Standalone 2.2 Kw Laboratory Prototype of DFIG Based Wind Turbine Emulator

Nitin Prasad Thakur[1] Rameshwar Singh Dewra[2] Bheru Das Vairagi[3] Shruti Bhadviya[4]
[1]Student [2,3,4,]Assistant Professor
[1,2,3,4]Department of Electrical Engineering
[1,2,3,4]Geetanjali Institute of Technical Studies, Udaipur

Abstract— The paper presents the development of a DC motor based Wind Turbine Emulator (WTE) and its performance verification through simulation. The torque signal that represents the actual wind turbine with environmental effect was made to generate at the DC motor shaft. Particularly, the study incorporates the turbine power control strategy including the effect of stochastic and deterministic load components with the shaft dynamics. The WTE with the Wind Energy Conversion System (WECS) is studied to verify the effectiveness of the WTE in the presence of various wind characteristics. The envisaged wind system is based on a DFIG (Doubly fed Induction generator) directly connected to the wind turbine shaft, while the DC output load is supplied by a rectifier and a chopper. The DC load is considered as a resistive load with wide values range. Experimental investigations are provided in partial load regime. The power optimization is performed through power loop in two ways: by controlling the electrical power or by controlling the electromechanical power.

Key words: Wind Turbine Emulator, Wind Energy Conversion System, DFIG, Pitch Control

I. INTRODUCTION

The wind power generation has become the most promising technology today to generate electricity from the renewable energy sources. The major advantages of using renewable energy sources are abundance and lack of harmful emissions. Wind turbines are arguably the most developed source of renewable electrical energy with ratings of commercial wind turbines now exceeding 10 MW (Polinder et al., 2007). Also, it is the most cost competitive amongst all the environmentally clean and safe renewable energy sources in the world. It is environment friendly in the sense that for every 1 kWh of electricity generated by wind, the emission of CO2 is reduced by 1kg, and operation of a wind turbine weighing 50 tons prevents burning of 500 tons of coal annually.

Because of above mentioned advantages, the total installed capacity of wind power is growing tremendously in the global market. It has been estimated that even if 10% of raw wind potential could be put to use, all the electricity needs of the world would be met. Of course, the main drawback of wind power is that its availability is somewhat statistical in nature and must be supplemented by additional sources to supply the demand curve.

The global cumulative wind power capacity from 1999 to 2020 is shown in Fig. 1.1, where it can be seen that wind power has grown very fast to a capacity of 520 GW in the year 2016, and it is expected to achieve 760 GW in 2020 as per reports of (REN21-Renewables report, 2016; and WWEA report, 2016) in spite of several challenges faced by the wind industry like downward pressure on prices, increased competition among turbine manufacturers, and reductions in policy support driven by economic austerity.

As far as markets and manufacturers are concerned worldwide, U.S. became the largest markets with over 13.1 GW capacity installed in 2012, together with China (13 GW) and the EU (11.9 GW) sharing around 87% of the global market. The Danish company Vestas first gives out the top position among the largest manufacturers since 2000, while GE catches up to the first because of the strong U.S. market since 2012.

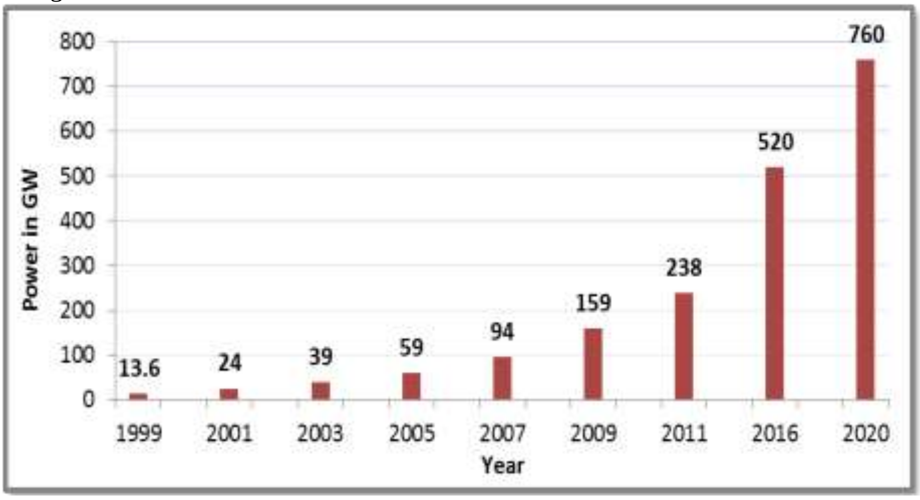


Fig. 1.1: Global cumulative installed wind power capacity from 1999 to 2020.

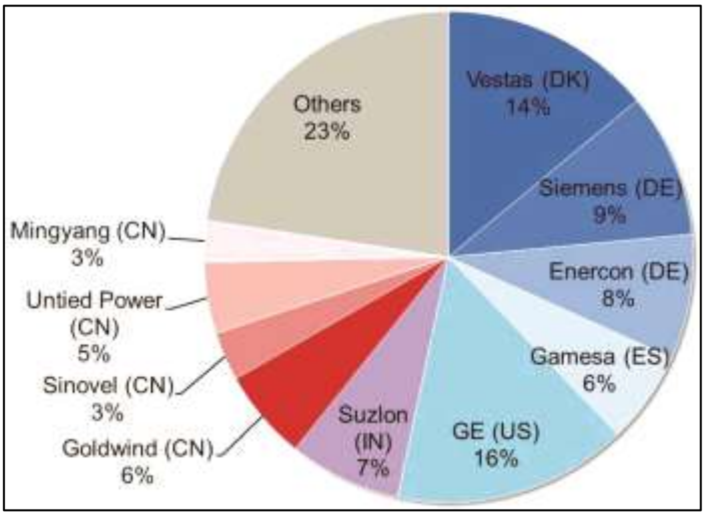


Fig. 1.2: Distribution of wind turbine market share by the manufacturers in 2016 (REN21- Renewable 2016 Global Status Report, 2016).

Fig.1.2 presents the worldwide top manufacturers of wind turbines in the year 2012. It is seen that there are four Chinese companies in the top 10 manufacturers with a total market share of 16.6%, which is a significant drop compared with the 26% in 2016 as per reports of (REN21-Renewables report, 2016).

II. Wind Energy Conversion System Structure

A Wind Turbine Emulator is a piece of hardware that represents the static and dynamic characteristics of an actual wind turbine. This system has a DC motor coupled with the doubly fed induction generator. In this work, a wind turbine emulator which drives the DFIG is developed for laboratory tests. To maximize the energy yield, an optimal "perturbation and observation" type maximum power point tracking (MPPT) scheme is developed in simulation environment and, it is also realised and validated in hardware laboratory prototype through WAVECT control unit and MATLAB/Simulink using XSG (Xilinx System Generator) blockset. As it can be seen in Fig. 2.1, matrix converter is used for interfacing with the load, and SVPWM control is effectively used to achieve low harmonic characteristics. In the following sections, different elements of the proposed system are described.

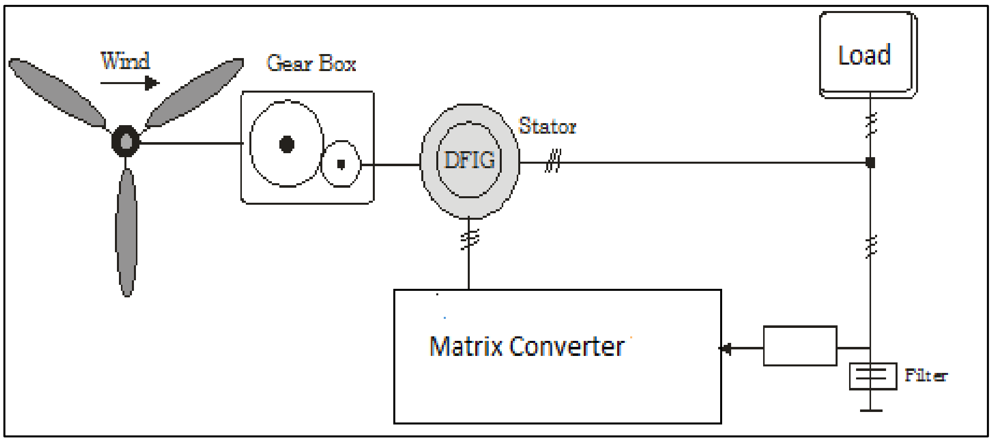


Fig. 2.1: Proposed Wind Energy Conversion System.

A wind turbine emulator which drives the DFIG is developed for laboratory tests. Fig.2.2 presents the structure of the wind emulator. The wind speed changes and load switching conditions are performed using the wind turbine emulator, which consists of chopper dc drive, whose control is implemented through MATLAB/Simulink using XSG (Xilinx System Generator) blockset. It obtains the wind speed values to calculate the torque command of the wind turbine by using the turbine characteristics and speed of dc motor. In this way, it is able to reproduce the steady and dynamic behavior of a real wind turbine to the energy conversion system.

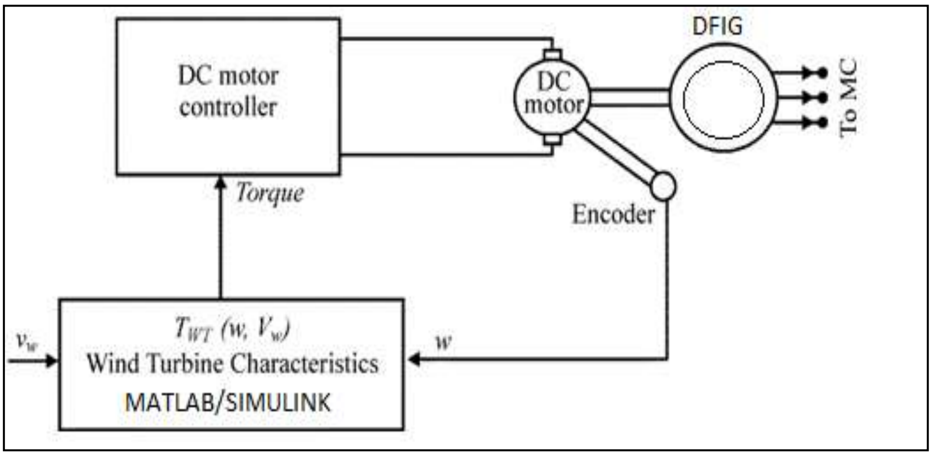


Fig. 2.2: Wind emulator system

In variable speed type grid connected wind energy conversion system has rectifier on generator side which converts the generator voltage or current to a dc link. Thus controls the generator operation and the wind turbine. The dc link decouples the grid frequency and generator frequency. The performance of dc link is influenced by the voltage and current level within it. The grid is supplied via the inverter. Thus the system has speed regulator, power regulator, pitch angle regulator and inverter controller as the main controller during power system operations.

III. BASIC PRINCIPLES OF WIND TURBINE

The power extracted from wind through a turbine is given by the following equation.
The aerodynamic torque (Tm) and power captured (P0) by a wind turbine is given by:

$$T_m = \frac{1}{2}\pi\rho C_p(\lambda)\, R_\omega^3 V_w^2$$

$$P_0 = \frac{1}{2}\rho C_p A_r V_w^3$$

where P0 is the power in watt, ρ the air density in kg/m3, Cp a dimensionless factor called power coefficient, Ar the turbine rotor area in m2 (Ar = πRr2, where Rr is the rotor blade radius), and Vw wind speed in m/s.

$$\text{Tip Speed Ratio } (\lambda) = \frac{\text{Turbine Tip Speed (m/s)}}{\text{Wind Speed (m/s)}}$$

The approximate relationship for power coefficient, Cp for a turbine is given.

$$C_p = \frac{1}{2}(\gamma - 0.022\beta^2 - 5.6)e^{-0.17\gamma}$$

$$\gamma = 2.237\, V_\omega / \omega_\beta$$

where, V_w is the wind speed (m/s), W_B is the blade angular velocity (rad/s), y is the reciprocal of the tip speed ratio and B is the pitch angle (rad).

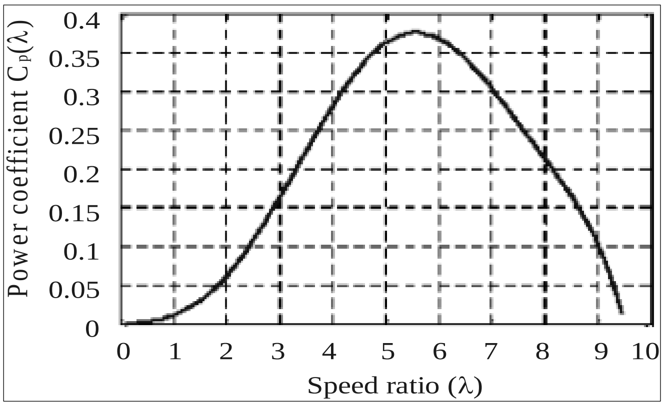


Fig. 3.1: CP −□□□characteristics of wind turbine

When the generated power increases above the rated power of the generator, the extracted power by the wind turbine is controlled to avoid over loading of the generator. This can be achieved by pitch control or stall control. The relation between the generated power and wind speed for pitch controlled and stall controlled wind turbine is shown in Fig 3.2. The four regions of operation in a WECS are denoted.

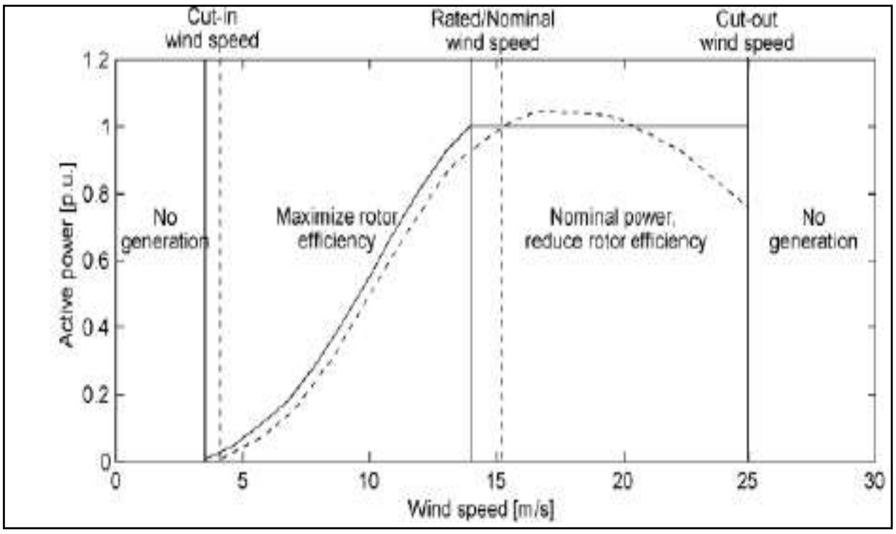


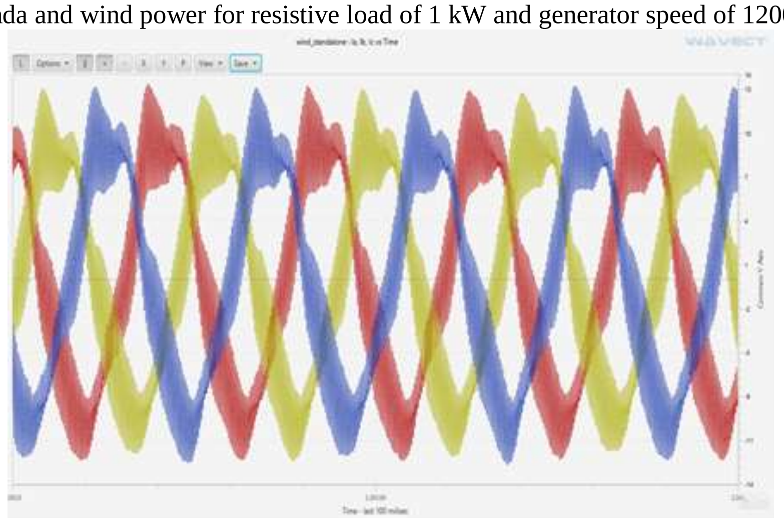
Fig. 3.2: Typical power curves for a stall controlled (dashed) and pitch controlled (solid) wind turbine

IV. RESULT

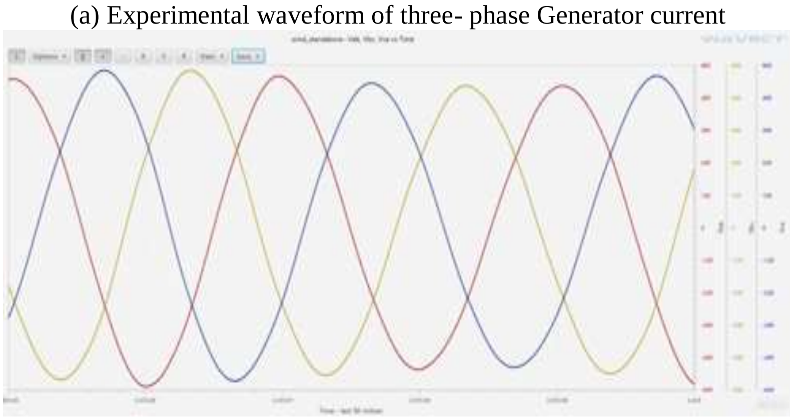
To verify the control methods for developed laboratory 2.2 kW prototype of matrix converter based wind energy conversion system, experimental investigation is carried out under isolated mode for different conditions.

A. Response during Constant Resistive Load

During islanded mode, wind turbine is controlled to deliver power to an external load through unidirectional indirect voltage boosted matrix converter. Prototype has been tested experimentally under different resistive load ranging from no load to 2.5 kW at different generator speeds. Figures 5.1 illustrate various experimental waveforms of three phase load voltage, load current, theta slip and its reference, generator output voltage, generator output current, d-axis and q-axis of stator voltage and current of DFIG, wind lamda and wind power for resistive load of 1 kW and generator speed of 1200 rpm.

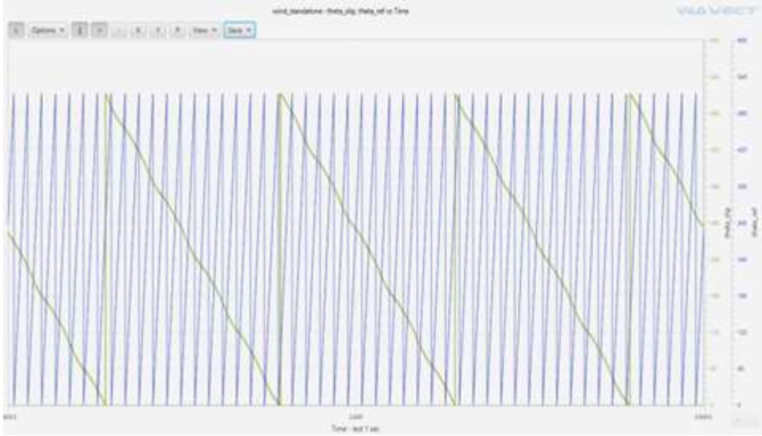


(a) Experimental waveform of three- phase Generator current



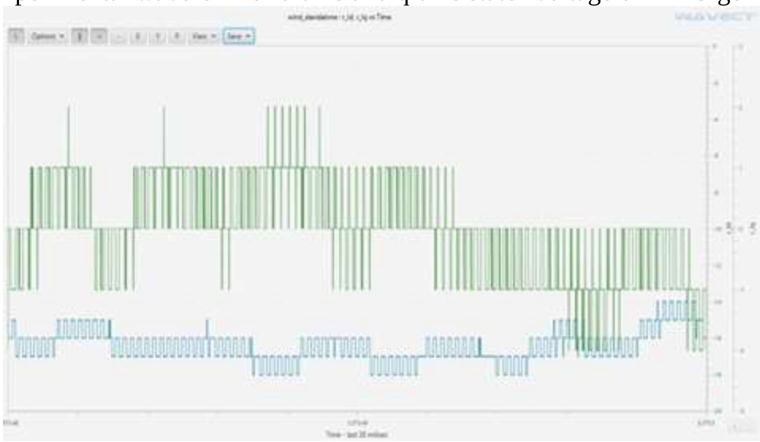
(b) Experimental wave form of three phase output load voltage

(c) Experimental waveform of three phase output load voltage

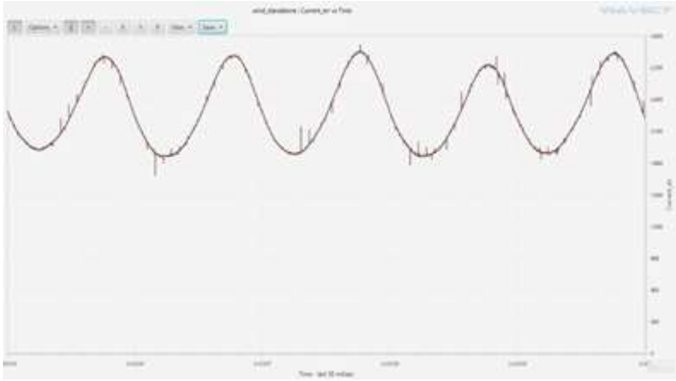


(d) xperimental waveform of theta slip and theta reference

(e) Experimental waveform of d-axis and q-axis stator voltage of DFIG generator



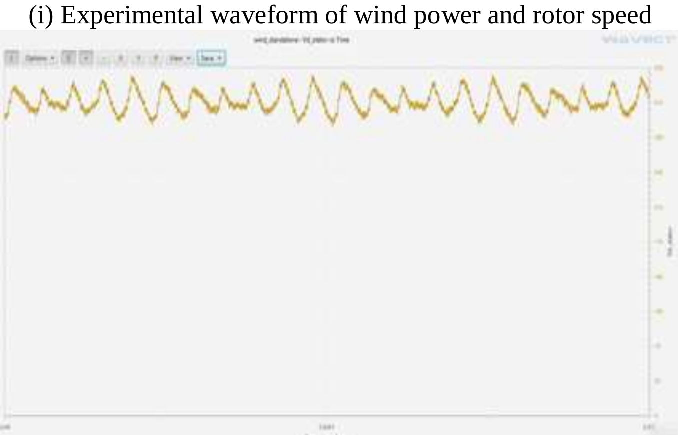
(f) Experimental waveform of d-axis and q-axis stator current of DFIG



(g) Error of dc motor current and ref. dc motor current

(h) Experimental waveform of d-axis stator voltage of DFIG

(i) Experimental waveform of wind power and rotor speed



(j) Experimental waveform of wind power, wind lamda and wind CP

Fig. 5.1: Experimental waveforms during constant resistive load of 1 kW at 1200 rpm and 6m/s wind speed

From experimental results, it is examined that controller works very well and shows excellent performance in terms of balanced and regulated voltages and currents with low-THD of 4.8 % as per IEEE standards.

V. CONCLUSION

a wind turbine emulator which drives the matrix converter interfaced doubly fed induction generator for wind energy conversion system (WECS) is proposed and 2.2 kW hardware laboratory prototype of the same has been developed. Wind Turbine Emulator represents the static and dynamic characteristics of an actual wind turbine. Detailed mathematical models are provided to enable steady-state and transient study of the overall system. Various important points are concluded as:

A good equilibrium among the load currents and voltages can be seen from the experimental results.

The load voltage and current waveforms are properly balanced and well-regulated sinusoidal for resistive load. Also, it can be seen that total harmonic distortion (THD) of load voltage and load current is 2.3% and 2.4 % respectively, which is less than 5% which consent with the permissible limits of IEEE standard 1547, IEEE-519 and IEC 61727 and thus satisfies the general standards of produced power in terms of voltage and current inside 5%. Low THD is due to the use of space vector pulse width modulation (SVPWM) switching for the matrix converter. This improvement in power factor results into reduction of about 13% in the generator conduction losses.

REFERENCES

[1] Kazmierkowski M. P., Krishnan R., Blaabjerg F.: Control in Power Electronics Selected Problems, Academic Press, USA, 2002
[2] Pena R. S., Clare J. C., Asher G. M.: Implementation of vector control strategies for a variable speed doublefed induction machine for wind generation system, Proc. EPE, Sevilla, 1995, pp. 3075-3080
[3] Brune C. S., Spée R., Wallace A. K.: Experimental evaluation of a variable-speed, double-fed wind power generation system, IEEE Transactions on Industry Applications, vol. 30, no. 3, may/june 1994, pp. 648-655
[4] Bhowmik S., Spee R., Johan H. R.: Performance Optimization for Doubly Fed Wind Power Generation Systems, IEEE Transactions on Industry Applications, Vol. 35, No. 4, July/August 1999
[5] Chinchilla M., Arnaltes S., Rodriguez-Amenedo J.L.: Laboratory set-up for Wind Turbine Emulation, 2004 IEEE International Conference on Industrial Technology (ICIT)
[6] Monfared M., Kojabadi H. M., Rastegar H.: Static and dynamic wind turbine simulator using a converter controlled dc motor, Renewable Energy 33 (2008) 906–913 (Available online at www.sciencedirect.com)
[7] Battaiotto P. E., Mantz R. J. and Puleston P.F.: A Wind Turbine Emulator based on a Dual DSP Processor System, Control Eng. Practice, Vol. 4, No. 9, pp. 1261-1266, 1996
[8] Cárdenas R., Peña R.: Sensorless Vector Control of Induction Machines for Variable-Speed Wind Energy Applications, IEEE Transactions on Energy Conversion, Vol. 19, No. 1, March 2004
[9] Kojabadi H. M., Chang L., Boutot T.: Development of a Novel Wind Turbine Simulator for Wind Energy Conversion Systems Using an Inverter-Controlled Induction Motor, IEEE IEEE Transactions on Energy Conversion, Vol. 19, No. 3, September 2004
[10] Munteanu I., Cutululis N. A., Bratcu A. I., Changa E.: Optimization of Variable Speed Wind Power Systems Based on a LQG Approach, Control Engineering Practice 13 (2005) 903–912. (Available online at www.sciencedirect.com)
[11] Polinder, H., Bang, D., Van, R., McDonald, A. S. and Mueller, M.A. 2007. 10 MW Wind Turbine Direct-Drive Generator Design with Pitch or Active Speed Stall Control. IEEE International on Electric Machines & Drives, 2:1390-1395.
[12] Executive Summary Power Sector September 2016" (pdf). report.
[13] Central Electricity Authority, Ministry of Power, Govt. of India. 30 September 2016. Retrieved 18 November 2016.
[14] REN21- Renewables 2016 Global Status Report, 2016
[15] Freries, L.L. 1990. Wind energy conversion systems. Prentice Hall, New York, USA.
[16] Ackermann, L.S.T. 2000. Wind Energy Technology and current status. a review. Renewable and Sustainable Energy Review, 4:315-375.
[17] Bansal, R.C., Zobaa, A.F. and Saket, R.K. 2005. Some Issues Related to Power Generation Using Wind Energy Conversion Systems: An Overview. International Journal of Emerging Electric Power Systems, 3(2):1-19.
[18] Hansen, A.D., Iov, F., Blaabjerg, F. and Hansen, L.H. 2011. Review of contemporary wind turbine concepts and their market penetration. J. Wind Eng., 58(4):1081-1095.