



A Study of Reducing Harmonic Instability and Reasonable Problems in PMSG based Wind Farms

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ABSTRACT

Unlike conventional power systems where harmonic resonances are coming from passive inductive and capacitive elements, large-scale power electronic systems like wind farms present a more complex system, where the fast dynamics of the power electronic converters may present an inductive or capacitive behavior. Therefore, the interactions between the fast controllers of the power converters and the passive elements may lead to harmonic instability and new resonances at various frequencies. This paper presents an optimum design technique for the Wind Turbine (WT) inner controllers in a PMSG based wind farm in order to reduce the number of resonances and to mitigate harmonic instability. In the approach, a PMSG based wind farm is modeled as a Multi-Input Multi-Output (MIMO) dynamic system by modeling the high bandwidth control loops of the power converters. Resonance frequencies and oscillatory modes of the wind farm are identified based on the MIMO matrix. Afterwards, a multi-objective optimization procedure based on Genetic Algorithm (GA) is proposed to put the oscillatory modes of the wind farm in suitable locations in order to minimize the number of the resonances and to guarantee a stable operation of the wind farm. A 400-MW wind farm is studied in the PSCAD/EMTDC software environment to confirm the validity of the proposed optimum design technique.

1. INTRODUCTION

Today's most promptly growing renewable energy source is wind energy. A wind turbine operates at a fixed or variable speed [1]. Developing new

megawatt scale wind turbines based on variable-speed operation with pitch control using either a permanent magnet synchronous generator (PMSG) or a doubly fed induction generator is preferred by most of the manufacturers (DFIG) [2]. Though the variable speed wind turbine with a multi-pole PMSG and full-scale/fully controllable voltage source converters (VSCs) is considered to be more efficient, it is not popular wind turbine concept [3]. The advantages of such a PMSG configuration are 1) gearless construction [4]; 2) elimination of excitation system [5]; 3) maximum wind power extraction and grid interface; and 4) ease in accomplishing fault – ride through and grid support [6]. Therefore, the efficiency and reliability of a VSC-based PMSG wind turbine is assessed to be higher than that of a DFIG wind turbine [7]. Due to the intensified grid codes, a PMSG wind turbine with full VSC-based insulated gate bipolar transistor (IGBT) converters are becoming more and more enhanced by the wind power industry [3]–[7]. At the present time, however, commercial PMSG technology mainly uses a passive rectifier followed by an IGBT inverter [8]–[9]. The highly efficient vector – controlled technology for a PMSG wind turbine that uses a full voltage – source IGBT converter configuration is still under investigation and not widely adopted by the wind power industry. The direct-current vector control technology is a vector control technology that has been developed recently to control the synchronous generator only in a variable – speed PMSG wind turbine and for control of a VSC – based HVDC system. Compared to the conventional vector control strategies, direct – current vector

control has illustrated many advantages in those applications, such as enhanced system stability, reliability, and efficiency. But it is not clear whether the direct-current vector control can be employed in a PMSG wind turbine for control of both PMSG machine – and grid- side converters (GSCs), and how the PMSG system will be have in the integrated environment for multiple PMSG control purposes. This paper presents mechanisms for optimal control of a PMSG wind turbine system under a direct-current *dq* vector control configuration. Based on the proposed control structure, the overall control functions of a PMSG system are developed, including maximum power extraction control, dclink voltage control, reactive power control, and grid voltage support control.

II. Model of PMSG and Concept of Direct Power Control

In the study, the shaft of a significantly larger turbine is coupled with PM generator. The speed of the PM generator will not be affected by the load power. In other words, the output frequency won't change during operation, despite heavy load or light load is connect. This simplifies the control system design. The dynamic d-q model is used for the PMG to eliminate the time-varying inductances. With the Park transformation the variables in a-b-c coordinates are transformed to d-q coordinates, as shown in the following equation.

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin \omega t & \sin(\omega t - \frac{2}{3}\pi) & \sin(\omega t + \frac{2}{3}\pi) \\ \cos \omega t & \cos(\omega t - \frac{2}{3}\pi) & \cos(\omega t + \frac{2}{3}\pi) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

The basic concept of direct control of active and reactive powers can be understood from the phasor diagrams based on the equivalent circuit of the permanent magnet synchronous generator as shown in Fig. 1. From the phasor diagram in Fig. 2 it is noted that the Component i_d of the stator current has to be controlled in order to control the stator active power P and i_q has to be controlled to control the stator reactive power Q . This is achieved in turn by controlling the rotor currents i_d and i_q , respectively, in conventional field oriented control strategy. Wound rotor in a synchronous generator and the stator in a PMG have similar structure. In addition there is no difference between the back EMF produced by a

permanent magnet and that produced by an excited coil. The mathematical model of a PMG can be derived from the model of a synchronous generator. The only difference is the equations of the damper windings and the field current dynamics can be removed. Finally, the equivalent circuits of d-axis and q-axis of a permanent magnet synchronous generator are illustrated in Figure 1.

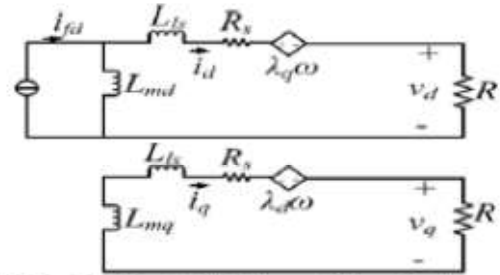


Fig. 1 Equivalent Circuit of The Permanent Magnet Synchronous Generator in d-q Axis

III. Maximum Power Point Tracking

This is the base of the well-known Maximum Power Point Tracking (MPPT) from the prior treatment of the wind turbine model it can be appreciated that in order to extract the maximum amount of power from the incident wind, C_t should be maintained at a maximum. In order to achieve this objective, it can be appreciated from Fig. 6 that the speed of the generator rotor must be optimized according to instantaneous wind speed. In wind generator applications capturing the maximum available wind power is essential. Regarding that, it has been shown that variable-speed (VS) configurations generate more total annual energy at any wind speed than constant speed configurations becoming more and more attractive in low power applications. VS configurations the WG's rotating speed is changed guiding the aerodynamic system to operate at the maximum power point (MPP) for every wind speed. The latter is usually achieved through the generator's load variation by means of power converters. The amount of power output from a wind energy conversion system (WECS) depends upon the accuracy with which the peak power points are tracked by the maximum power point tracking (MPPT) controller of the WECS control system irrespective of the type of generator used. This study provides a review of past and present MPPT controllers used for extracting maximum power from the WECS using PMSG.

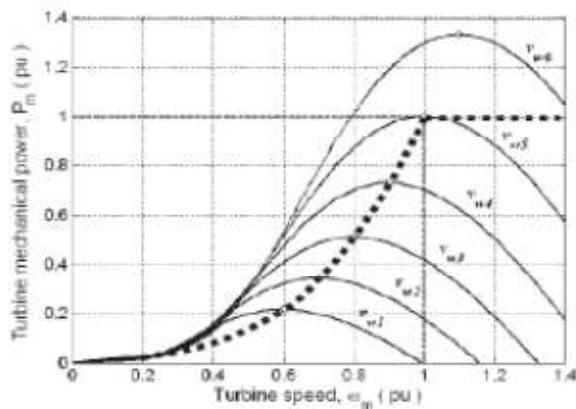


Fig 2: Wind Turbine Characteristic of the Variable Speed PMSG.

The above shows turbine mechanical power as a function of rotor speed at various wind speeds. The power for a certain wind speed is maximum at a certain value of rotor speed called optimum rotor speed. This is the speed which corresponds to optimum tip speed ratio. In order to have maximum possible power, the turbine should always operate at optimum tip speed ratio. This is possible by controlling the rotational speed of the turbine so that it always rotates at the optimum speed of rotation.

IV. MPPT Control Methods for PMSG Based WECS

Permanent Magnet Synchronous Generator is preferred more and more in developing new designs because of higher efficiency, high power density, availability of high-energy Permanent magnet material at reasonable price, and possibility of smaller turbine diameter in direct drive applications. Presently, a lot of research efforts are directed towards designing of WECS which is reliable, having low wear and tear, compact, efficient, having low noise and maintenance cost; such a WECS is realisable in the form of a direct drive PMSG wind energy conversion system. The power electronics converter configurations most commonly used for PMSG WECS are shown in Fig. 7.

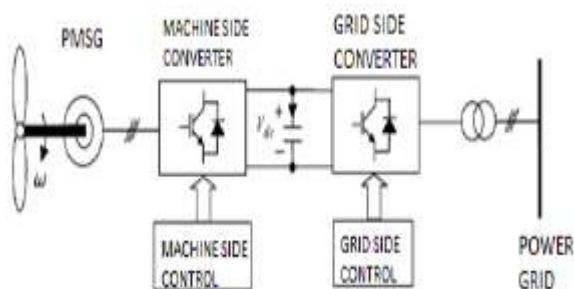


Fig.7. PMSG wind energy conversion systems

Depending upon the power electronics converter configuration used with a particular PMSG WECS a suitable MPPT controller is developed for its control.

V. Software Implementation

In this circuit, the adaptive MPPT controller and DPC technique is used to minimize the THD. The circuit operation is explained in the following points.

Uniform random number block is used as wind source to provide the input to the adaptive MPPT controller and PMSG. It is used to provide both steady and variable speed to the wind turbine (ie., it will change for every 0.05 seconds). The MPPT controller gets the wind source output and turbine speed as its input and is provided to the wind turbine characteristics. Thus it will get the optimum point such that the maximum power curve output will be greater than the recorded demanded output power and also provides the torque output to the PMSG. Torque is a force that causes something to spin around a central point, thus the rotor rotates. PMSG is designed such that it will provide five different outputs. They are rotor speed, electromagnetic torque, stator current, direct and quadrature axis currents. VI measurement block in MSC measures the stator torque and current and it is given to the PWM rectifier which converts AC to DC. DC link provides real and reactive power to both PWM rectifier and grid side inverter. It acts as common link and also as storage device. Thus the distortions produced in MSC are measured by FFT analysis method; it will be in an order of 24 to 11.29%. So it must be reduced in GSC. MSC gets stator voltage, rotor speed and turbine speed as three inputs and by using the DPC technique PI controller and PLL is used. PI controller is used to increase the speed of the response and to eliminate the steady state error. PLL is used to synchronize on a set of variable frequency. Thus the produced dq0 axis currents are transferred into abc transformation to produce PWM by using dq0 to abc transformation and PWM generator blocks. The DC current is converted into AC by grid side inverter block. The coupled inductor is used to limit the flow of AC current to the grid. Here also produced stator voltage and current by the grid side inverter is measured by VI measurement block. The GSC gets six input signals to control the total harmonic distortion finally. The inputs are PWM rectifier outputs, measured stator voltage and current, then finally output of coupled inductor. It works similar to MSC with PI controller and PLL and generates PWM output and provides the generated

output to grid side inverter to convert as AC. Thus one of the problems in the production of electricity is distortions which is analyzed and reduced by MATLAB simulink method. The THD is reduced up to 1.42% which can be shown by using discrete power gui (FFT analysis).

Table 1.Parameter of the PMSG Wind Turbine

Parameter	Value	Units
Generated rated power	2500	KVA
f(frequency)	50	Hz
Generated rated voltage	400	V
Stator resistance	0.2	p.u.
Stator leakage inductance	0.02	p.u.
Permanent magnet flux	0.175	p.u.
dc-link capacitor	6.6	μf
Grid-filter resistance	1	Ω
Grid-filter inductance	0.05	H

VI. Results and Discussion

To evaluate the maximum power extraction, DC link voltage control, grid voltage support control of a PMSG wind turbine the optimal control strategy has introduced, an integrated simulation of a complete PMSG system including MSC and GSC is developed using DPC and detailed models in MATLAB simulink in which both steady and variable wind conditions are considered. In this chapter, obtained results are shown and discussed.

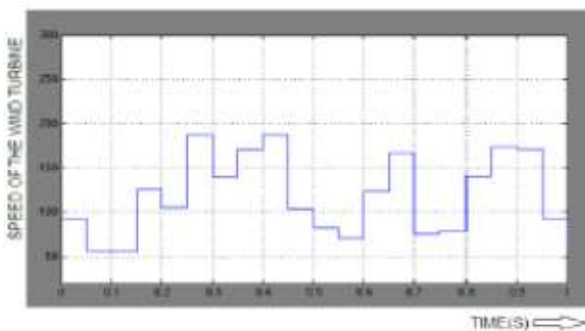
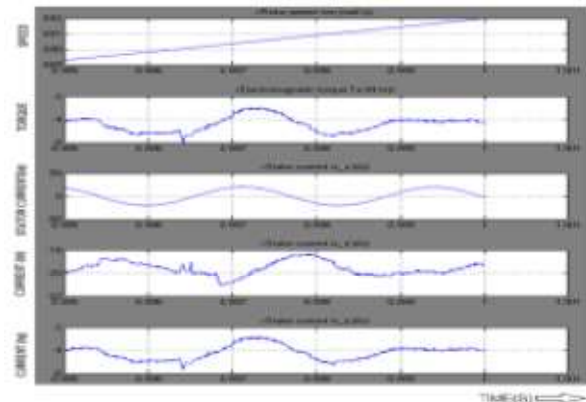


Fig 8: Wind Source Output

The wind source output which is varied for 0.05 seconds from 0 to 1 such that the turbine rotates at both steady and variable speeds as shown in Fig.8. After the system is settled, the output power is very

close to the maximum power that can be captured by the turbine at the wind speed.

The rotor speed, electromagnetic torque, d-axis current, q-axis current and a single phase A is taken from produced three phase stator currents as shown in Fig.9. The rotor speed increases linearly as the rotor starts to rotate. Electromagnetic torque produced by the PMSG is gradually decreased as shown in figure. d-axis and q-axis currents also decreased, finally the stator current (a) can be measured with the limits (10,-10) as peak to peak current in amps



PMSG Output

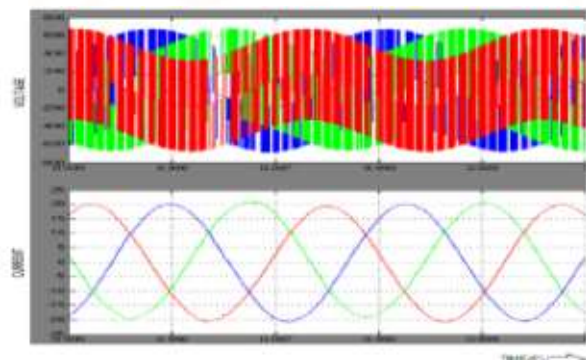


Fig.10.Voltage and Current Measurement for MSC Side

The Voltage and Current are generated by the rotation of PMSG as it gets the torque as input from Adaptive MPPT. This is used to measure 3 phase voltages and currents in a circuit. When connected in series with a three phase element, it returns the three phase to ground voltages and line currents. This can output the voltages and currents in per unit values or in volts and amperes. The generated 3 phase stator voltages, stator current in MSC side are shown in fig 10.

CONCLUSION

This project presents the direct-power control designs for a PMSG wind turbine. This project shows how

integrated MSC and GSC control is designed using direct-power control configurations to implement the maximum power extraction, DC link voltage control, grid voltage support controls and also how the distortions are reduced in the PMSG wind turbine. Comprehensive simulation studies demonstrates that a PMSG wind turbine, based on direct power control structure can effectively accomplish the wind turbine control objectives with superior performance within the physical constraints of the system under both steady and variable wind conditions. The proposed control approach operates in an optimal mode by controlling the MSC for maximum power extraction as the first priority and controlling the GSC to stabilize the DC link voltage as the main concern. Thus the proposed system shows the excellent performance and confirms the feasibility with less distortion level output (1.42 %).

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