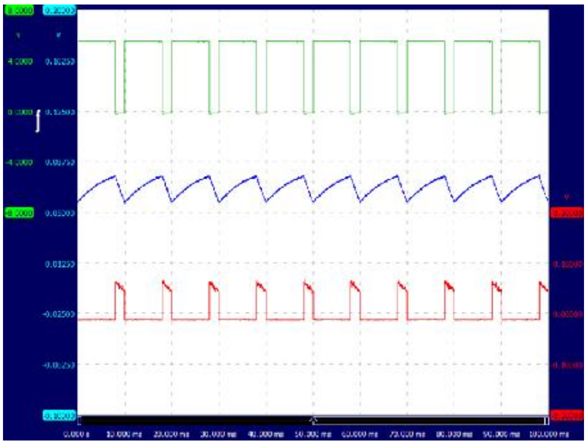

Figure 8. Recorded waveforms of control voltage, coil current and drain current.

The control voltage, the coil current and the current through diode, mounted in parallel with ZL impedance, are presented in next figure for the 80% duty cycle.

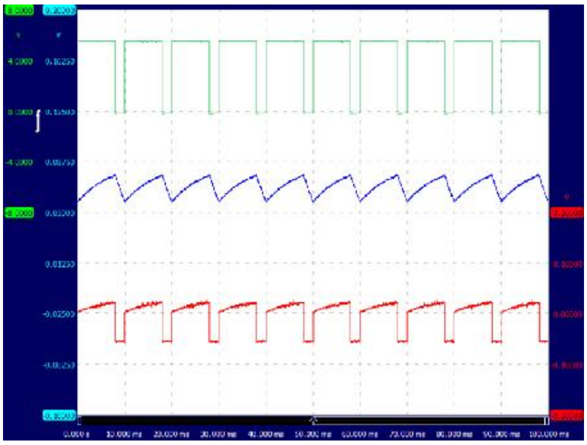

Figure 9. Waveforms of the control voltage, current through coil and forward current through reverse diode ZL terminals.

The next figure shows the transient waveforms of the control voltage and drain current recorded for high and low states of “valid” signal.

Figure 10. Transients of drain current and control voltage.

During the transients, the behavior of the load current depends on the time constant of L and R parameters of the load circuit. The same parameters have an influence on the forward transfer function of controlled system and the settling time in dynamic evolution.

The average value of voltage to coil terminals has been measured. A characteristic has been represented for steady-state operation using various duty cycles. From 10% to 95% the dependence between average voltage and duty cycle is linear.

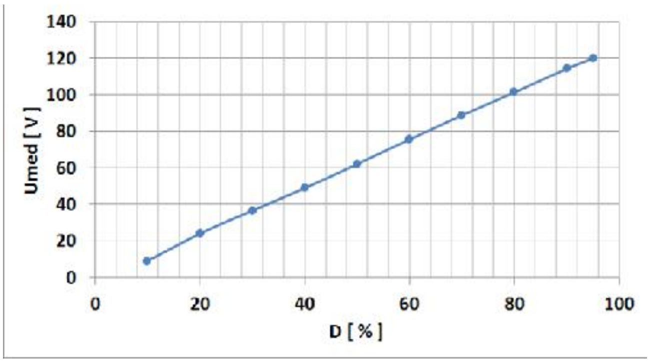

Figure 11. Average values of the voltage to coil terminals as function of D .

Also, the effective values of these voltage have been measured. The maximum values have been obtained for the 50% duty cycle.

A low level of harmonics was measured for the lowest and highest value of duty cycle and their level reaches about 50% from the maxim value. The dependence between effective value of terminals load voltage and duty cycle is parabolic (fig.12.).

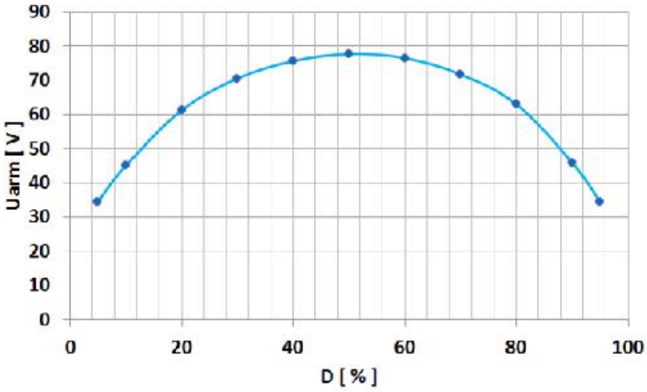

Figure 12. Effective value of voltage to coil terminals as a function of D.

Using a spectrum analyzer, the harmonic components have been represented for measured voltage at coil terminals. Only odd harmonics are present in this spectrum (fig.13). The amplitude of harmonics decreases while its order increases. If the inductance of load is not high enough to reduce the ripple of current, then an additional inductance can be used.

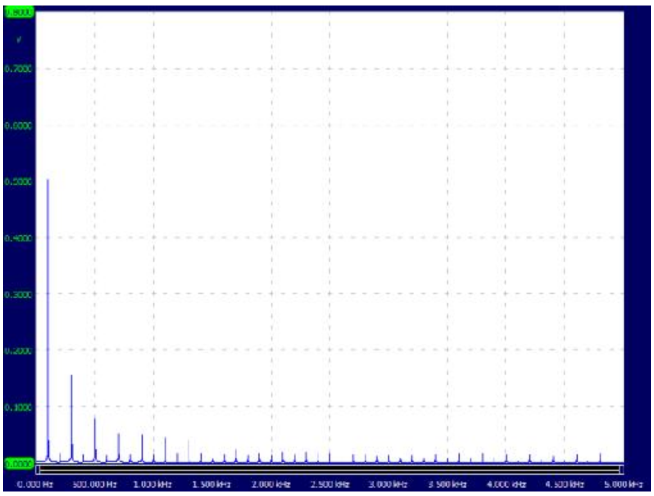

Figure 13. The spectrum of coil voltage for the 50% duty cycle.

5. Final conclusions.

The paper shows a simple structure circuit for the synthesis of the control signal and the driver for the low side power semiconductor device. Also, the driver for the high side power semiconductor it is presented to allow the half-bridge or full-bridge converter control. The closed loop control strategy wasn't approached in this paper because the control law is a user's choice depending on the control criteria. The equation (3) allows the consideration of the converter as a linear element in the control scheme. The average value of output voltage and the controlled current depend on the control voltage by a constant; this also results from experiments (fig.11. and fig.14.).

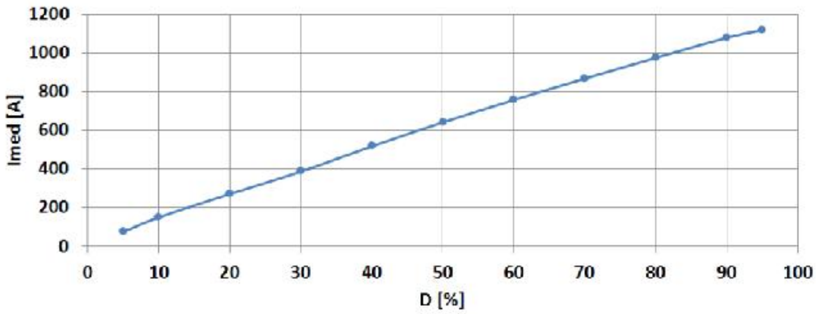

Figure 14. The average value of measured coil current as a function of control voltage

This simple d.c.-d.c. converter can be used in:

●excitation systems of d.c. or synchronous machines to control the excitation field value (fig. 15);

●electronic control of secondary starting resistence in wound rotor circuit of asynchronous machine.

The main advantages of fiber optic links (electric isolations, immunity to interference, no need for ground circuit, no shock hazard, no danger of explosion if optical circuit is interrupted, and other) recommend this simple structure for many applications.

On the one hand, because the analog fiber optic links are expensive their implementation in applications is relatively reduced. On the other hand, the components of digital fiber optic links are more accessible. The analog fiber optic link presented in the paper has a high stability of operation to temperature changes in a wide range.

In closed loop control strategy the reference voltage can be provided by output of the analog controller or by a digital to analog converter controlled by a low cost minicontroller.

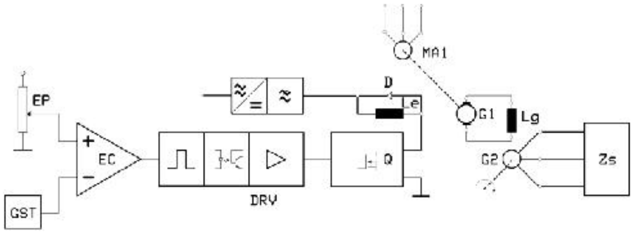

Figure 15. Open loop control of d.c. machine excitation system.

When the converter is used in a control system the power supply of AFOE module may be the same type as the supply used in the driver of power semiconductor device.

The analog fiber optic links can be introduced in multiple feedbacks of system to control the active power and voltage to the terminals of a.c. generator. These links send the measuring signals from transducers to inputs of the error amplifiers.

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