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Constant voltage and Constant frequency operation of DFIG using Lab view FPGA and cRIO

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Abstract: *This paper presents control of doubly fed induction generator using LabVIEW FPGA platform. NI LabVIEW FPGA enables fast and easy implementation of hardware control due to its graphical programming capability, inherent parallelism flexible design. Development of digital controller for hardware implementation is done with the help of LabVIEW graphical programming language instead of a complex VHDL programming language. Using a variable frequency drive speed of the prime mover is controlled with the help of analog analog output card. Based on the prime mover speed rotor converter frequency is adjusted to obtain a constant frequency from the stator. Modulation index of rotor side converter is adjusted to get a constant voltage. Constant voltage and constant frequency is obtained from DFIG with the help of rotor side converter control.*
Keywords*: LabVIEW FPGA, Inverter, Sine PWM, cRIO, DFIG.*

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I. Introduction

Demand for more electric power coupled with depleting conventional resources has motivated researchers the area of energy production from renewable energy sources such as hydro, wind, solar etc.In the last few decades the technological advancements in wind energy conversion and an increased support from governmental and private sectors made the wind power generation as quite promising energy source to meet the future energy demand.

The Doubly Fed Induction Generator (DFIG) based variable speed turbine is gaining the popularity these days. Using DFIG system constant voltage and constant frequency can be obtained for variable wind speeds. Variable speed constant frequency operation (VSCF) is becoming more attractive with the invention of modern power electronic devices and digital control systems. DFIG is a suitable generator for large size wind turbines (WT), to achieve all the benefits of VSCF systems. DFIG based VSCF operation has the advantages of higher energy capture, better stability and decoupled control of active and reactive powers, reduced mechanical stresses, lower acoustic noise and improved power quality[1-3].

The stator of doubly fed induction generator is connected to electrical utility and rotor is connected to electric utility via back-to-back PWM converters as shown in Fig.1. Total control of the machine is achieved by a fractional power rated converter in the rotor circuit, which is the main advantage of doubly fed induction generator based wind power generation.

This back-to-back arrangement of two PWM converters with a common dc link makes the system extremely flexible to control active and reactive powers. The machine can be operated both in sub synchronous and super synchronous modes because the rotor circuit is capable of sourcing and sinking the slip power.

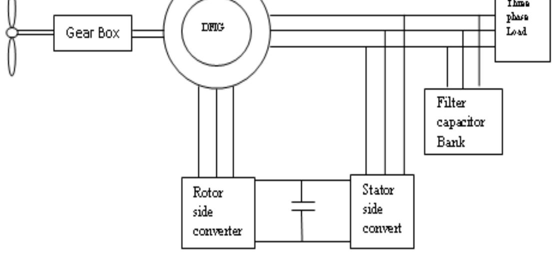

Fig.1 Wind Energy conversion system based on DFIG

Conventional integrated environments like Micro controllers, DSP and FPGA boards are relatively complex and they deal with low level languages. To learn the low level language one needs lot of training and time. In order to simplify the hardware implementation approach cRIO from National Instruments is used. NI LabVIEW FPGA enables easy and fast implementation of the control hardware due to its graphical programming capability, inherent parallelism flexible design (re configurability) and tight integration with LabVIEW software. It is very much user friendly. Indeed, the basic data structures are same as general VIEW software and only a limited number of customized functions need to be studied to enable an effective FPGA chip programming[6].

Developing code for various algorithm becomes very simple compared to other hardware platforms and also time-efficient . The developed system is comparable with other systems created in Very High-Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL), but the LabVIEW FPGA tools simplify many complicated steps[7].

The national instruments Compact RIO is a reconfigurable embedded control and data acquisition system. The cRIO system's rugged hardware architecture includes I/O modules, a reconfigurable FPGA chassis and an embedded controller. NI c series I/O modules are used for measurement. These modules contain all necessary circuitry to measure, A/D and D/A conversion occur in the module before the data reaches the chassis[11].

II. Control Of Rotor Side Converter

Fig.2 shows the block diagram of rotor side inverter control using cRIO and LabIEW FPGA . The sinusoidal pulse width modulation is implemented using LabVIEW VI. After successful compilation of the VI, driving pulses are dumped into NI 9401 DI/O. Output of DI/O are connected to driver circuit of IGBT inverter circuit. The modulation index ratio and frequency of reference wave can be varied from the front panel of LabVIEW VI in P.C.

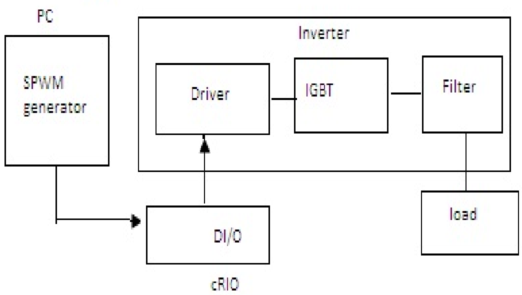

Fig.2 Block diagram for driving signals generation from cRIO

Fig.2 shows the block diagram of rotor side inverter control using cRIO and LabIEW FPGA . The sinusoidal pulse width modulation is implemented using LabVIEW VI. After successful compilation of the VI, driving pulses are dumped into NI 9401 DI/O. Output of DI/O are connected to driver circuit of IGBT inverter. The modulation index ratio and frequency of reference wave can be varied from the front panel of LabVIEW VI in P.C.

Reference sine wave is compared with a carrier triangular wave and pulses are given to DI/O channels. Dead time is provided between upper and lower switches. In LabVIEW FPGA mode loop rate is 40 MHz. IGBT switches are being operated at 9 KHz in real time.

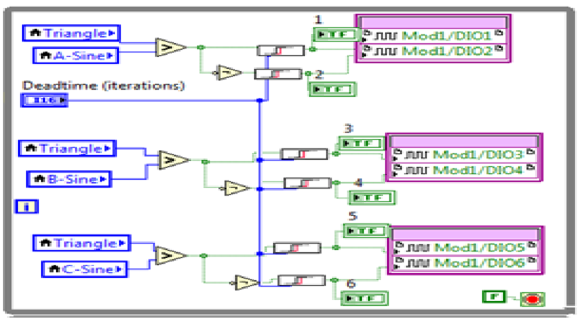

Fig.3 LabVIEW VI for sine PWM

III. Prime Mover Control

In case of wind energy conversion system wind turbine acts as a prime mover. Variable wind speeds can be realized by varying the prime mover speeds. In this prototype squirrel cage induction motor acts as a prime mover and it's speed is controlled by using variable frequency drive. Using one of the channel of analog output card
NI 9264, reference voltage to the VFD is varied and there by the speed of the prime mover is being controlled. Fig.4 shows the front panel to control the speed of prime mover.

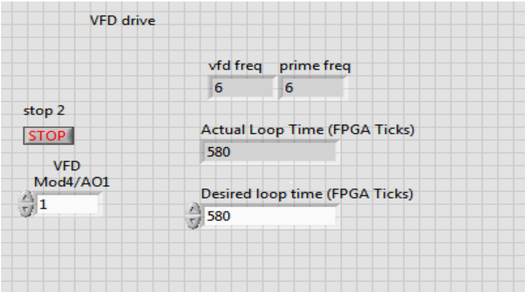

Fig.4 Prime mover speed control

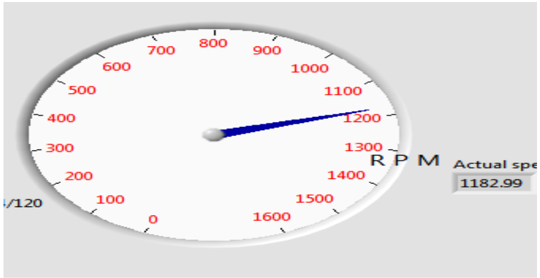

Fig.5 Measurement of speed using D I/O

Speed of the prime mover is sensed by a encoder mounted on the shaft of DFIG system. Quadrate encoder outputs are being given to NI 9403 card and the digital output of encoder being converted into corresponding speed. Speed of the prime mover is sensed and displayed on the front panel as shown in Fig 5.

IV. Phase Locked Loop

Phase locked loop block is used to identify the grid voltage frequencies .Grid voltage is obtained by one of the channel of NI 9225 voltage sensing card. The input to PLL block is given from NI 9225 card. The grid frequency is monitored continuously. Fig.6 shows the front panel of PLL block where grid frequency is monitored.

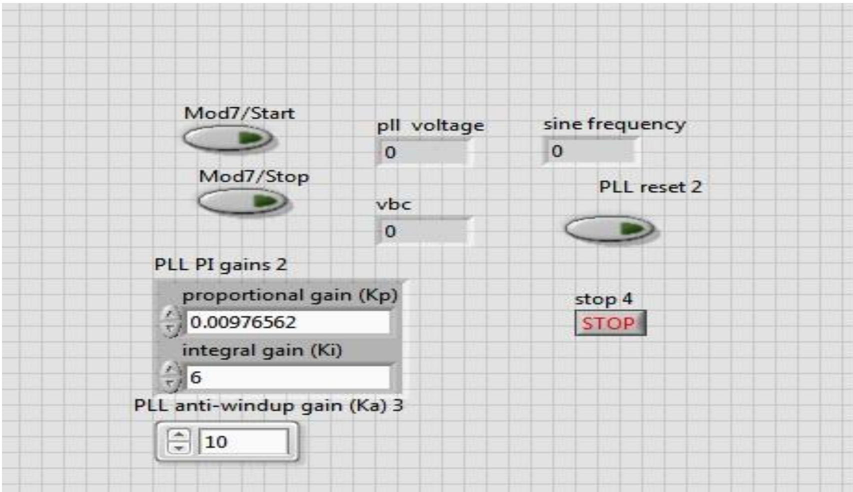

Fig.6 PLL for frequency monitiring of grid voltages frequency

V. Experimental Setup

Fig.7 shows the block diagram of prototype model of wind energy conversion system based on the doubly fed induction generator. Different components in this prototype are V.F.D to control the squirrel cage induction motor (prime mover).Rotor side converter (RSC) is controlled by using front panel of LabVIEW VI.RSC is used to obtain constant voltage and frequency from the stator.

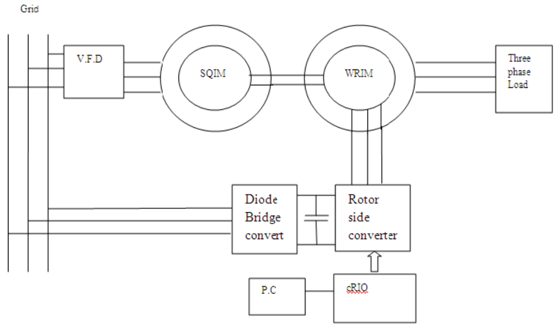

Fig.7 Block diagram of DFIG system

Fig.8 shows various cards used to obtain a constant voltage and constant frequency from the DFIG system. Prime mover speed is controlled by NI 9264.NI 9403 is used to sense the speed of prime mover.NI 9401 is used to pulse generation of rotor side converter. NI 9225 and NI 9227 are used to sense stator generated voltage and currents.

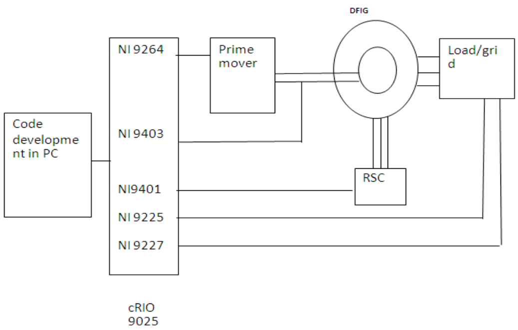

Fig.8 Implementation of DFIG control using NI LabVIEW platform

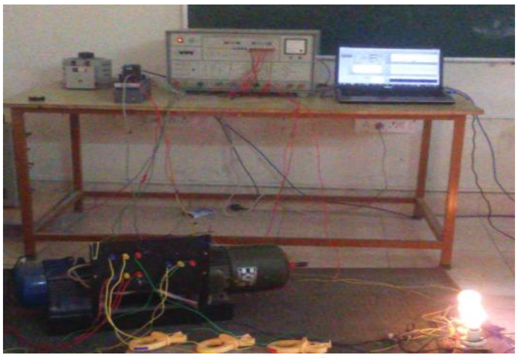

Fig.9 Experimental setup

Fig.10 shows the front panel of LabVIEW VI developed to obtain a constant voltage and frequency operation of DFIG. For a constant analog out voltage squirrel cage induction motor runs with constant speed. Speed of the prime mover is obtained by NI 9403 .Using PLL block grid frequency is sensed using NI 9225 voltage sensing card. Frequency of rotor side converter should be at slip value. So reference sine wave frequency is obtained as the difference between PLL frequency and prime mover frequency. Amplitude of sine wave is used to control the stator output voltage. The prime mover speed is varied by analog output card NI 9264 and there by the rotor converter frequency to obtain the constant frequency and modulation index is varied to get a constant voltage. For various prime mover speeds rotor side converter is used to obtain a constant voltage and constant frequency. Fig.10 shows stator generated output voltage and currents. T.H.D obtained in this setup is less than 1%.

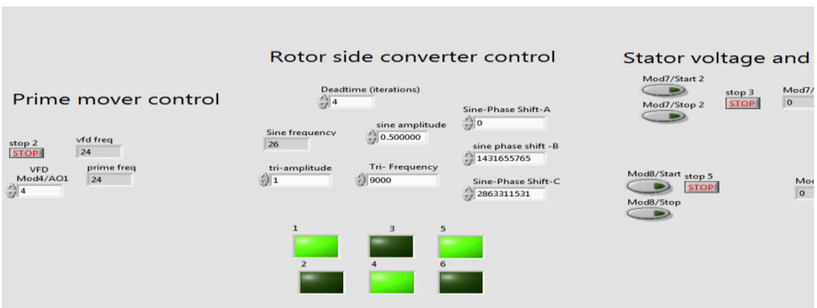

Fig.10 Front panel of LabVIEW FPGA VI for DFIG control

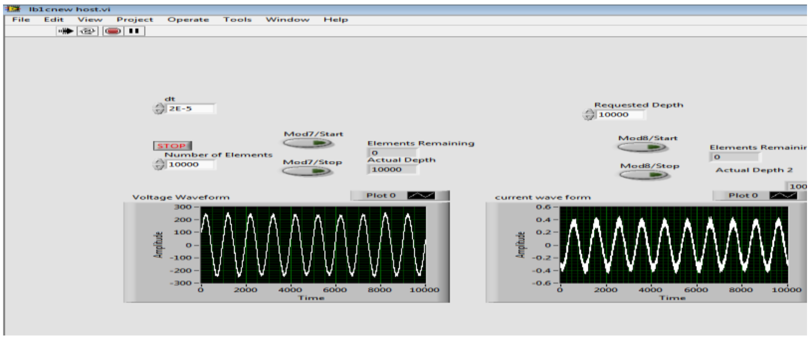

Fig.11 DFIG output voltage and currents

Table.No.1 Show the output voltage and frequency of DFIG for various prime mover speeds. When prime mover speed is varying rotor converter frequency and modulation index ratio are modulated automatically to get a constant voltage and frequency from the stator.

Table No.1 experimental results

S.NO	AO voltage (volts)	Prime mover frequency (Hz),rpm	PLL frequency (Hz)	Inverter frequency (Hz)	DFIG frequency (Hz)	Modulation index	load voltage (vac) (volts)
1.	2	12 (356)	50.1	38	50	0.8	230
2.	3	18 (532)	50.1	32	49.8	0.7	230
3.	4	24 (715)	50.1	26	50	0.54	220
4.	5	30 (894)	50.1	20	49.9	0.45	220
5.	6	36 (1075)	50.1	14	49.8	0.34	227
6.	7	42 (1255)	50	8	49.9	0.22	225

For different prime mover speeds (wind speeds) the constant voltage constant frequency is obtained from the stator circuit. Using Analog output card 2V is applied to VFD and input frequency is set at 12Hz and there by the prime mover runs with 356 rpm speed. The prime mover speed is automatically sensed by NI 9403 card. NI 9225 module output is given to PLL block to sense the grid frequency. The reference signal for SPWM is obtained as the difference between these two frequencies. By varying the modulation index constant voltage constant frequency is achieved for various prime mover speeds. When speed of the prime mover increases the modulation index decreases to achieve the same voltage.

VI. Conclusions

This paper shows that cRIO and LabVIEW FPGA environment is a powerful platform for real time applications. In the developed wind energy conversion system prototype, variable wind speeds are realized by varying the prime mover speed using an analog output card. In order to generate constant voltage and constant frequency from DFIG, rotor side converter is used. Sinusoidal pulse width modulation technique has been implemented using LabVIEW FPGA VI. Based on the speed of the prime mover, rotor side converter controller adjusts the modulation index and frequency to obtain constant voltage and frequency from DFIG. For digital controlled applications LabVIEW FPGA along with cRIO is one of the easiest platform for real time control Power converters.

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