DSP-based doubly fed induction generator test bench using a back-to-back PWM converter

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Abstract: Present Paper describes the design of a doubly fed induction generator (DFIG) test bench with active crowbar, using a PWM voltage-fed inverters connected between the grid and the rotor. A vector control scheme is proposed in order to control the power-side and the rotor-side of the converter. A control board, based on a digital signal processor (DSP) and a FPGA, has been developed to manage the overall equipment. Real time system supervision is implemented by a monitor program.

INTRODUCTION

Doubly fed induction generator has become during the last years in one of the most used systems in wind power production. The major advantage of the doubly-fed induction generator is that the power electronic equipment only has to handle a fraction of the total system power. This means that the losses in the power electronic equipment are reduced in comparison to power electronic system which has to handle total power. Cost saving of using a smaller converter is an important reason too. However, control of the doubly-fed induction machine is more complicated than the control of a standard induction machine and bas some important limitations. e.g., starting problem, synchronization and oscillatory transients. A doubly fed induction generator test bench using a back-to-back PWM converter connected between the rotor and the grid (known as Seberbius drive) has long been a standard option for high-power applications. Most Scherbius DFIG equipments described employ either a cycloconvertor or a current-fed DC-Link converter in the rotor circuit. Using a current-fed DC-link converter has some disadvantages. The DC-link choke is very expensive and an extra commutation circuit is required for Operation at synchronous speed, and this has resulted in poor performance at low slip speeds. In addition such a converter draws rectangular current waveforms from the supply. The problem at synchronous speed may be overcome by the use of a cycloconvertor. Both schemes have the disadvantages of requiring a transformer to form the neutral; in addition naturally commutated DC-link and cycloconvertor schemes may, in many cases , require a transformer for voltage matching. In this paper, a complete doubly fed induction generator test bench has been designed; two functional hardware boards have been developed and implemented. The first one, the handling & measuring board, adapts sensors information from the power electronic to the control system, controlling the signal levels and its possible saturation. It also handles the power switches of the system to connect-disconnect the power-side and the stator side to the grid. The PWM pattern and control signal to the IGBT drives are also generated in this board. It is based on a Texas instrument® DSP and a Xilinx® FPGA. DSP perform the control algorithmic of the system meanwhile FPGA manages encoder signals.

A schematic diagram of the overall system is shown in Fig. 1. The main characteristics of the DFIG used are the following:

Table 1: Asynchronous doubly fed generator characteristics
Asynchronous doubly fed generator
General Electrica EspafIola, Asynchronous generator
UNELEC, Class B type FN122SMx4,
50 Hz, 54 CV, 40 KW 1470 rpm, Δ/Υ 220/380170/190 A,
Rotor A 200V 120A, Temperature protection

Table 2: Squirrel cage motor characteristic
Back to Back converter:
As we can see in figure 1, the DFIG system has been implemented using a IGBTs based, back-to-back converter between the rotor-side and the power-side, three single-phase chokes of 1.2 mH have been used. The doubly fed induction generator is a 40 K.W, 50Hz, 1470 rpm, 4 pole machine, whose parameters are given in Table-I. A squirrel cage motor is used to emulate the wind turbine. Three power switches connected: disconnect power and rotor sides to the grid; KM1; KM2 and KM3. The DFIG connection to the grid must be done in five steps. The first step consists on the power side-connection of the converter. The DC-link is charged to 300 volts through three 220 ohms resistances using the anti-parallel diode rectifier of the IGBT’s (working as a no-controller rectifier). After that, the power switch KM2 is closed and KM3 opened and the direct connection is realized starting the commutation process and, consequently, the controlled-rectification of the DC-link voltage. Third step would be the regulation of the statoric voltages and the correspondent synchronization with the grid voltages. After that, following step consists in the stator connection to the network, closing power switch KM1. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the fifth step is the power regulation between the stator and the network. A crowbar protection has also been implemented. It can be designed in many ways [7]. For example, the rotor can be short-circuited by two pairs of anti-parallel connected thyristors connected between the phases, Fig.2 (a)

Another possibility is to employ a diode bridge to rectify the phase currents and use a single thyristor to control the shorting, Fig. 2(b). In the developed system, the second option has been chosen due to it can cut the short-circuit current whenever needed.

A. Hardware control system: The hardware control system is based on two designed boards, figure 3, the handling and measuring board and the control board. First one is the interface of the control board with the power electronic system. All analog signals from sensors, as voltages and currents or temperatures are filtered and their levels adjusted in this board. Hall Effect sensors are used to transducer current measurements with power-side, rotor-side and stator-side, as we can see in figure 1. To measure voltages with power, stator and rotor-side we have employed transformers, meanwhile a Hall Effect sensor is used to DC-link voltage. Grid-side power switches and rotor-side power switch are also managed. The crowbar protection and digital encoder signals are interfaced too.

Temperature protections are been implemented in the asynchronous doubly fed generator and the back-to-back converter. The PWM signals are also managed employing this board, see figure 1. General purpose pins are accessible to use them in the future. In other way, the control board manages the overall system. The DSP used in the control board is a Texas Instruments® TMS32DVC33, with the following characteristics: floating point, Harvard memory structure, low power, high performances. A co-processor based on a Xilinx® Spartan FPGA is also used to process encoder signals. External 12-bits analog to digital converters are used to obtain the sensors information by the digital processor. PC communications, based on asynchronous RS-232 protocol, are implemented by the PC16SS2D, an universal dual receiver/transmitter (UART). A programmable universal I/O interface device, MSM82CSSA, is used to latch digital I/O signals.
B. Software control system

TMS320VC33 control program is the core of the overall system. The main of the DSP Program consists on the power and the rotor side control strategies and algorithms. It manages all the data acquisition and digital signals from the test bench. A digital filtering of the different measures has been implemented too. In order to avoid the induction machine and power electronic damages, analog and digital signals, as driver errors, temperature alarms, and voltage measures, are processed and a system protection has been realized. The connection-disconnection of the different power switches (KM1, KM2 and KM3) is synchronized by the control software. Other important task is DSP-PC communication; polling and interruption strategies are used to implement the asynchronous protocol. The core of the program has been structured as a machine, this implies a huge programming effort; however, this philosophy improves the debugger task. TMS320VC33 DSP has been programmed employing the Code Composer Tool® which enables a deeper visibility for a quick and precise problem resolution, simplifies tedious guess work and enables a better management for real-time applications.

C. PC monitor program

Real time PC monitor software has been developed. The main characteristics of this program are the following, as shown in figure 4: Real-time sensors information displaying, Digital calibration, PI controllers parameters establishment, System alarm events and system status, Oscilloscope function, Signals plot storage, PC-DSP communication status, FIG test bench local and stand-alone control.

III. DOUBLY FED INDUCTION GENERATOR TEST BENCH CONTROL

The control of the DFIM test bench using back-to-back PWM scheme is well known. It has two main parts: the DC-link voltage regulator and the rotor voltage controller.

The DC-link voltage controller is a vector controller that permits keeping constant the DC-link voltage level. The rotor-side controller is a vector controller that enables independent control of the induction machine active and reactive powers.

A. Control of supply side three-phase-PWM rectifier

A control scheme for connecting the converter system to the grid has been proposed in this paper and it is shown in Fig. 5. It consists in an outer loop to control the voltage of the DC-link $V_{dc}$. A reference of active power $P_{dc}$ is obtained from a PI controller and it is used to generate the current references $I_{ad}$ and $I_{bd}$ in static axis based on the Self Tunned Vectorial Filter STVF. The objective of the proposed STVF is to extract (filtering) the positive sequence symmetrical component of the fundamental harmonic of the grid voltage. The idea behind the filter was to generate a narrow band pass filter with unitary gain and zero phase at the fundamental harmonic.
capacitor is over 300 V the direct connection is realized and 315 V in DC-bus are reached, at this moment the rectifier begins to control the bus, after a time it is disconnected to connect and disconnect again. We can see the bus discharge at least when the power-side is opened.

B. Induction machine control
The wound-rotor induction machine control scheme is presented in figure 7. It is based on conventional control diagrams. A decoupled control between the active and reactive power is achieved. To control the induction machine, a rotating reference axis d-q oriented along the stator flux is employed. Stator voltages \( v_{us}, v_{ws} \) and \( v_{ws} \) stator and rotor currents at \( i_{ud}, i_{vd}, i_{wr} \), and \( i_{wr}, i_{vr}, i_{wr} \) respectively, and rotor position \( \theta_r \) measurements are used to implement this algorithm. Under the consideration of that the stator resistance is small, the stator magnetizing current \( i_{ms} \) can be considered constant. The active and reactive power errors are processed by the PI controllers to obtain \( i_{dr} \) and \( i_{qr} \) current reference which are compared with the measured currents and using other PI stage we obtain \( v'_d \) and \( v'_q \) respectively. After adding a compensation term, the references \( v'_d \) and \( v'_q \) are obtained. After that, a \( \alpha\beta \) scheme is obtained and a 2 to 3 variable conversion is realized to obtain \( v_{us}, v_{ws} \) and \( v_{ws} \). These are the voltage references to the PWM converter, as we can see in figure 7.

IV. Conclusion and Experimental Results
The purpose of this research project is to implement a doubly fed induction generator test bench and implement the control of the system, to analyze the different techniques and its advantages. Actually, Power electronic system and control electronic boards, DSP based, has been designed and implemented successfully and are well suited to the power electronic control. Photography of the system can be seen in figure 8.
Developed monitor program makes easier the system magnitudes visualization, as voltage, current and temperature sensors signal or PWM templates. At the same time, PC program enables remote real-time control of the complete system. Photography of complete system. Where two Pcs are used, one to monitor the system and a second one with the debugger tool can be seen figure 9. Control Software of the system is being programming and the power-side of the converter is already correctly working. Rotor-side converter control is being implemented.
V. References


