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VYSOKORYCHLOSTNÍ GENERÁTOR S MIKROTURBÍNOU

High-speed Micro Turbine Power Generator

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Abstract: This paper describes some experience gained with a construction of an experimental testing stand for micro turbine power generation with high-speed permanent magnet synchronous motor and its control. The main goal of this research is to create an affordable small (order of kW) power supply preferably for cogeneration – electrical energy and heat, that could be used in households, portable power generators etc. This approach promises lower fuel consumption, lower emissions and better efficiencies that classical piston based portable power generators. The presented test stand parameters are 40000 RPM, torque 7Nm. Some specific problems with high speed synchronous motor control, experience with inverter construction for high speed motors is discussed and some experimental results are shown.

Key words: micro turbine, power generator, high-speed synchronous motor

1. Introduction

In present days there is a clearly visible trend in new energy sources. New principles and devices for power generation are created and developed like solar, wind, tidal power plants and many others. Although a discussion about their utility, environmental friendliness, ecologic impact or efficiency is quite vivid, the technologies are developed very fast and represent an interesting alternative for electrical power produced centrally in thermal or nuclear power plants. There is a boom of local energy production. Irrespectively from the impact to the grid, those solutions provide some advantages to the customer who is a producer at the same time. The locally produced energy can either be used also locally, stored in some form or sold to the power grid in case of surplus.

One of the principles with good perspectives is the micro energy generation with a micro turbine. This solution uses a miniature gas powered turbine powered e.g. with natural gas, biogas, gasoline etc. The turbine is coupled to a generator providing electrical energy. The advantages over a classical piston based generator are significantly higher efficiency and smaller dimensions for the same output power. They are also less sensitive for fuel impurities. However there are also quite some technological challenges. The turbine is running at very high speeds, usually over 50 000 rpm and with temperatures around 800°C. To couple such a turbine with an electrical generator normally means to use some transmission to reduce the speed and only after the transmission to connect the generator. This however decreases efficiency and produces mechanical problems. One solution is to connect the generator directly to the turbine shaft. In this case the generator has to run at the same speed as the turbine. One promising implementation of the generator is to use a permanent magnet synchronous motor (PMSM) controlled with an inverter. There are some emerging PMSM allowing such high speeds. The main problems of those PMSM are presently mainly the bearings and also the possible damage of permanent magnets with higher temperatures. Although significant, these issues are however not the scope of this paper. This paper will focus on challenges of inverter control of a high speed PMSM generator and present the experimental setup currently being created at the Faculty of Mechanical Engineering of the Czech Technical University in Prague.

2. Theoretical analysis of the torque control

The lowest feedback control level at high speed drive is the torque control. Standard method for torque control of PMSM goes out from Equation 1.

$$M = 1.5 \cdot p_p \cdot (\psi_d \cdot i_q - \psi_q \cdot i_d) \tag{2.1}$$

ψ_d is magnetic flux linkage component in axis d, ψ_q is magnetic flux linkage component in axis q, i_d is stator current component in axis d, i_q is stator current component in axis q, p_p is number of pole-pairs on the machine. Using synchronous machine mathematical model equations Equation 1 can be written as

$$\begin{aligned} M &= 1.5 \cdot p_p \cdot [(\psi_f + L_d \cdot i_d) \cdot i_q - L_q \cdot i_q \cdot i_d] = \\ &= 1.5 \cdot p_p \cdot i_q \cdot (\psi_f + L_d \cdot i_d - L_q \cdot i_d) \end{aligned} \tag{2.2}$$

ψ_f is rotor magnetic flux linkage, L_d is synchronous direct-axis inductance and L_q is synchronous quadrature-axis inductance. If machine works in full magnetic flux mode, the i_d (stator current component in axis d) equals zero and for the torque holds

$$M = 1.5 \cdot p_p \cdot \psi_f \cdot i_q \tag{2.3}$$

Equation 3 holds for field weakening regime too when L_d=L_q. This equality is usually fulfilled on PMSM. In field weakening regime i_d (stator current component in axis d) acts against permanent magnet flux and enables to operate the machine in high revolutions with constant stator voltage. Equation 3 is expressing an analogy with DC machine. Current and torque control can be performed either in transformed coordinate system or by controlling instantaneous stator current with respect of instantaneous rotor position. In regime of full magnetic flux the current of given phase is controlled in such a way that the current amplitude occurs in time when the rotor is perpendicular with this phase. Other current values in remaining phases are 120^0 shifted. The stator current space vector is 90^0 ahead of the rotor. Space stator current vector of i_d (stator current component in axis d) acts against permanent magnets magnetomotive force (MMF) in field weakening regime. With other words the space vector i_d is 90^0 ahead according to the stator induced voltage U_i. That means the voltage drop $j\omega L_1 I_d$ has orientation against the induced voltage vector U_i.

3. Structure of feedback torque control and its implementation

The torque control structure of PMSM implemented for tests of the high speed drive 40 000min^{-1} uses the controller on base TMS320F2812. It works in orthogonal coordinate system d-q and cooperates with appropriate transformation blocks. Block scheme is shown on Fig. 1.

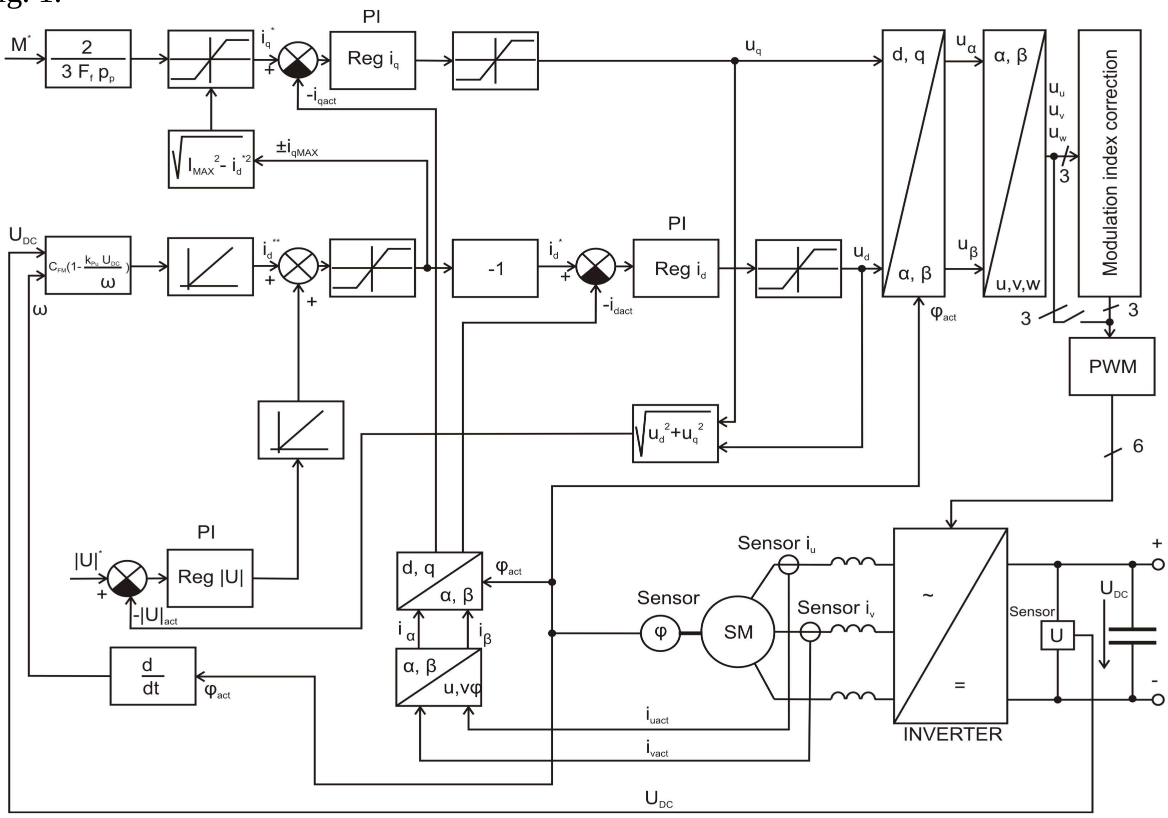

Figure 1 – Torque structure control of high speed drive

4. Experimental system description

As can be seen form the block diagram on figure 2, the experimental system is composed of several blocks. The power network voltage is rectified with an inverter to DC voltage. The inverter has to be able to transfer the energy not only from the power network, but also back. For this reason a standard diode rectifier can not be used, but the structure has to incorporate transistor switches. At the present time this block has not yet been implemented, therefore it is dashed in the diagram. The DC voltage is supplying an insulated gate bipolar transistor (IGBT) inverter build for this purpose. The inverter is using power module SKM75GD124D and IGBT/MOSFET driver SKHI61 both from Semikron [7]. The inverter is shown on figure 3.

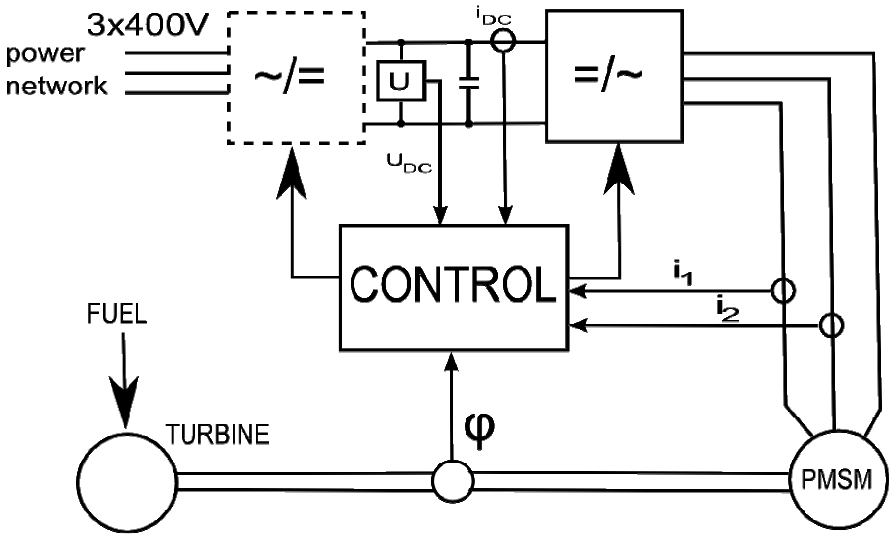

Figure 2 – Block diagram of experimental system

Figure 3 – Build IGBT power inverter

For the purposes of control and efficiency measurement, the system is equipped with current and voltage sensors in the DC intermediate circuit and on the three phase output of the inverter. The inverter is connected to PMSM with the following parameters: type 2AML406B-S from VUES Brno, nominal voltage 179V, nominal torque 1,2Nm, nominal current 12,2A, nominal speed 25 000 rpm, maximal speed 40 000 rpm, maximal torque 7Nm. The motor is shown on figure 4.

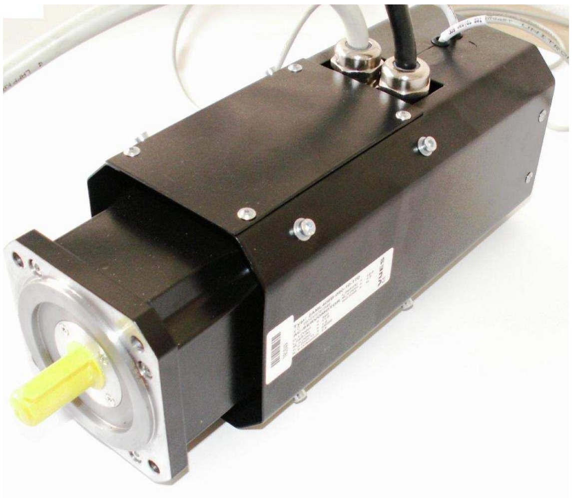

Figure 4 – Used high speed PMSM

As the control algorithm necessitates information about PMSM rotor position a resolver is embedded into the motor and connected to a developed resolver to digital unit. This unit provides 4096 positions per one revolution [1]. A DSP controller based on TMS320F2812 is used for the control of the whole system. A more detailed description can be found in [3]. This system is shown on Fig. 5.

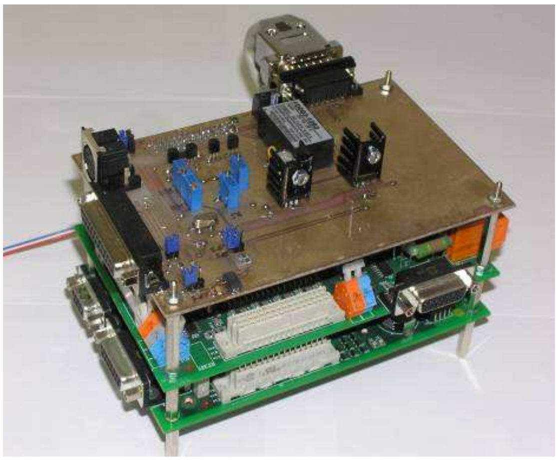

Figure 5 – DSP controller with resolver to digital add-on on the top

The turbine is created by means of a standard car turbocharger. This has the advantage of good availability, high reliability and low price. For the purpose of system testing the turbocharger is connected to a compressed air supply, in the future a combustion chamber will be build. Also some other alternatives for the turbine have been considered like a model aircraft turbine or a real aerospace turbine. However those solutions have a big disadvantage in reliability. Model aircraft turbines require complete maintenance only after aprox. 10 hours of service. This is unacceptable for a power generator. An aerospace turbine is better in reliability, however its price starts somewhere above 100 thousand Euros and this is also unacceptable. For this reason the idea is to use an automotive turbocharger and to add a combustion chamber later.

5. Conclusions

This paper presented some general ideas about control of a high speed micro turbine power generator. The experimental system is presently under construction. System components are being tested individually and coupled to the motor and turbocharger. Future work will therefore be the whole system testing at speeds 40 000 rpm with different power generation modes. An advantage of such system is higher efficiency and lower volume as compared to a classical piston generator. The system can also be used for cogeneration as it can provide heat and electrical energy at the same time. At the time being, a disadvantage of this system is its high price as the components are not produced in larger volumes and a more difficult control requiring a DSP. However it can be expected that if a system like this would be produced industrially, its cost would drop considerably.

Acknowledgement

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References

[1] ČAMBÁL, M.; NOVÁK, M.; NOVÁK, J. 2005. Study of Synchronous Motor Rotor Position Measuring Methods. Zagreb. Korema 2005. p. 62-66. ISBN 953-6037-42-4

[2] ČEŘOVSKÝ, Z.; MINDL, P. 2007. Electric Power Divider for Hybrid Car Propulsion Systems. Aalborg .12th European Conference on Power Electronics and Applications EPE 2007. ISBN 9789075815108

[3] ČEŘOVSKÝ, Z.; NOVÁK, J.; NOVÁK, M.; ČAMBÁL, M. 2008. Digital Controlled High Speed Synchronous Motor. Poznaň. EPE PEMC 2008. p. 997-1002. ISBN 978-1-4244-1742-1.

[4] LETTL, J.; RATZ, R. 2005. Contribution to Induction Motor Vector Control. Prague. XIII. International Symposium on Electric Machinery ISEM 2005. ISBN 80-01-03328-7

[4] NOVÁK, L.; NOVÁK, J; NOVÁK, M. 2009. Electrically Driven Compressors on Turbocharged Engines with High Speed Synchronous Motors. Lille. Proceedings of The 8th Electromotion Conference, EPE Chapter “Electric Drives”. HEI Graduate School. ISBN 978-2-915913-25-5.

[5] SEMIKRON. 2007. Sixpack IGBT and MOSFET Driver [on line]. [accessed 18.3.2007]. Available on: http://www.semikron.com/internet/webcms/online/pdf/SKHI_61_71.pdf