A Review on Permanent Synchronous Generator Based Wind Energy Conversion System Optimization of Power and Voltage

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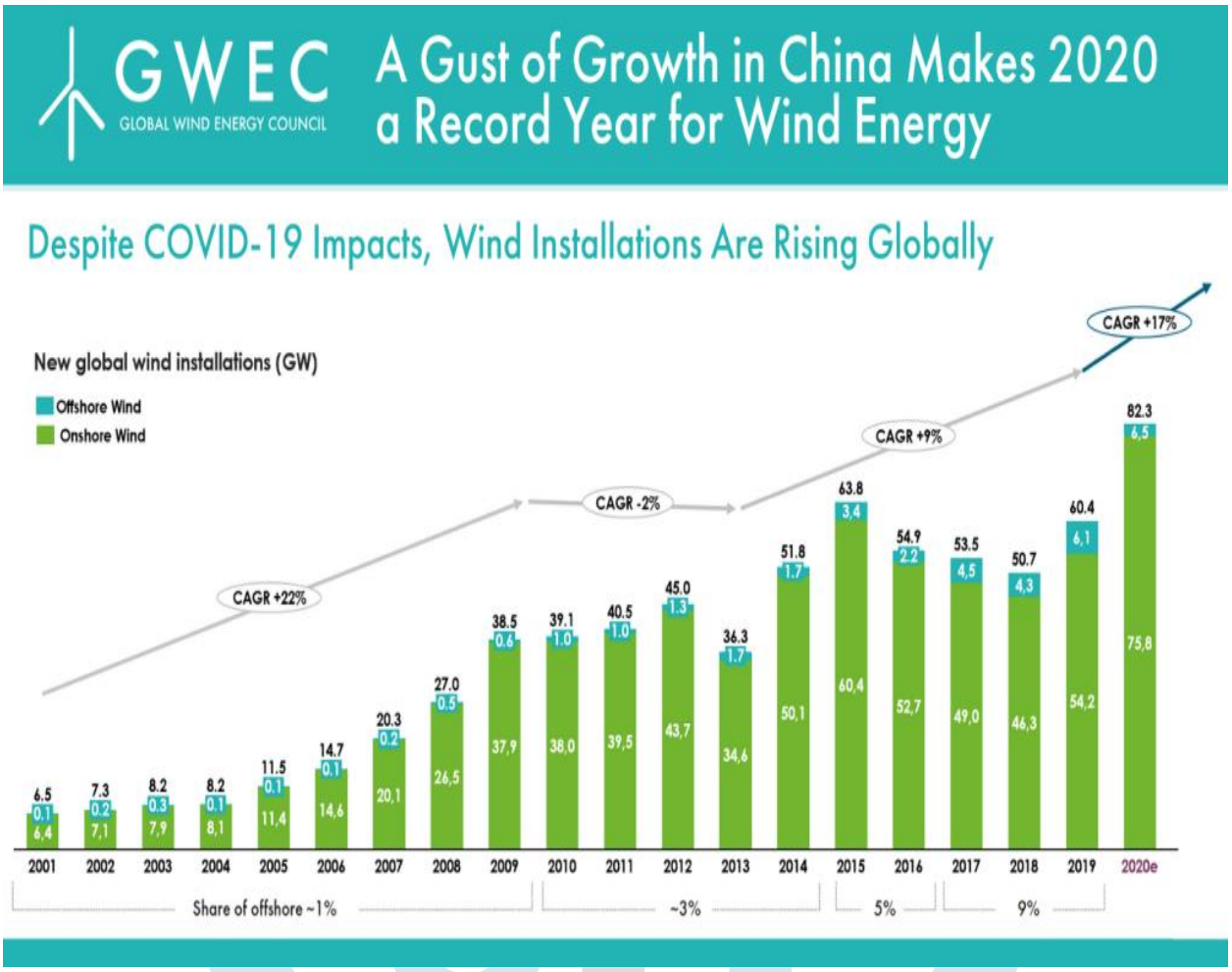
***Abstract*: In view of resolving rising environmental concern arising out of fossil fuel based power generation, more electricity has to be generated from renewable energy sources. Out of the several renewable energy options available today, wind energy is considered to be the most promising one due to its high energy conversion efficiency compared to one of its competitors, i.e. the solar photovoltaic system. Now-a-days, large wind farms are generating thousands of megawatts of power feeding to the grid. In literature, number of controllers such as conventional proportional integral (PI) control, linear parameter varying (LPV) control, gain scheduling control, robust control, model predictive control have been proposed for both torque and pitch control. In these controllers, some of the important issues such as robustness for nonlinear dynamics of wind turbine and stability are not considered simultaneously. Hence, it is necessary to design appropriate controllers for extracting maximum power from the wind turbine whilst the robustness and stability of the Wind Energy Conversion System (WECS) are ensured. Hence, in this thesis, firstly the focus is made to design control system for the wind turbine coupled with the DFIG (torque and pitch control) using one of the very promising robust control paradigm called sliding mode controller for achieving robustness, reducing chattering phenomenon and stability of the WECS. Since the number of terms in control inputs (i.e. torque and pitch angle) and outputs (i.e. DFIG output power and speed) are more in wind control dynamics, selection of significant terms is important for reducing the complexity of controlling. Therefore, a model of the WECS has been developed. Subsequently for the WECS, the power converters connecting the DFIG to the grid have been designed. For controlling stator active and reactive power of DFIG connected to the grid, a state feedback controller for the DFIG has been developed using a linear quadratic optimal theory with preview concept.**

***Keywords*: Wind Energy. Generator, Power etc.**

I. INTRODUCTION

Due to the increasing environmental concern the old ways of power generation by burning fossil fuel has been substituted by much suitable and environment friendly renewable sources. Scientists have predicted that there is only a limited amount of fossil fuels in the earth's crust and it is going to deplete within 30-50 years. So, we need to come up with some other viable and more effective alternative which lead to increased focus on renewable sources. Wind energy is safe, inexhaustible, environment friendly and is capable of supplying growing energy demand. But, due to the erratic nature of wind a smart control strategy have to be designed to capture power equivalent to the theoretical limit. The development of modern WECS (wind energy conversion system) goes back to the year 1970 but it is the recent decade that has shown a rapid growth in this field. It was the late 1990s when the technique evolved enough to put it into mass production. Some of the key player in the global market of wind energy are China (115 MW), USA (66 MW), Germany (39 MW), India (22.5 MW) and Spain (22 MW) as shown in the Figure 1. Also from the chart in Figure 2 it is evident that the wind energy industry has been growing at a rate of 30 percent every year from 2001-2020 with a minor setback in the year 2013. The increased demand of wind energy has raised its current demand to 369,597 MW or 370 GW. And it is expected to grow at a rate of 40 percent in the coming years. The major contribution to the success of WECS is due to the latest development and research going in the field of power electronics and electrical machine which has lowered its cost as well as increased its efficiency. In order to obtain maximum efficiency and for maximum utilization of wind turbine system it is necessary to extract as much power as can be extractable at any wind speed. This is so because of the erratic nature of wind speed and its seasonal availability. Form the Figure 1.3 it is clear that there exist only one optimum power point for any speed. As the turbine do not always operate at optimum wind speed and depends on generator loading hence it keeps on varying due to fluctuation in load and wind speed. This process of power conversion is in-effective as it leads to wastage of wind energy. There comes the concept of maximum power point tracking (MPPT), which is designed to track the optimum point in power versus speed curve at different wind speed. These remote areas do not have other sources and hence people in such places rely completely on renewable energies. Wind energy is a preferred choice where there is abundant supply of wind at most of the season of the year. There are other benefits of wind energy which can be of great use such as it is environment free, it can be a great source of local economy s they can sell excess energy to grid and they earn handsome money out of it, also it gives a nation self-sufficiency and help them stabilize their economy during macro-economic crisis. But due to the erratic and unpredictable nature of wind it is needed to design a control strategy to optimize power production at different wind speeds.



II. LITERATURE RIVIEW

M. Nasiri, J. Milimonfared n, S.H. Fathi

This paper reviewed various LVRT enhancement methods for PMSG based wind turbine, which is an important issue in the wind turbine systems. All methods are classified in two foremost types as external devices and modified controller based methods.

Mojtaba Alizadeh*, Shokrollah Shokri Kojori

PI controller plays a prominent role in control system of each wind energy conversion system. However, it is not a very good choice in dealing with such a nonlinear system. What makes it to not be very suitable in coping with nonlinear systems has deep roots in its non-adaptive fixed structure. The proposition of this workwas to add an offline-trainedWNNto each closed control loop of a PMSG_WECS, in series with PI controller, to reprocess the PI control signal and to virtually change its gains in online operation.

Bhavna Jain n, Shailendra Jain, R.K. Nema

As the wind energy penetration to the grid is increasing drastically, it is very much essential to build up reliable and quality control methods within the system. Controlled converters mostly based on current control techniques are commonly used for reliable operation of WECS when interfaced to the grid.

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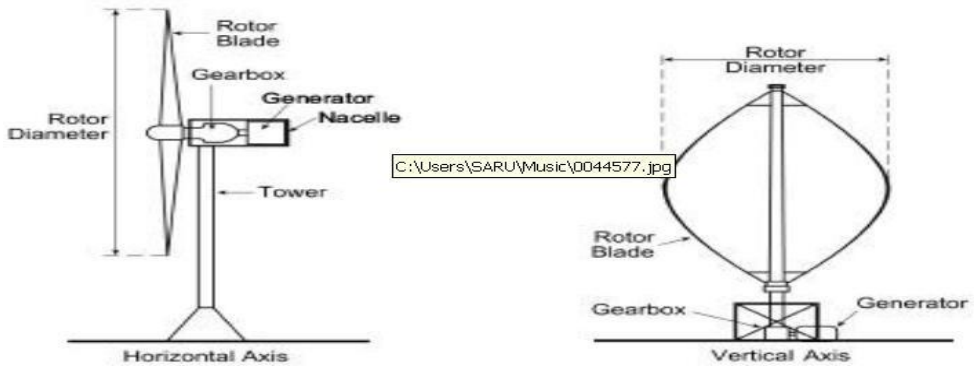
Thus by using the proposed hybrid control strategy, the output power is maximised with an efficiency of 98.1% compared to 97.3% achieved using an individual MPPT control strategy and 96% using an individual control strategy in below rated wind speed; generator power can be optimised and regulated it the rated value of 3 kW in high wind speed regions.

III. Wind Energy Conversion Technique

As the name suggests the horizontal axis wind turbine (HAWT) blades are placed along the horizontal axis. The general construction of a HAWT involves a tower with a flat horizontal base at the top called nacelle. The nacelle mounts the generator and gearbox arrangement. Therefore HAWT are mechanically more complex, the gyroscopic action of turbine blade produces stress when yaw mechanism turns to catch the wind. Overtime this stress can crack the turbine blade and the entire structure will be destroyed. It has higher installation cost as it requires a stronger support and maintenance. But due to its higher conversion efficiency and self-starting action makes it popular in wind power plants. The turbine blades of a HAWT always faces the wind which leads to more lift force, and the higher altitude placement of HAWT gives it the ability of self-starting.

The wind turbine is vertically mounted above the ground as shown in the Figure 4. The generator and the gearbox is located at the base of the structure. The VAWT needs lower cost of installation and vary less maintenance requirement compared to HAWT.

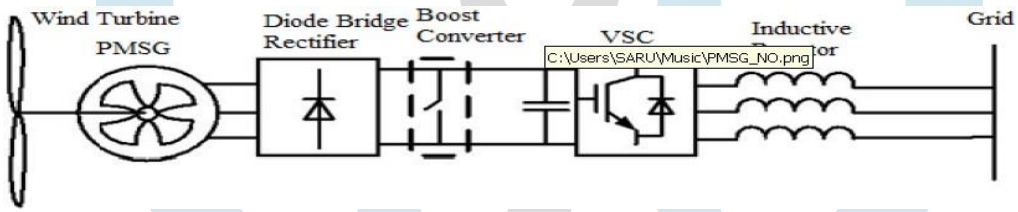


Another advantage of VAWT is that, its operation is independent of the direction of wind speed and it works fine at low wind speed. The major disadvantage is that it has low wind energy conversion coefficient, it has high torque fluctuation, it cannot be used for high wind operation and they are not self-starting. This limits its uses in large-scale production, but it can be used in urban places on the top of houses.

Synchronous Generator

The generator has poles as rotor housed on the prime mover carrying a three phase winding and armature as stator housed inside the body. According to the rotor design synchronous generators are of two type salient rotor and cylindrical rotor. Salient pole synchronous generator are large in size and are used in low speed high torque application. Cylindrical rotor are used for high speed and low torque application. Depending on type of excitation synchronous generators are of two type permanent magnet synchronous generator (PMSG) and Wound field synchronous generator (WFSG). Higher power application require WFSG whereas PMSG is preferred for low power application.

Induction Generator



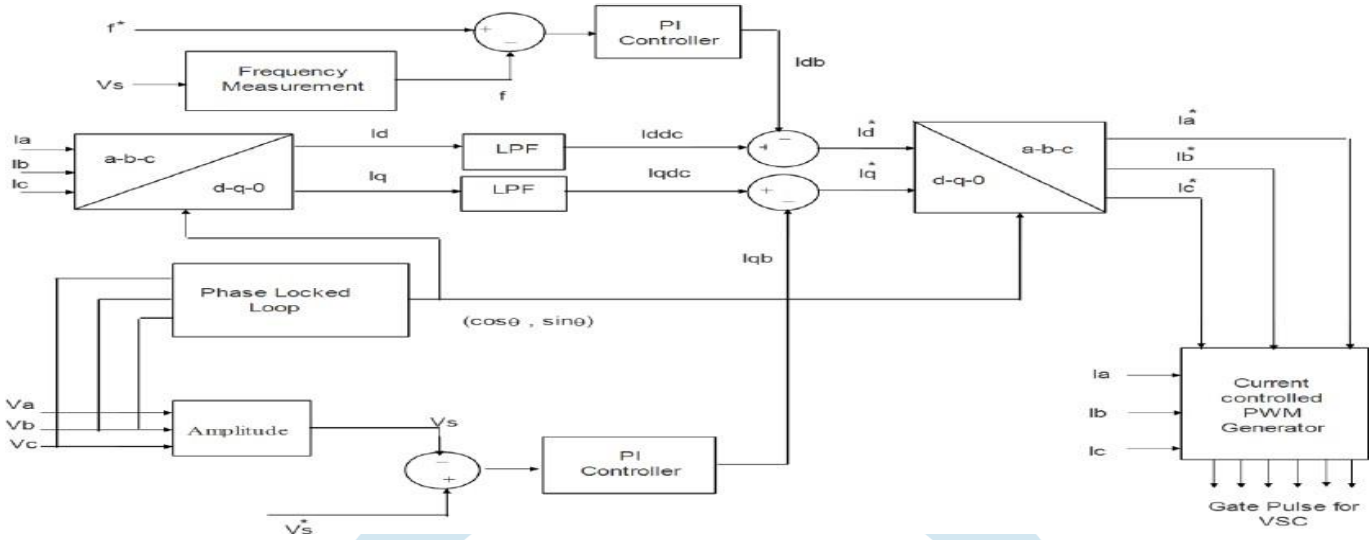
Induction generator or asynchronous generator is also a suitable candidate for variable- speed application. There are two types of induction generator, first one is doubly fed wound rotor induction generator (DFIG) and the second one is squirrel cage induction generator (SCIG). As the name suggests DFIG has two sources of excitation, the stator which is directly linked to AC grid providing required magnetizing current and the rotor is coupled with Acrid through converter-inverter arrangement. The power ratings of the converters are very low compared to the rated capacity equivalent to the slip power. Also, DFIG can automatically regulate power between stator and rotor winding. The major disadvantage of DFIG is that it uses slip rings and the slip ring has to be replaced frequently which needs frequent maintenance.

IV. MPPT ALGORITHM DESIGN

The boost converter does two purposes, it acts as an interface between PMSG power and Grid power, and at the same time it helps in power optimisation. The converter duty cycle is changed according to the MPPT algorithm. The output of the DC-DC boost converter is represented by;

$$V_0 = \frac{V_{in}}{1-d}$$

In the Voltage-Frequency controller the active and reactive part of reference load current is calculated using synchronous reference field theory (SRF) and PI controllers are tuned to nullify steady state error. The load current is transformed from a-d-c frame to d-q-0 frame with the help of Park's transformation.



Working Principle

Whenever a fixed speed squirrel cage induction generator is subjected to variable wind speed, its rotor speed changes with the change in wind speed. As it cannot be compensated by any means (there is no provision for power to flow from rotor side), so this change in rotor speed reflects as a change in frequency of output (i.e. Stator frequency). It can be expressed by the following formula:

$$f\ STATOR = \frac{ROTOR\ SPEED\ X\ NUMBER\ OF\ POLES}{120}$$

It can be seen that, with variation of rotor speed stator frequency varies, which is undesirable. The solution to the problem is the use of variable speed fixed frequency generators. DFIG is a popular form of variable speed generator whose stator frequency is given by the following formula:

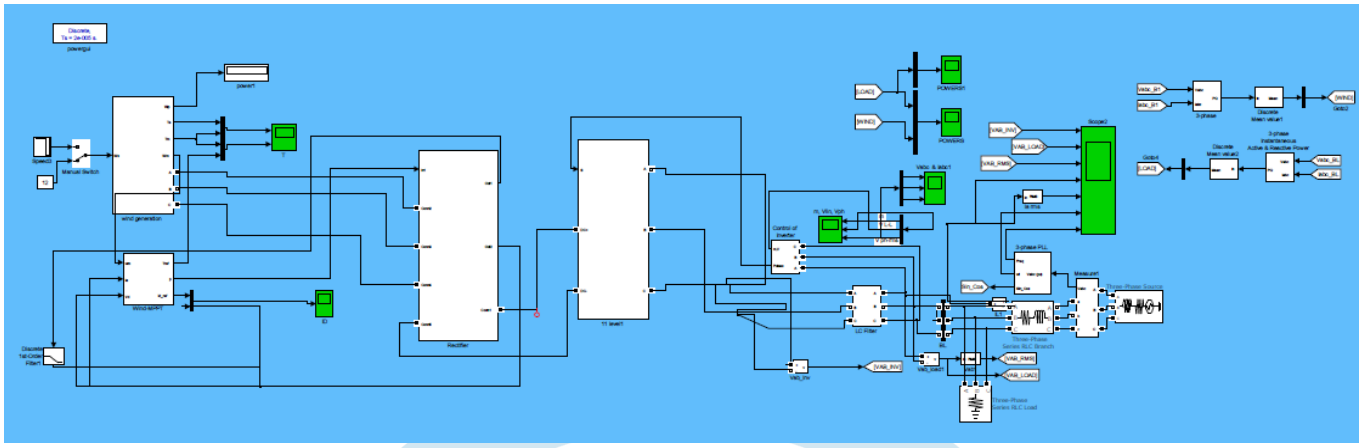
$$f\ STATOR = \frac{ROTOR\ SPEED\ X\ NUMBER\ OF\ POLES}{120} \pm f\ ROTOR$$

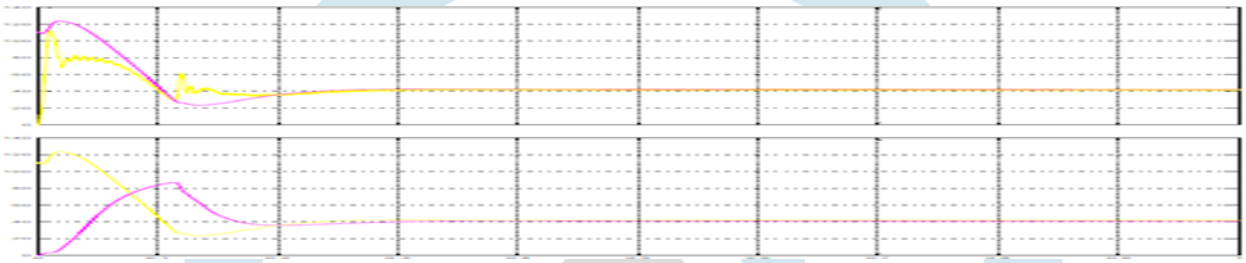
From the above equation it can be seen that, even if the rotor speed varies, by the adjustment of rotor frequency properly we can get a constant stator frequency. This is the principle of DFIG.

When the generator is in super synchronous mode i.e. when it is running above synchronous speed, then to maintain the rotor frequency at constant value, we have to add a negative frequency component (**$-f_{rotor}$**). Here negative components means, power is delivered by the rotor to grid. Similarly when the generator is running at a speed less than the synchronous speed we have to add a positive rotor frequency (**$+f_{rotor}$**), so as to maintain the stator frequency at a constant value. During synchronous speed the rotor frequency will be zero that is a pure dc is fed to rotor. Hence we can say that in synchronous speed, DFIG will act as a synchronous generator.

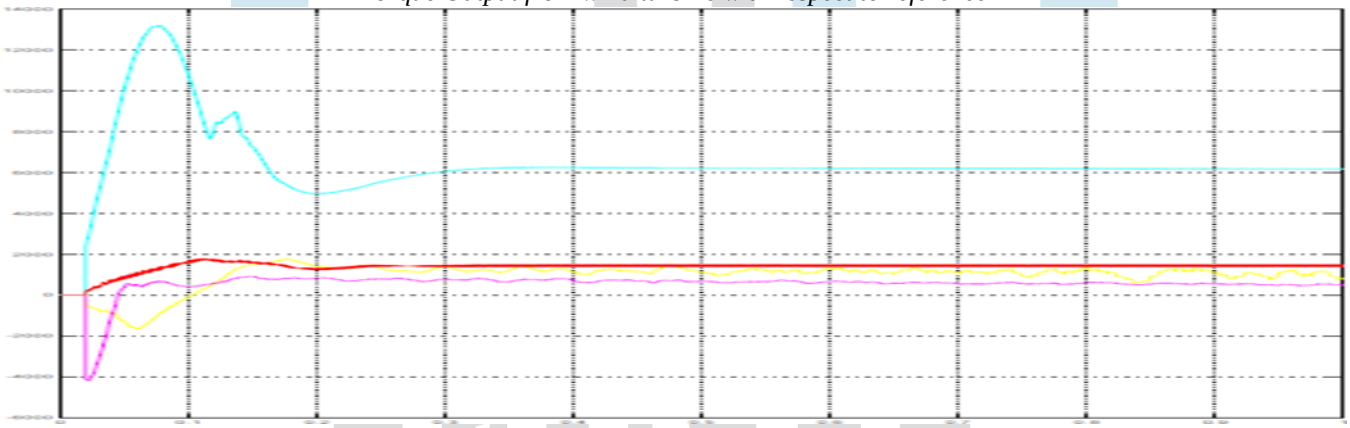
V. RESULT AND DISCUSSION

The dynamics of WECS has been simulated in MATLAB/SIMULINK and implemented in FPGA. The developed sliding mode controller is applied for a wind turbine with a 2.5 kW DFIG. Speed and power regulation of DFIG are regulated by SM controller in torque and pitch control of wind turbine and has been simulated in MATLAB/SIMULINK and implemented in FPGA. Sliding mode controllers for both torque and pitch control are implemented for a 2.5kW DFIG coupled with wind turbine. The rated wind speed is considered as of 12m/s, while the mean wind speed increases from 11m/s to 14m/s and then it is kept over the rated value with the wind turbulence and in the simulation the turbulence intensity is 8 percent. The pitch rate is assumed to be limited as 8deg/s. The simulation results are presented into two regions. The region $\omega g \leq \omega^* g$, the torque controller tries to maximize the generating power, while in the region $\omega g \geq \omega^* g$, the torque control and pitch control operate in harmony to regulate the DFIG inlet power. Various parameters are plotted i.e. wind speed, torque, pitch angle, DFIG generated power, three phase voltage, three phase current at DFIG stator terminals, rotor speed of DFIG and frequency at stator terminals of DFIG.

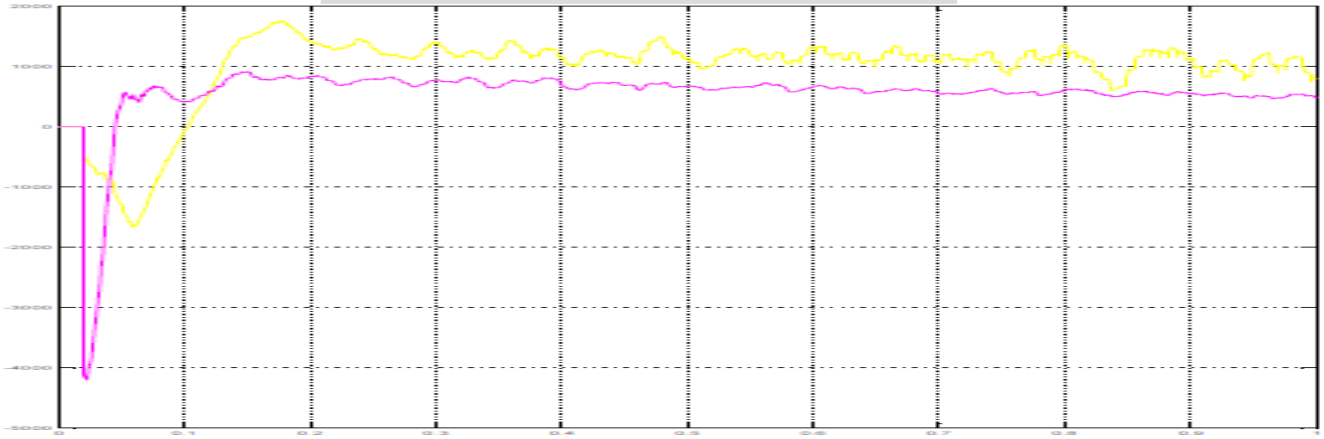




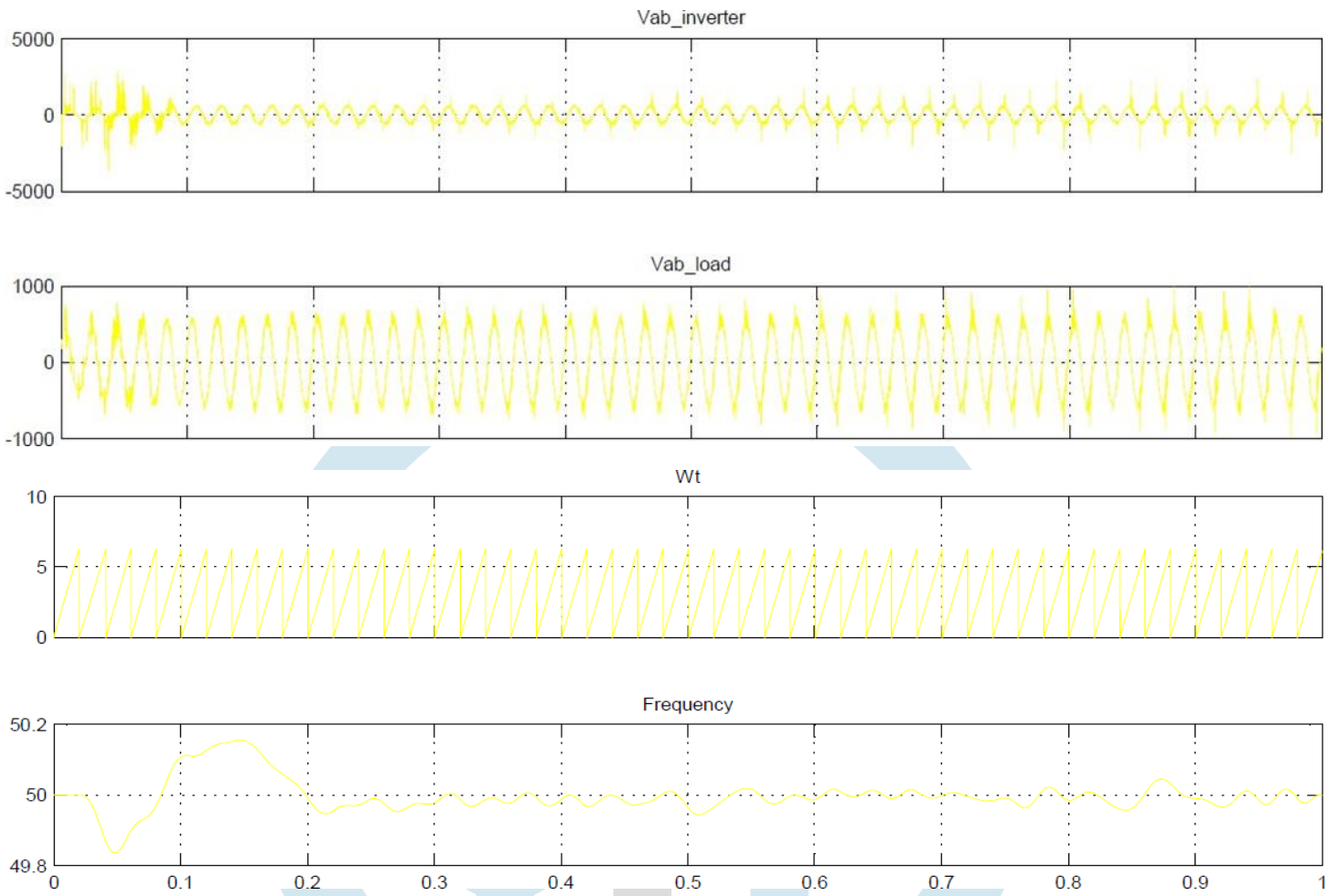
Torque Output from wind turbine with respect to reference



Wind Power Output



LOAD power output



From results, it has been observed that, stator active and reactive power are controlled by rotor q-axis current and d-axis current respectively for a given stator voltage using stator voltage oriented control. Faster current control dynamics for DFIG are achieved by adjusting the weighing factors in performance index. Feedforward compensation has also been done for eliminating the cross coupling induced emf and emf induced due to stator flux of DFIG. It is observed that steady state stability and zero steady state error are achieved in face of transient disturbances. Simulation Results obtained show the effectiveness of the proposed WECS system has been verified and it is observed that harmonic content is very low according to grid codes.

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

Controllers such as field oriented control, direct torque control, direct power control, rotor current control, model predictive control; linear parameter varying control has been studied. Different MPPT techniques for wind turbine have also been studied. In order to capture the nonlinear and time varying dynamics of variable speed variable pitch DFIG based WECS, is used to develop an adaptive controller for speed and power regulation of DFIG connected to wind turbine. A new performance index is formulated with weighting factors for control input. From the obtained results, it is seen that the actual rotor currents approach the desired reference currents with zero steady state error. Faster current control dynamics for DFIG are achieved by adjusting the weighing factors in the aforesaid performance index. Simulation results show the effectiveness of the proposed technique by comparing its performance with that of sliding mode field oriented control and sliding mode direct power controllers.

Future Work

In the thesis, stator side unbalanced voltage conditions are considered for controlling active and reactive power. But the performance of the DFIG based WECS under unbalanced voltage conditions on grid side should be considered. For investigating this problem, impedance matching on grid side should also be taken into consideration. Low voltage ride through problem has to be investigated, since current increases drastically for low voltage dips on grid side. There are two main problems that must be overcome in achieving the ride through requirements of DFIG during the voltage dip. The first one is the peak rotor fault current that may exceed the rotor-side converter limit, and the second one is the dc-link overvoltage. The ride through control is triggered if the rotor current limit is 2 pu (per unit) and the dc-link voltage limit is 1.2 times its nominal value.

REFERENCES

[1] Global Wind Energy Council, "Global statistics", 2014. http://www.gwec.net/global- figures/graphs.html].
[2] Mauricio B. C. Salles and Et al., "Dynamic modelling of transverse flux permanent magnet generator for wind turbines," Journal of Microwaves, Optoelectronics and Electromagnetic Applications, 2010.
[3] A.Yogianto, H. Budiono and A.I. Aditya, "Configuration hybrid solar system (PV), wind turbine, and diesel," IEEE Trans. Power Engineering and Renewable Energy, 2012, pp. 1-5, 2012.
[4] Jiang Zhenhua, "Power management of hybrid photovoltaic- fuel cell power systems," IEEE Trans. Power Engineering and Renewable Energy, pp.1-4, 2006.
[5] Manoj Kumar, M.K. Mishra, "Power management with power quality enhanced operation in off-grid hybrid power systems," IEEE Trans. Power Engineering and Renewable Energy, pp. 342-347, 2014.
[6] M.M. Freeman, M.R. Perschbacher, "Hybrid power an enabling technology for future combat systems," IEEE Trans. Pulsed Power Conference, pp. 17-22, 1999.
[7] S.T. Boroujeni, S.H. Fathi, J.S. Moghani, "Hybrid PV/wind power system control for maximum power extraction and output voltage regulation," IEEE Trans. Control, Instrumentation, and Automation, pp.59-64, 2013.
[8] F. Morea, G. Viciguerra, D. Cucchi, C.Valerncia, "Life cycle cost evaluation of off- grid PV-wind hybrid power systems," IEEE Trans. Telecommunication Energy, pp. 439-441, 2007.
[9] S.S. Murthy, B. Singh, P.K. Goel, and S.K.Tiwari, "A comparative study of fixed sped and variable speed wind energy conversion systems feeding the grid," Power Electronics and Drive Systems, pp. 736-743, 2007.
[10] M. Neufeld, O. Ramirez, and A. Ustinovich, "Comparative study of fixed sped vs. variable speed control of a series configuration pipeline pumping application," Petroleum and Chemical Industry Technical Conference, pp. 491-500, 2014.
[11] N. Rosmin, S. Samsuri, Y.M. Hassan and A.H. Rahman, "Power optimization for a small-sized stall- regulated variable-speed wind turbine," Power Engineering and Optimization Conference Melaka, Malaysia, pp. 373-378, June 2012.
[12] Xinyi Liu, Jianxing Liu, S. Langhrouche and M. Cirinione, "MPPT control of variable speed wind generators with squirrel cage induction machines," IEEE Transaction on Friendly Energies and Application, pp. 1-6, Nov. 2014.
[13] L.F.M. Gevaert, De Kooning, J.D.M, T.L. Vandoom, and J. Van de Vyver, "Evaluation of the MPPT performance in small wind turbines by estimating the tip speed ratio," IEEE Transaction on Power Engineering Conference, pp. 1-5, Sept. 2013.
[14] M.A. Abdullah.; A.H.M. Yatim, Chee Wei Tan; "A study of maximum power point tracking algorithms for wind energy system," Clean Energy and Technology (CET), 2011 IEEE First Conference, pp.321-326, 27-29 June 2011.
[15] J. Hui and A. Bakhshai, "A new adaptive control algorithm for maximum power point tracking for wind energy conversion systems," IEEE Conference on Power Electronics Specialists, pp. 4003 - 4007, June 2008.
[16] R. Sharma, P. Samuel, S.K. Bagh, S. Banerjee, "A grid interconnected WECS with modified MPPT," Power Control and Embedded Systems, pp. 1-6, Dec. 2012.
[17] J.S Thongam,.; P. Bouchard; R. Beguenane; A.F. Okou; A. Merabet; "Control of variable speed wind energy conversion system using a wind speed sensorless optimum speed MPPT control method," IEEE Conference on Industrial Electronics Society, pp. 855 – 860, 2011.
[18] C.N. Bhende,; S. Mishra; S.G. Malla, "Permanent magnet synchronous generator- based standalone wind energy supply system," IEEE Trans. on Sustainable Energy, vol. 2, no. 4, 2011, pp. 361 -373.
[19] E. Koutroulis and K. Kalaitzakis, "Design of a maximum power tracking system for wind-energy-conversion applications", IEEE Trans. Ind. Electron., vol. 53, no. 2, pp.486 -494, Apr. 2006.
[20] S. M. Raza Kazmi, H. Goto, Hai-Jiao Guo and O. Ichinokura, "A novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 29-36, Jan. 2011.
[21] J. Hui and P.K. Jain, "Power management and control of a wind energy conversion system (WECS) with a fuzzy logic based maximum power point tracking (MPPT)," IEEE Journal, pp. 5966-5971, Oct. 2012.
[22] Q. Wang and L.C. Chang, "An intelligent maximum power extraction algorithm for inverter-based variable speed wind turbine systems," IEEE Trans. on Power Electronics, vol. 19, Sept. 2004, pp. 1242-1249.
[23] Q. Zeng, L. Chang and R. Shao, "Fuzzy-logic-based maximum power point tracking strategy for Pmsg variable-speed wind turbine generation systems," Canadian Conference on Electrical and Computer Engineering, pp. 000405-000410, May 2008.
[24] R. Dev Shukla and K.R. Tripathi "Speed-sensorless voltage and frequency control in autonomous DFIG based wind energy systems," IEEE Transaction on Power Engineering, pp. 1-6, Oct. 2014.
[25] G. Vijayalakshmi, and M. Arutchelvi, "Design and development of controller for PMSG based wind energy conversion system," IEEE Transaction on Circuit, Power and Computing Technologies, pp. 573-578, Mar. 2014.
[26] B. Singh, and S. Sharma, "SRF theory for voltage and frequency control of IAG based wind power generation," IEEE Trans. on Power systems, pp. 1-6, Dec. 2009.
[27] O. Ojo, O. Omozusi, A. Ginart and B. Gonoh, "The Operation of stand-alone single- phase induction generator using a single-phase pulse-width modulated inverter with a battery supply," IEEE Trans. on Energy Conversions, vol.14, no.3, pp. 526-531, Sept.1999.
[28] B. Singh and G.K. Kasal, "Voltage and frequency controller for a three phase four- wire autonomous wind energy conversion System," IEEE Trans. on Energy Conversion, vol. 23, no.2, pp. 509- 518, June 2008.
[29] S. Bhattacharya, B. Banerjee and D.M. Divan, "Synchronous frame based controller implementation for a hybrid series active filter system," Industry Applications Conference, 1995, vol. 3, pp. 2531-2540, Oct. 1995.
[30] K. Premalatha, V.V. Daliya, and S. Vasantharathna, "Voltage and frequency control of independent wind power

generating system," Control Automation, Communication and Energy Conservation, pp. 1-5, June 2009.
[31] B. Singh, and V. Rajagopal, "Digital control of voltage and frequency of induction generator in isolated small hydro system," Power Electronics, Drives and Energy Systems, pp. 1-7, Dec. 2012.
[32] T. Ahmed, E. Hiraki, O. Noro, and M. Nakaoka, "Terminal voltage regulation characteristics by static var compensator for a three-phase self-excited induction generator," IEEE Trans. Industry Applications, vol. 40, no. 4, pp. 978-988, July- August 2004.
[33] G. K. Kasal and B. Singh, "Decoupled voltage and frequency controller for isolated asynchronous generators feeding three-phase four-wire loads, " IEEE Trans. Power Delivery, vol. 23, no. 2, pp. 966-973, Apr. 2008.
[34] B. Singh, G. K. Kasal, and S. Gairola, "Power Quality Improvement in Conventional Electronic Load Controller for an Isolated Power Generation, " IEEE Trans. Energy Conversion, vol. 23 no. 3, pp. 764-773, Sep 2008.
[35] F.A.O. Aashoor, and F.V.P. Robinson, "A variable step size perturb and observe algorithm for photovoltaic maximum power point tracking," University Power Engineering Conference, pp. 1-6, Sept. 2012.
[36] T. Esram, and P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Transactions on Energy Conversion, 22(2): pp. 439-449, 2007.
[37] N. Femia, and Et al., "Predictive & Adaptive MPPT Perturb and Observe Method," IEEE Transactions on Aerospace and Electronic Systems, 2007. 43(3): p. 934-950.
[38] D. Sera, R. Teodorescu, J. Hantschel, and M. Knoll, "Optimized Maximum Power Point Tracker for fast changing environment conditions," IEEE International Symposium on Industrial Electronics, 2008, pp. 2401-2407, June-July 2008.
[39] The Scottish Government Riaghaltas na h-Alba, "Planning for micro renewables annex to PAN 45 renewable energy technologies", 2006..
[40] www.elsevier.com/find/fuel