Brushless Wind Power Generator for Limited Speed Range

Project 38509-1 Progress Report 2015-04-30

Project leader

Prof. Chandur Sadarangani

Project goal, purpose and method

The goal of the project is to develop a wind generator system that is built on the same principle as the Doubly-Fed Induction Generator(DFIG) but without the use of slip rings and brushes. The concept that is studied and developed is built on the integration of two electrical machines; first machine (main machine) handles the main part of the active power while the second machine handles slip power. The machine is controlled through the rotating power electronic converter mounted on the shaft. The power electronic converter is rotating with the speed of the shaft. The switching of the power electronic converter will be done via wireless means. The prescribed topology is shown in Fig. 1 where a schematic view is given in (a) and the equivalent laboratory set-up is given in (b).

One purpose of the project was to develop a control system for the concept and implement it in the laboratory set-up to demonstrate that the concept works. Another goal was to design and build a wireless controlled Rotating Power Electronic Converter (RPEC). Finally, the RPEC will be mounted on the shaft to demonstrate the RPE-BDFIM.

A full scale 2.5 MW RPE-BDFIM will be evaluated both technically and economically. A PhD dissertation will be presented by Naveed-ur Rehman.

Project participants

Naveed ur Rehman Malik (PhD student), Dr. Alija Cosic (senior researcher), Yanmei Yao (PhD student). Yanmei is not financed by the project but has been included in the project team as her project has overlapping interest especially concerning wireless control.

Has the project plan been followed?

The project has followed the project plan very well. Naveed is planning to defend his PhD in October this year. His has submitted 1 journal paper. Two more are completed and are awaiting internal revision. The main results from the project are summarized in the journal papers:

- Journal paper 1: Describes the developed control system for the RPE-BDFIM and experimentally verifies on the laboratory set-up that the system works according to the theory
- Journal paper 2: Demonstrated the unique ability of the RPE-BDFIM to operate normally at the synchronous speed of the main machine. This is not possible with other competitive BDFIM systems.
- Journal Paper 3: Evaluates a full scale 2.5 MW wind power system based on the RPE-DFIM.

Naveed has previously published more than 5 conference papers. The remaining goal for his thesis work is to write a summary of his thesis.

The goal to build an RPEC has been found to be more complicated than anticipated. The main cause for this is that this work lies slightly outside our main competence area. We have therefore a parallel activity has been started by Dr. Cosic to address this goal. Yanmei is present assisting him to this purpose. The status-quo for this project is also reported in the results. The project cost is higher than budget as a result of the parallel activity but will not affect to total cost for the project.

A master thesis on a concurrent concept has been proposed by KTH. This will be discussed at the next reference group meeting at ABB on the 29th of April 2015. This thesis work will be supervised by ABB. Recruitment on a suitable candidate for this position is ongoing.

Project results

a) Activities of Naveed ur Rehman

The project started in October 2009 with the literature study of the existing Brushless Induction Generators present in the past literature. Closed Loop control of the topology shown in Figure 1 has been implemented in the lab.

Experimental Evaluation: The prototype of the brushless generator with the rotating power electronic converter has been setup in the laboratory. The 11 kW and 6 kW machines were bought for this purpose while ABB delivered the converter for the load machine. The closed loop feedback control has been developed, implemented and tested. Two power electronic converters were used; one of them was connected to the rotor of the induction machine while the second was connected to the synchronous machine. The converters were controlled using the dSpace systems. The laboratory set-up has been a success; it is working, and has been demonstrated to the steering committee in autumn 2014. Measurements and results are documented in the form of journal and conference papers. A pictures of the setup is given below in Figure 1(b).

Exchange visit to USA: From April 30th to August 15th 2014, Naveed traveled to USA for an exchange research visit to North Carolina State University (NCSU) at Department of Electrical and Computer Engineering in Raleigh. Naveed did research on thermal aspects of the rotating power electronic converter which resulted in a paper which he wrote together with the professor in NCSU, USA which he will present in a conference in USA in May this year.

PhD Courses: PhD course on 'Perspectives on Energy Systems' offered by Swedish Energy Agency was taken in autumn of 2013 and Naveed also took course on 'Experimental Methods in Power Electronics' in Autumn 2014. Currently, he has 71.5 ECTS credits and 60 ECTS credits is the requirement for the PhD Thesis.

Journal Papers: Naveed has submitted one journal paper, whereas the second journal is complete and will be submitted soon. He is working on the third journal and after its completion he start writing his PhD thesis. He plans to defend in October 2015.

Conference Papers: Two conference papers have been written. One is accepted and he will present next month in a conference in USA. The second conference paper is submitted to a conference.
Teaching Assistant: Apart from the project, Naveed is also teaching tutorials for the Course 'Electrical Machines and Drives' at the department at KTH.

Soon Naveed will start writing his PhD thesis and plans to defend in October 2015.

b) Activities of Dr. Alija Cosic

Construction of the Power electronic converter: The construction of the converter has started and runs in parallel with other sub projects. The first part in the construction was identification of the different components. Based on the simulation results specifications were provided such as the current and voltage ratings for the IGBT (Insulated Gate Bipolar Transistors) module, size of the capacitors, etc. The converter will be mounted on the rotor shaft thus there will be no mechanical connection between the operator and the converter itself. In order to operate the converter, it will be equipped with a microprocessor which will provide the PWM (Pulse Width Modulated) signal pattern to the IGBT modules. It will also take care of measured signals from current and voltage sensors etc. All communication between the operator/main controller and the converter will be performed through the wireless communication protocol.

Chosen Components: The chosen processor is from an ARM Cortex M series. It is a powerful and stable microprocessor which is well suited for the motor control application. The processor has been chosen on account of its speed and number of input and output ports as well as its availability from a number of different manufacturers. There is also number of different tools developed for the processor family which makes the processor easy the work with.

The ZigBee module has been chosen for the wireless communication. This technology has been developed as a low cost, low power technology that is able to operate in a very tough industrial environment.

DC/DC converter commercially available was not able to meet the tough requirements, therefore a suitable DC/DC converter is being developed at the department as a subproject.

A full bridge IGBT module has been chosen with respect to the voltage and current ratings. Full bridge modules offer a better mechanical stability which is one of the main issues in the design process due to the high centrifugal forces involved due to the rotation.

A number of different driver IC circuits have been considered. A full bridge driver IC was chosen which is simple to implement and control with the help of chosen processor.

Voltage and the current sensors have been chosen based on the rated voltage and currents of the electrical machines.

So far: The simple PWM patterns have been developed and implemented into the ARM-microprocessor equipped evaluation board. These patterns have been tested together with the driver IC and the IGBT module. Further testing is required although we have some positive initial results.

Evaluation of the gate driver: This section will provide a short description of the current status on the construction of the power electronic converter

Testing: The first prototype equipped with gate driver was tested with good preliminary results. However, during further testing under load conditions it was evident that the gate driver was not able to provide enough current in order to have satisfying results during TURN ON and TURN OFF of IGBT-module. The testing prototype with IGBT module was reconfigured and improved in order to be able to provide enough current. This prototype is shown in Fig. 4(a). However, it was soon discovered that the current paths were too long and the system was sensitive for disturbance. A new prototype board was developed and manufactured; see Fig. 4(b).

During the testing of the new test prototype the problem that was discovered is that the signal from the CPU (red PCB board in Fig. 4(b)) is picking up lot of disturbance which affects the switching of the IGBTs. Installing RC- filter on the output did not result in satisfying results. The next step is to redesign the connection interface between CPU and the gate driver circuit in order to minimize to disturbance in the signals.

The work on ZigBee modules is ongoing.

c) Activities of Yanmei Yao

Yanmei Yao started her PhD study from October 2011. She works on a novel topology of induction machine using a rotor integrated converter with a floating capacitor. The stator windings of the induction machine are Y-connected while the rotor windings are connected to a converter with a floating capacitor. The converter together with its controller can be integrated into the rotor and rotate with it. Therefore, the carbon brushes and slip rings of the induction machine are avoided. The communication between the controller and the computer can be achieved via a wireless module, for instance a ZigBee module. Fig. 2 shows a layout of the RPEC concept.

Yanmei has developed a dynamic mathematical model of the system with the open-ended rotor windings fed by a back-to-back converter with a floating capacitor. Fig. 3 shows a schematic view of the system. The transient performance of the induction machine based on the dynamic model has been implemented in Matlab/Simulink and verified experimentally in the lab. Speed is controlled by setting the fundamental frequency of the switching signals to the converter. The stator power factor can be improved within a wide range of load. Moreover, the DC-link voltage over the floating capacitor is considerably low compared with the full voltage.

However, the rotor current suffers from zero-sequence component in the topology using back-to-back converter because of the open-end connection of the rotor windings. An optimized topology is thus developed, where the rotor windings are Y-connected and the back-to-back converter is replaced by single converter. Similar performance on speed control and power factor improvement can be achieved. The capacitor voltage is twice of that in the back-to- back topology. However, it is sufficiently low compared with the rated voltage. Furthermore, the zero-sequence component in the rotor current is eliminated as expected.

On the topology using back-to-back converter, one paper has been published in the conference Electro-motion in 2013 and another journal paper on the dynamic performance investigation has been submitted to IEEE Transaction on Industrial Electronics. On the topology using single converter, one full paper will be submitted to IECON in Japan and a one-page digest to ICEMS in Thailand in 2015.

Yanmei is currently working on the program of the micro-controller, IGBT board testing and wireless communication.

Reference group meetings

A reference group meeting was held on the 19th of Nov 2014 (see appendix 1 for the meeting notes). The next meeting will be held on the 29th of April at ABB Corporate in Västerås. The minutes of this meeting are given in Appendix 2.

Diagrams and photographs illustrating the project activities

See appendix.

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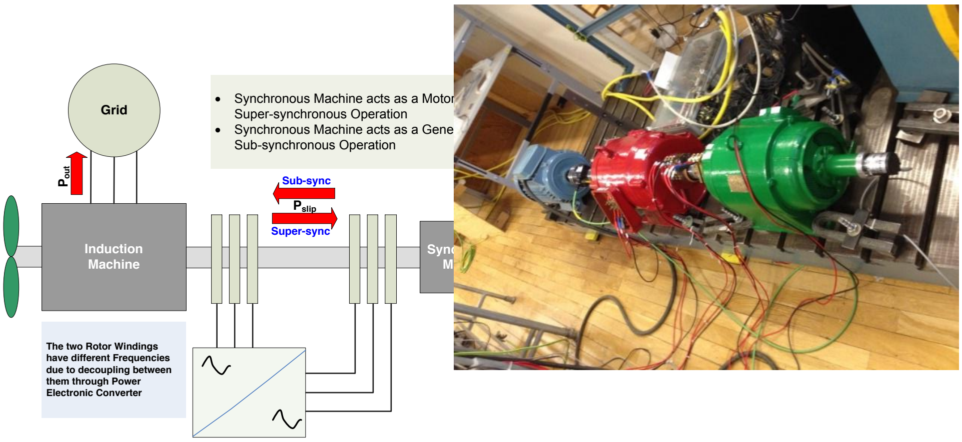


(a) (b)

Figure 1: Brushless Doubly-fed Induction Machines and exciter (a) schematic view (b) laboratory set-up

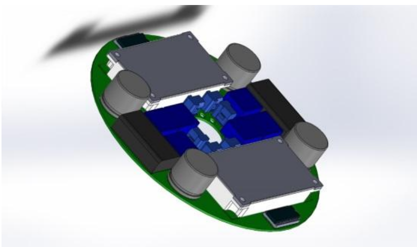


Figure 2 -Layout of the rotating power electronics converter

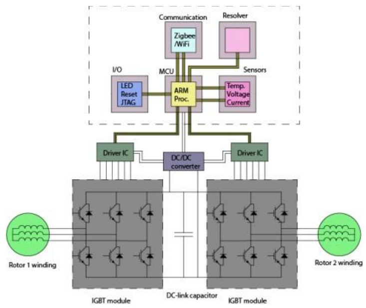
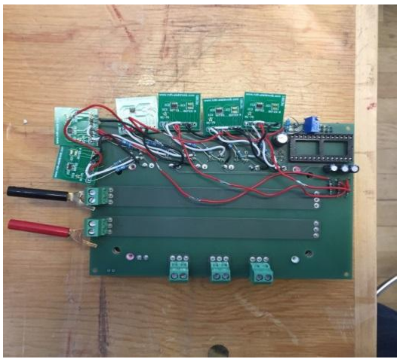
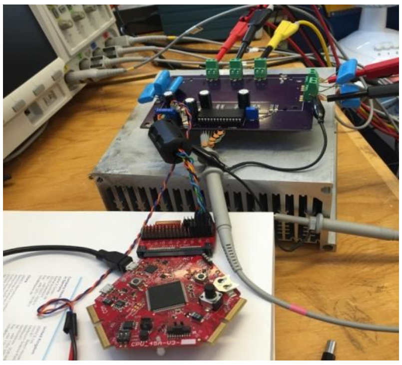


Figure 3 - Schematic view of the rotating power electronic converter



(a)



(b)

Figure 4 - Two different test-prototypes a) modified prototype with improved current capability b) Second prototype with optimized current paths.