THE CONTROL SYSTEM OF THE FLYWHEEL ENERGY STORAGE

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Abstract: In this article authors described the control system for Flywheel Energy Storage. The device consists of the power electronic system and control system. The control system based on the FPGA. The power electronic system consists of the special rectifier and converter.

1. INTRODUCTION

The paper presents an experimental investigation of a flywheel energy storage system. The device is based on a flywheel concept and stores mechanical energy. This device contains a brushless DC motor supplied by an electronic commutator. A steel barrel performs the function of the flywheel. From the power network side this device is perceived as the unity power factor load. This is achieved owing to the use of the rectifier with sinusoidal source current. Energy storage is one of the main problems of contemporary technology. Currently, the following methods for energy storage are used:

– magnetic accumulator – the energy is kept in the magnetic field of a superconductive induktor;
– battery with supercapacitors – its disadvantage is the low voltage (1,8-2,4V);
– battery with lead-acid or alkaline cells; the disadvantage of this solution is a very low charging and discharging efficiency;
– electromechanical accumulator – flywheels store energy mechanically in the form of the kinetic energy.

2. FLYWHEEL ENERGY STORAGE

Stored energy, in Flywheel Energy Storage, depends on moment of inertia of the rotor and the square of the rotational speed of the flywheel. The moment of inertia depends on the radius, mass and height (length) of the rotor. Energy is transferred to the flywheel, when the machine operates as motor, charging the energy storage device. The flywheel is discharged when the electric machine regenerates through the drive.

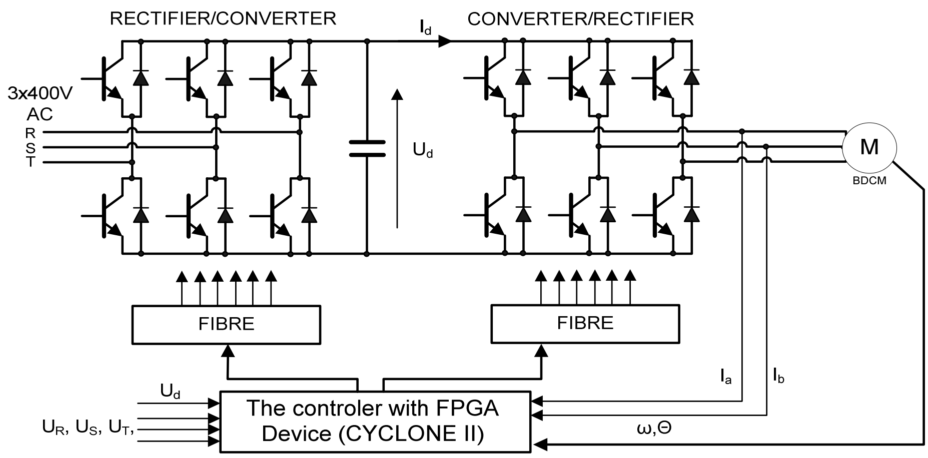

Fig. 1. The scheme of the FES supply system

3. POWER ELECTRONIC SYSTEM

Power electronic converters consist of two circuits: a control system (measuring sensors, controllers, PWM sections, dead time elements, contactors and pushbuttons control, protection algorithms, algorithms for the system control in specific operation modes, e.g. system starting) and a power circuit (power semiconductor devices, passive LC elements, contactors).

Three phase rectifier is a part of Power Electronic system for supply of brushless DC motor (BLDCM). In this device the three phase transistor converter which worked as a rectifier with sinusoidal source current was introduced. Additionally, bidirectional power flow (possibility of energy return from drive system to supply system) and DC voltage stabilization was possible. The converter, supplying the machine, was constructed on the basis on 3rd generation Intelligent Power Module (PM50RLA120) with integrated gate drive and brake-control. The PWM with unipolar voltage switching was used in inverter, which resulted in following advantages:

– reduction of the switching losses in the transistor;
– reduction of the ripple voltage with switching frequency.

The control system was constructed on the basis of a FPGA–CYCLONE II (Altera). In Fig 2 the realization of the switching transistors in converter is shown. The signals Sa, Sb, Sc are received from the Hall Sensors.

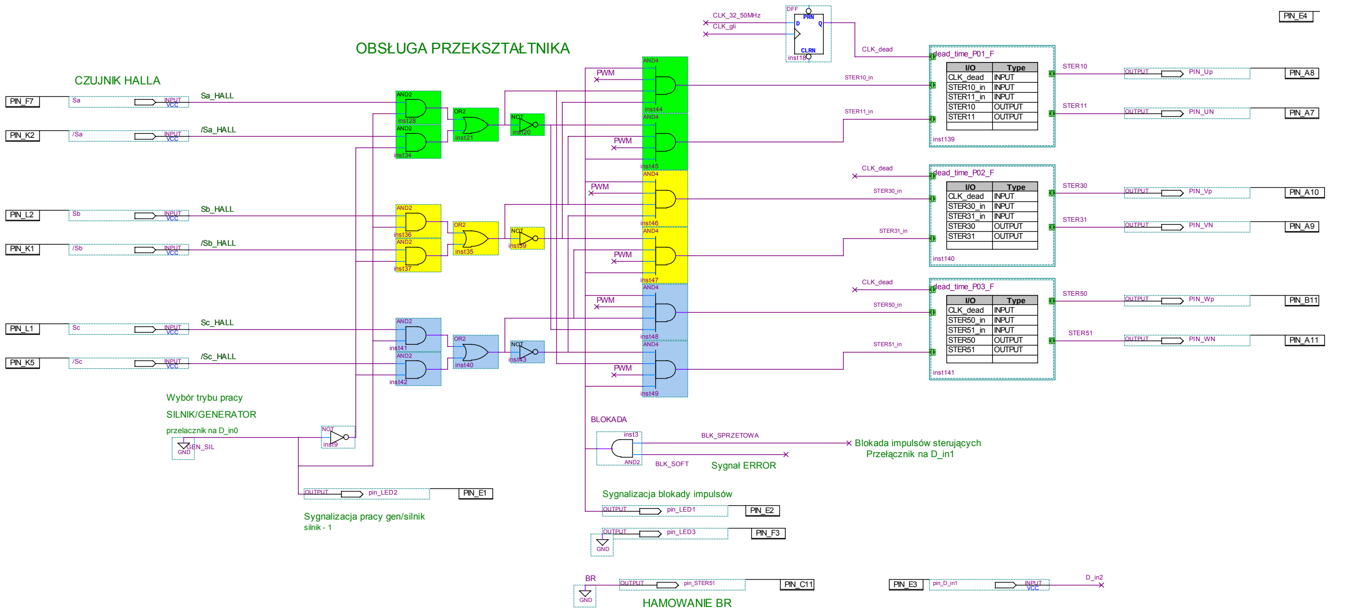

Fig. 2. The control system of the converter in Cyclone II (QUARTUS)

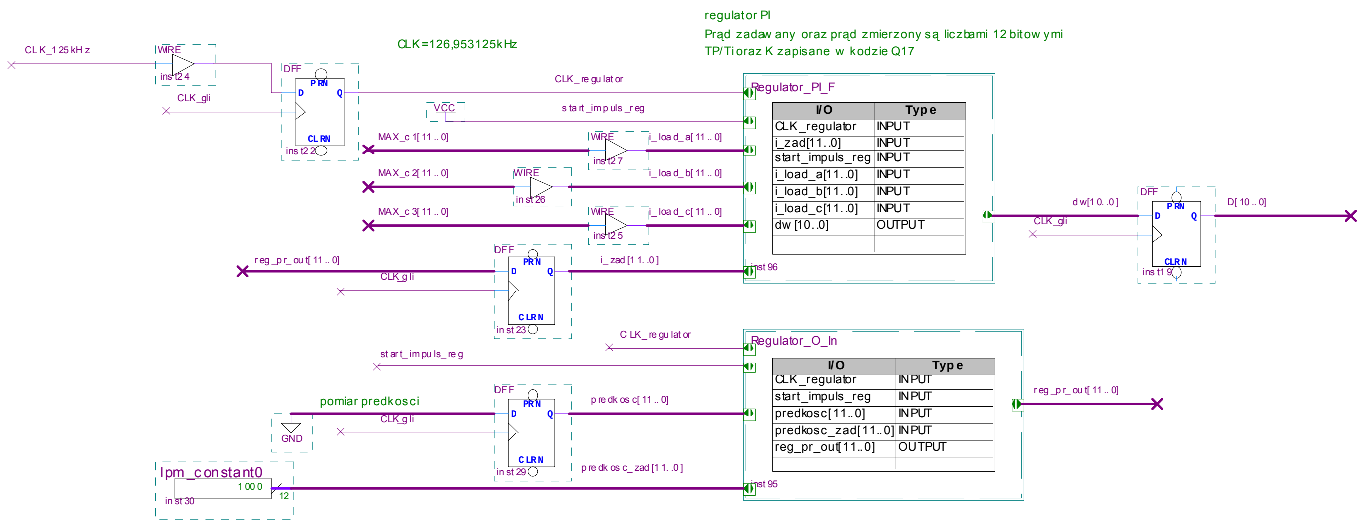

Fig. 3. The diagram of the control system in QUARTUS

Field Programmable Gate Arrays (FPGA) are now commonly applied to control and signal analysis systems. FPGAs hardware resources (logical elements, DSP modules, memories and PLLs) are used in building converter system elements capable of simultaneously executing several real-time algorithms. The paper presents FPGAs application opportunities, illustrated with actual applications in converter systems control. A method for real-time simulation of control systems implemented in FPGA elements, is also presented in this paper. The method utilizes the FPGA computing parallelism and is dedicated for rapid, safe and cheap prototyping of physical processes controllers, as well as control and protection algorithms, e.g. for power electronic converters.

CYCLONE II EP2C20:
Features:

The Cyclone II offers the following features:

- high-density architecture with 18,752 Les;
- M4K embedded memory blocks;
- 4,096 memory bits per block (4,608 bits per block including 512 parity bits);
- variable port configurations of ×1, ×2, ×4, ×8, ×9, ×16, ×18, ×32, and ×36;
- up to 260-MHz operations;
- embedded multipliers;
- 18- × 18-bit multipliers are each configurable as two independent 9- × 9-bit multipliers with up to 250-MHz performance;
- optional input and output registers;
- advanced I/O support;
- 315 I/O pins;
- single-ended I/O standard support, including 2.5-V and 1.8-V, SSTL class I and II, 1.8-V and 1.5-V HSTL class I and II, 3.3-V PCI and PCI-X 1.0, 3.3-, 2.5-, 1.8-, and 1.5-V LVCMOS, and 3.3-, 2.5-, and 1.8-V LVTTL;
- four PLLs per device provide clock multiplication and division, phase shifting, programmable duty cycle, and external clock outputs, allowing system-level clock management and skew control.

In Fig. 1 the diagram of power electronic system with control system is shown. The analog signals (current) were measured by LEM sensors. The analog signals were converted by fast 12-bits A/D converters. The MAX1309 is a 12-bit, analog-to-digital converters (ADCs) offer eight independent input channels. Independent track-and-hold (T/H) circuitry provides simultaneous sampling for each channel. The MAX1309 provide a ±5V input range with ±16.5V fault-tolerant inputs. ADCs convert two channels in 0.9µs, and up to eight channels in 1.98µs, with an 8-channel throughput of 456ksps per channel. Other features include a 20MHz T/H input bandwidth, internal clock, internal (+2.5V) or external (+2.0V to +3.0V) reference, and power-saving modes. A 20MHz, 12-bit, bidirectional parallel data bus provides the conversion results and accepts digital inputs that activate each channel individually. All devices operate from a +4.75V to +5.25V analog supply and a +2.7V to +5.25V digital supply and consume 57mA total supply current when fully operational.

Most computations (the rotor position, actual speed, current error, regulators) are carried out by CYCLONE II. Output data, in the form of transistor's driving pulses, are fed back to the FPGA structure, where control logic was generated allowing for safe switching of transistors in the inverter's branch. The current regulation of BLDC motor can be worked out in the same way as for classic DC machine with separately excited, by means of PI controller. The feedback signal for PI controller is a signal, which is proportional to current wave (absolute value Id) of DC source.

This signal can be received:

a) directly from DC current sensor (as absolute value of DC source current);
b) as signal proportional to the sum of module of load phase AC current.

The control algorithm is implemented in CYCLONE II. In Fig. 3 the scheme of the control system, where the signal in control loop is proportional to the sum of absolute value of load phase AC current, was shown.

4. THE PRACTICAL RESULTS

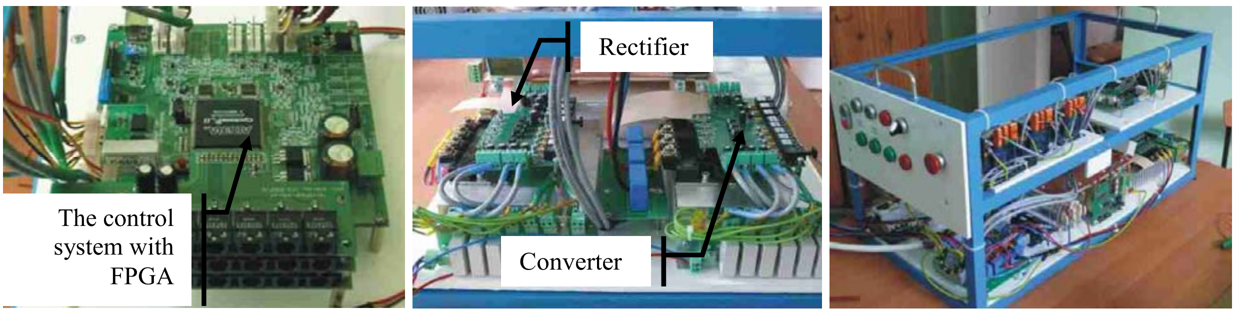

Fig. 4. The appearance of supply and control system of FES

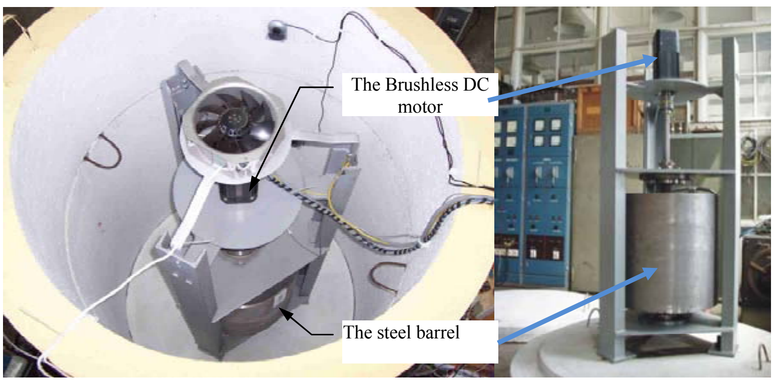

Fig. 5. The appearance of the FES

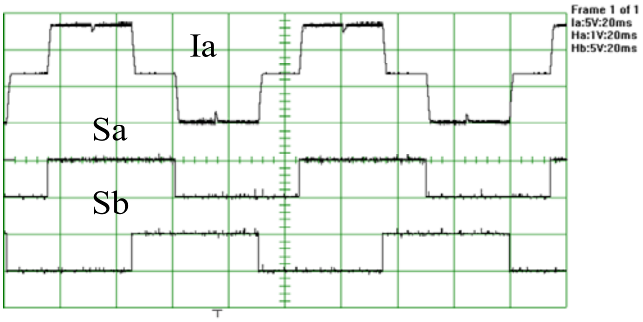

Fig. 6. The phase current and the Hall sensors signals

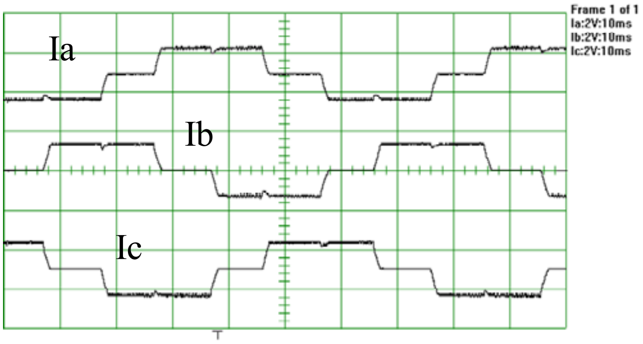

Fig. 7. The waves of phases current

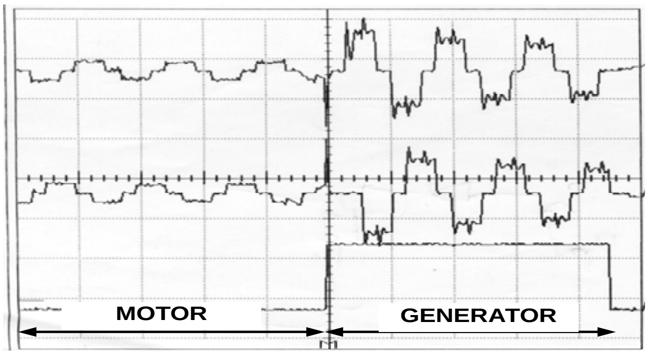

Fig. 8. The phase current waves. Motor and generator work

In Fig. 7 the waves of phases in the BLDC motor are shown. The rotor position is calculated on the basis of Hall sensors signals. In the Fig. 6 the signals from Hall sensors and phase current are shown. Above figures illustrate relationship between these waves. In the Fig. 8 the work as generator and motor work are shown (charging and discharging of FES).

5. CONCLUSION

Description and practical test results of the Flywheel Energy Storage System were presented. The system was developed on the basis of two power electronic devices: the rectifier with sinusoidal source current and the power electronic commutator for the brushless DC motor. The research on the Flywheel Energy Storage has proved that energy storage in the form of kinetic energy is highly efficient. The maximum speed of the barrel used in this research is limited. The current waves in real circuit are of better quality than the simulation results. The future research will concentrate on the control system based on FPGA only. The IPM of 5th generation with lower losses will be used in the inverter.

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