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Modelling and Simulation Result of a Permanent Magnet Synchronous Generator of Wind Turbine System

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ABSTRACT As a result of wind speed intermittency, wind turbine output power can be highly variable. The large variability in output power can adversely impact local loads that are sensitive to pulsating power. To mitigate large swings in power, the wind turbine output power can be smoothed by using a small energy buffer. A power conditioner is proposed to smooth the wind power output by utilizing the energy of an ultra capacitor. The conditioner is based on a single phase voltage source inverter (VSI) connected between the grid interconnection point and the ultra capacitor. The shunt VSI injects or absorbs active power from the line to smooth the wind power output by utilizing the short term storage capabilities of the ultra capacitor. The ultra capacitor is connected to the DC link through a DC-DC converter. The bidirectional DC-DC converter acts in buck mode during discharge and in boost mode during charging to maintain the voltage of the DC link relatively constant to provide good controllability of the VSI. The control strategies for the conditioner are presented in this thesis.

KEYWORDS:**Permanent magnet small wind turbine, maximum power from wind, boost converter, inverter connected to the grid**

I.INTRODUCTION

Nowadays, wind energy has become the fastest growing power sector in the world due to the fast increasing of energy demand and accelerating depletion of the world fossil fuels. It becomes more widely adopted in the future because it is cleanenergy source and infinite natural resources. Variable speedwind energy systems have several advantages over than fixedspeed systems such as yielding maximum power output while developing low amount of mechanical stress, improveefficiency and power quality . Power electronics deviceswith variable speed system are very important, where AC–DCconverter is used to convert AC voltage with variableamplitude and frequency at the generator side to DC voltage atthe DC-link voltage. The DC voltage is converted again to ACvoltage with constant amplitude and frequency at the load sidefor electrical utilization. The reliability of the variablespeed wind energy system can be improved significantly byusing a direct drive permanent magnet synchronous generator(PMSG). PMSG has several advantages over than other typesof generators which are used in wind energy systems such assimple structure, can operate at slow speed, self excitationcapability, leading to high power factor and high efficiencyoperation.

Throughout a day, wind power varies continually withchange in wind speed. Wind turbine can deliver maximumpower when the rotor speed of PMSG varies according to the change in wind speed. Most recent papers try to extractmaximum power from wind turbine without using mechanicalsensors because of using these sensors lead to inaccuratemeasurements due to it includes mechanical parts.

$$E = \tfrac{1}{2} M v^2 \qquad \text{(J)}$$

$$E = \tfrac{1}{2}(\rho A v t)\, v^2 \qquad \text{(J)}$$

$$W = \tfrac{1}{2}\rho A v^3 \qquad \text{(W)}$$

$$W_{turbine} = \tfrac{1}{2} C_p \rho A v^3 \qquad \text{(W)}$$

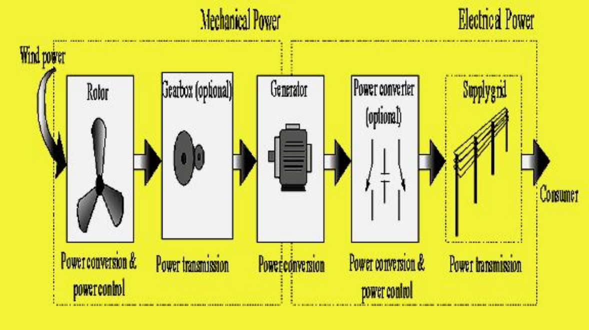

Figure-1 Wind Energy Conversion Systems

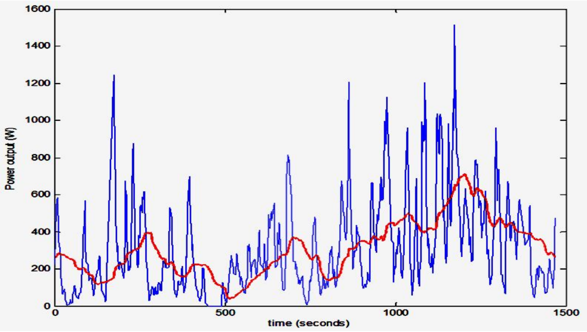

Figure-2 The Actual Output Power of Installed Wind

II. MODELLING OF A PMSM IN THE NATURAL ABC THREE-PHASE STATIONARY REFERENCE FRAME.

Before developing the mathematical model of the PMSM, several important assumptions need to be made

(1) the damping effect in the magnets and in the rotor are negligible;
(2) the magnetic saturation effects are neglected;
(3) the eddy current and hysteresis losses are neglected;
(4) the back electromotive force (EMF) induced in the stator windings are sinusoidal;
(5) for simplicity, all the equations of PMSMs are expressed in motor (consumer/load) notation, that is, negative current will be prevailing when the model refers to a generator. Negative current means that at the positive polarity of the terminal of a device the current is out of that terminal.

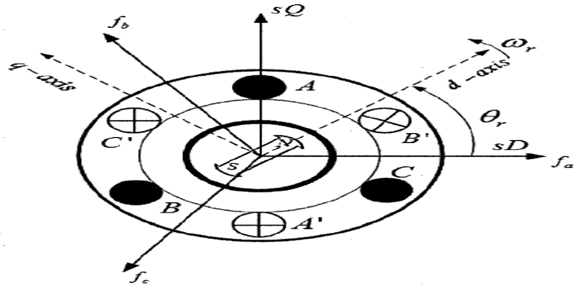

Figure-3

Figure-5 shows the cross-sectional view of a three-phase, two-pole PMSM. The fixed *abc* axes denote the direction of the MMFs (f_a, $f_b$andf_c) of the *a*, *b* and *c* phase windings, which are induced by the time varying three-phase AC currents in these stator phase windings. The flux caused by the permanent magnet is in the direction of the *d*-axis fixed at the rotor. Here, the dq-axes are rotating at the same angular speed of the PMs and rotor. Also, θ_r denotes the angle between the d-axis and the stationary a-axis.

The state space relationship of the terminal voltages of the PMSM to the phase currents and the phase flux linkages due to the PMs and stator currents can be written as follows.

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \cdot \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \lambda_{as} \\ \lambda_{bs} \\ \lambda_{cs} \end{bmatrix}$$

……..3.1

Where $v_{as}v_{bs}$andv_{cs} are the instantaneous a, b, and c three-phase stator voltages and $i_{as}i_{bs}$and $i_{cs}$are the instantaneous three-phase stator currents. Here,R_s is the stator winding resistance per phase, and again, $\lambda_{as}\lambda_{bs}$and $\lambda_{cs}$are the instantaneous flux linkages induced by the three-phase AC currents and the PMs, which can be expressed in expanded form as follows

$$\begin{bmatrix} \lambda_{as} \\ \lambda_{bs} \\ \lambda_{cs} \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \cdot \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \begin{bmatrix} \lambda_r \cos(\theta_r) \\ \lambda_r \cos(\theta_r - \frac{2\pi}{3}) \\ \lambda_r \cos(\theta_r + \frac{2\pi}{3}) \end{bmatrix}$$

……. 3.2

where,L_{aa},$L_{bb}$and L_{cc} are the self-inductances of the a, b, and c three-phases, and L_{ab},L_{ac}, L_{ba}, L_{bc}, L_{ca} and $L_{cb}$are the mutual inductances between these phases, while,λ_r is the rotor flux linkage caused by the permanent magnet. The self-inductances and mutual inductances are all functions of θ_r. Thus, all of the inductances are time varying parameters.

III.MODELLING OF THE PMSM IN THE DQ-AXES SYNCHRONOUSLY ROTATING REFERENCE FRAME

The *dq0* Park's transformation is a mathematical transformation which aims to simplify the analysis of synchronous machinery models, and was first introduced by R. H. Park in 1929. In the three-phase systems like PMSMs, the phase quantities which include stator voltages, stator currents, and flux linkages, are time varying quantities. By applying Park's transformation, which is in essence the projection of the phase quantities onto a rotating two axes reference frame, the AC quantities are transformed to DC quantities which are independent of time. The *abc* to *dq0* transformation can be expressed in matrix form as follows:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_r) & \cos(\theta_r - \frac{2\pi}{3}) & \cos(\theta_r + \frac{2\pi}{3}) \\ -\sin(\theta_r) & -\sin(\theta_r - \frac{2\pi}{3}) & -\sin(\theta_r + \frac{2\pi}{3}) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

…….4.1

The inverse Park's transformation is:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_r) & -\sin(\theta_r) & \frac{\sqrt{2}}{2} \\ \cos(\theta_r - \frac{2\pi}{3}) & -\sin(\theta_r - \frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \\ \cos(\theta_r + \frac{2\pi}{3}) & -\sin(\theta_r + \frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix}$$

……..4.2

In expressions,U_{abc} andU_{dqo} can represent the stator voltages, stator currents or flux linkages of the AC machines, respectively. Considering that under balanced conditions, U_o=0, the voltage function of the PMSM in the dq-axes reference frame can be expressed as follows

$$v_{ds} = R_s i_{ds} + L_d \frac{di_{ds}}{dt} - \omega_e L_q i_{qs}$$

$$v_{qs} = R_s i_{qs} + L_q \frac{di_{qs}}{dt} + \omega_e L_d i_{ds} + \omega_e \lambda_r$$

……..4.3

Where,v_{ds} and v_{qs} are the instantaneous stator voltages in the *dq*-axes reference frame, and $i_{ds}$and i_{qs} are the instantaneous stator currents in the *dq*-axes reference frame. Here,L_d and L_q are the *d*-axis and *q*-axis inductances, andω_e is the electrical angular speed ofthe rotor, while,λ_r is the peak/maximum phase flux linkage due to the rotor-mountedPMs. According to expressions, the equivalent circuits of the PMSM in the *dq-axes* reference frame can be drawn as shown in Figure below.

5.Power and torque analysis of a PMSM

For any PMSM, the electrical power input can be expressed in the *abc* reference frame as follows:

$$P_{abc} = v_{as} i_{as} + v_{bs} i_{bs} + v_{cs} i_{cs}$$

……..5.1

or in the *dq*-axes reference frame as follows:

$$P_{dq} = \frac{3}{2}(v_{ds} i_{ds} + v_{qs} i_{qs})$$

…….. 5.2

As a part of the input power, in the motoring mode, the active power is the power that is transformed to mechanical power by the machine, which can be expressed as follows:

$$P_{em} = \frac{3}{2}(e_d i_{ds} + e_q i_{qs})$$

$$e_d = -\omega_e L_q i_{qs} = -\omega_e \lambda_q$$

$$e_q = \omega_e L_d i_{ds} + \omega_e \lambda_r = \omega_e \lambda_d$$

Here,e_d and e_q are the back EMFs in the *dq*-axes reference frame, and $\lambda_d$and $\lambda_q$are the *dq*-axes flux linkages. Substituting expressions (2.19) and (2.20) into (2.18), the active power can be re-expressed as follows:

$$P_{em} = \frac{3}{2}\omega_e(\lambda_d i_{qs} - \lambda_q i_{ds})$$

…….5.3

Hence, the electromagnetic torque developed by a PMSM can be deduced as follows:

$$T_e = \frac{P_{em}}{\omega_e / \frac{p}{2}} = \frac{3}{2}\left(\frac{p}{2}\right)(\lambda_d i_{qs} - \lambda_q i_{ds})$$

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)(\lambda_r i_{qs} + (L_d - L_q) i_{qs} i_{ds})$$

…….5.4

where,p is the number of poles in the machine.

V. SIMULATION CIRCUIT DIAGRAM.

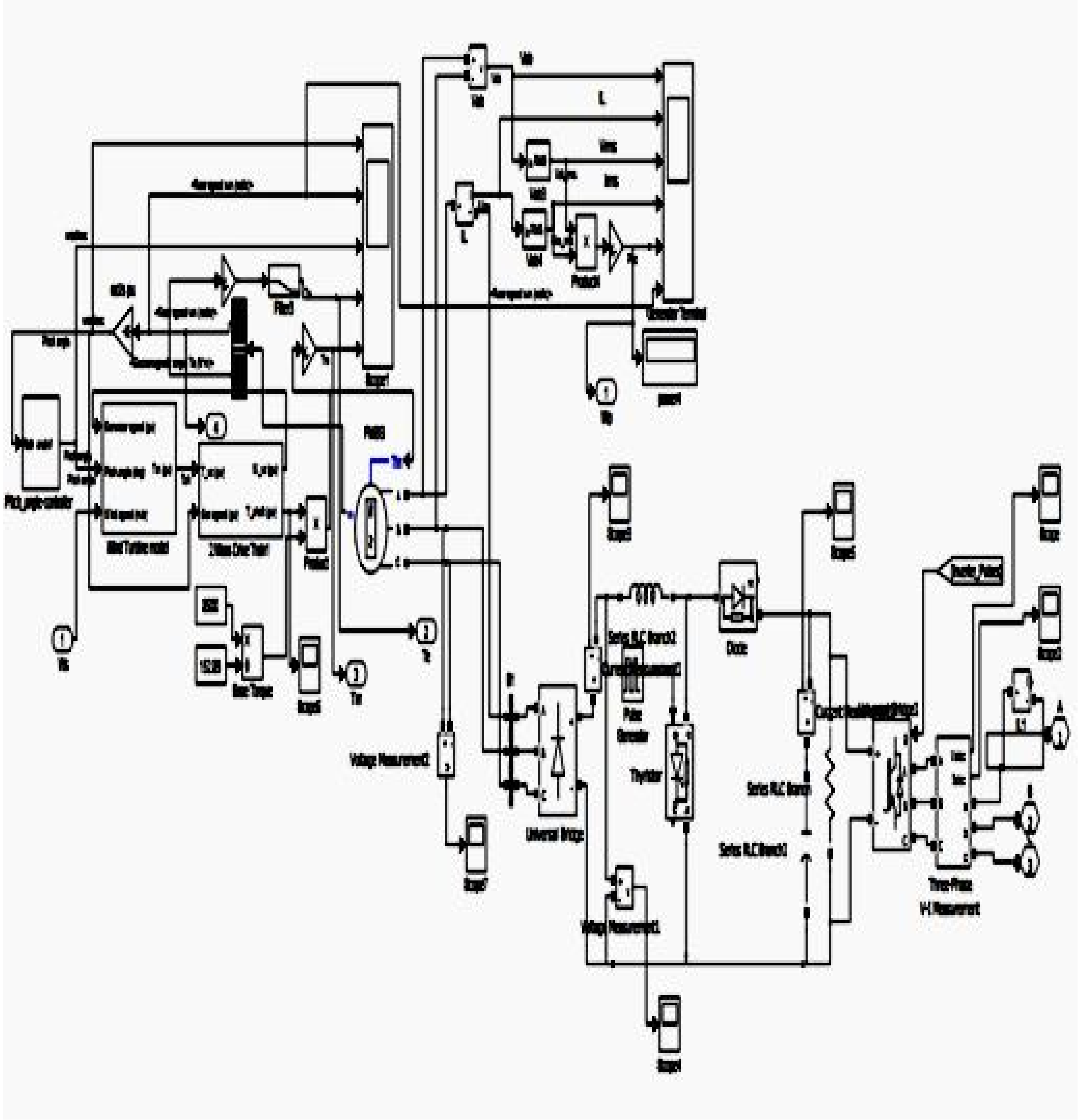

Fig. 4

VI. RESULT AND DISCUSSION

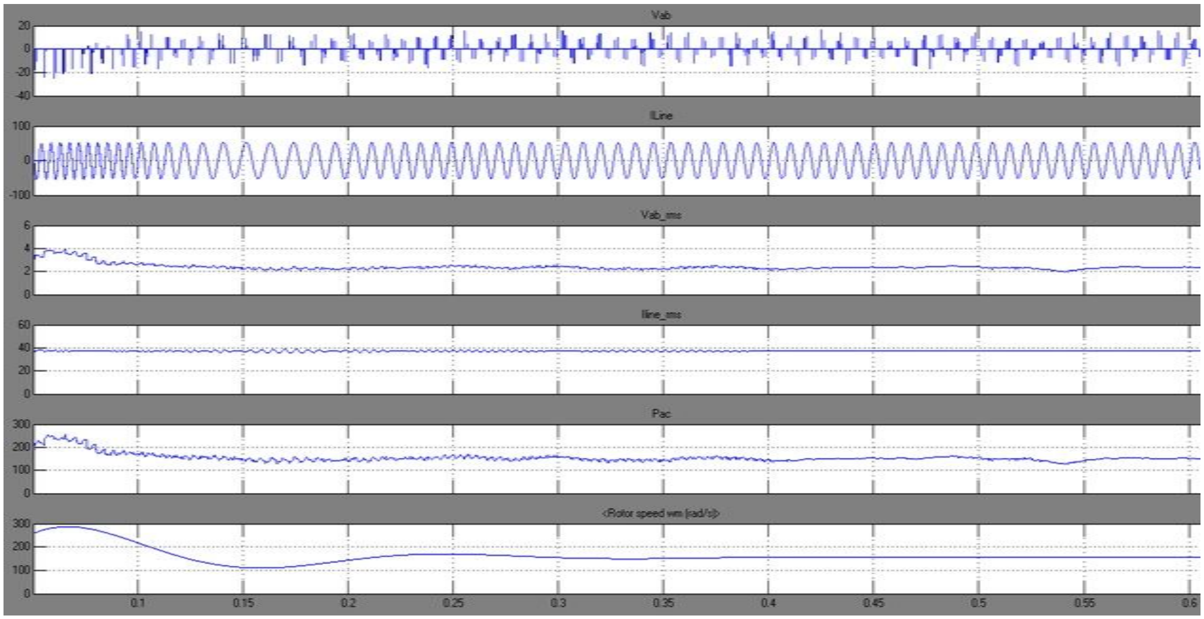

Figure-5(Line voltage, Line current, rms line voltage, rms line current, active power, and rotor speed of PMSG)

VII.CONCLUSION

- The whole system framework is illustrated, clarifies the aim of project and describes objects which will be achieved in this project.
- An overview of the fundamental principles relating to wind turbines with grid connection is presented. It briefly summarises what technologies are currently employed in the development of the converter wind turbine, and the achievement made by this project
- The non-dimension characteristic of the power coefficient of a wind turbine as function of the tip speed ratio is, successfully obtained. A MATLAB model for a PMSG system was created and simulated to meet the specifications of a 10kW wind turbine, and the outcomes demonstrate that the model meets the design parameters
- Demonstrates that the chosen diode rectifier with a boost circuit can be utilised for wind turbine generation with the generator voltage output less than that of the power grid. It means that this type of converter can be used in low wind speed conditions

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