Dynamic Performance of Self-Regulated Wind Turbine Generation System

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Abstract— The wind turbine generation (WTG) system is an developing method for distributed generation (DG) system. This is due to its easily available source, ecological responsiveness and cost effective. However, the wind turbine based power is highly un-predicting in nature due to environmental dependent factor. Hence, obtaining the consistent and effective power from these sources is a challenge. In this work, a dynamic performance of wind turbine generation system is presented as one of the consistent power. The wind turbine speed is kept constant within a limit by varying a pitch angle even wind velocity varies and loads are dynamics. In this, the closed loop control of pitch angel is presented to maintain the constant voltage. The wind turbine generation system includes a permanent magnet synchronous machine (PMSM) over other types of generator along with matrix converter to maintain the variable frequency to constant voltage, frequency power. The model of WTG is presented in Matlab/Simulink environment and its performance is studied through simulation results.
Index Terms—Distributed Generation System, Wind Turbine, PMSM.

I. INTRODUCTION

The distributed generation (DG) is system gaining more and more attention worldwide as an alternative source of power [1]. Among the various conventional DG source, the wind turbine generation system is most suitable DG system for the reliable power [1]. the wind turbine based DG have been obtained in the different way for land based and offshore application radial connected of turbines producing AC power output is the most common collection of turbine. In this view, the radial topology has also been explored for lossless and reliably issues. The major components of typical wind turbine generation system includes, wind turbine, generator and interconnection apparatus along with control schemes. The classification of wind turbine can be either vertical or horizontal types. The upcoming wind turbines are horizontal axis type [2]. These turbine having two or three blades, operating either down-wind or up wind velocities. The variable speed wind turbine can produce 8% to 15% more energy output as compared to constant speed [02]. However, they necessitate power electronics converters to provide a fixed frequency and fixed voltage at the load terminals. For small to medium power wind turbines, a permanent magnet synchronous machine and squirrel cage induction machine are often used to because of the reliability and cost advantage over other types of machines. The very often power electronics interfacing are used to deliver the generated power along with control schemes.

The modern power converter and inverter are forced commutation with pulse width modulation (PWM) based to provide fixed voltage and frequency output. For certain high power wind turbine application, the double PWM converter is used. This can provide a bi-directional power flow between the turbine generator and the utility grid. Currently, several wind turbine generation system are compete in the market. The can be collected into two main groups [1]. The first groups of wind turbine are constant speed wind turbine. These wind turbines are directly coupled to the induction generator and grid. The second version of wind turbines are variable speed. These wind turbine generation system are not directly coupled generator and grid. Hence, the rotor is permitted to rotate at any speed by enhancing the power electronics interfacing circuits between source and destination [1]. The dynamic performance of induction generator with controller in PSCAD/EMTDC several ways has been reported in [3]. Modelling and control of wind turbine generation using continuously variable transmission has been presented in [4]. In this, two controlled objectives for this study, maximizing energy captured and limiting dynamic loads are met in two steps. First is an algorithm are developed that uses a filter version of the actual value wind speed, the optimal tip speed ratio and the rotor diameter to create a set point. A dynamic model of a wind frame and its nearest utility grid addressing the dynamic interaction between wind and grid during normal and abnormal condition has been given in [5]. The model presented comprises the substation where the wind frame is connected, the internal power collection system of the wind frame, the electrical and mechanical and aerodynamics are considered. A techniques for output power leveling of wind turbine generation system has been proposed in [6]. The large inertia of the blade angle as compared to the generator. The inertia of the rotor behave like an inductor in an electric circuits. This helps in smooth output power storage, energy acceleration and restore of the declaration. The effectiveness power leveling controller is verified by simulations for the wind power generation system. The model and design of wind energy conversion system using a wind turbine with known dynamic characterizes and permanent magnet synchronous generator driven by back to back power converter topology is presented in [7].

In this literature study, it is proposed a variable wind variable statute control schemes with two different kinds of operation, namely maximum power point tracking and constant power. Also, it is demonstrated that, the system is controlled with speed control loop while that using torque control an unstable control results. The speed control of a modern pitch regulated wind turbine is investigated with control structure and significance controlled parameter are investigated in [8]. In particular, the influence of the speed control bandwidth on the speed variations, torque stresses and energy production are analyzed. The work depicted in [8] also states that, stricture operates without any wind speed or shaft torque instead of these quaintest are estimated from the rotor speed and electrical power. This paper presents the variable wind, constant speed, dynamic load wind turbine generation system in isolated modes. The system consist of wind turbine, PMSM and matrix converter along with power electrics interfacing are depicted in Matlab/Simulink environment and is simulated. In this work it is assumed that, the wind turbine is started and brought to the rated speed. The self-regulated wind turbine shall maintain the constant speed irrespective of load variation and wind speed within a limit.

II. WIND TURBINE GENERATION SYSTEM

The schematic of wind turbine generation system used in this research study is shown in Fig. 1. The system consists of wind turbine as a prime mover, PMSM, power electronics interfacing along with control schemes. The system consist of wind turbine with gear less coupled generator and matrix converter for variable AC to fixed AC power without storage. The matrix converter control schemes consists of active, reactive power (PQ) control schemes to deliver the wind power to utility grid.

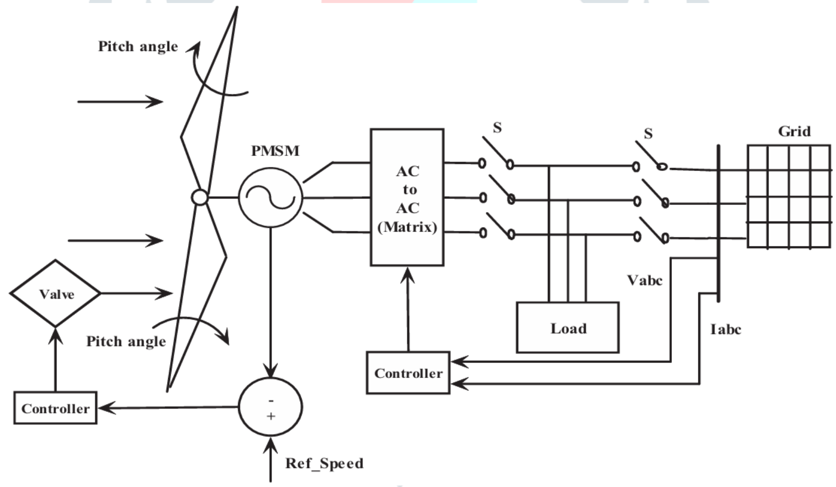


Fig. 1 Schematic of wind turbine generation system

A. Wind Turbine Model

The power generated by the wind turbine can be given by an expression as [12].

$$Pv = \frac{1}{2}\rho S v^3 \tag{1}$$

The aerodynamics performance of horizontal axis wind turbine is expressed by the power co-efficient Cp is written as

$$P_t = Cp(\lambda, \beta)Pv = \frac{1}{2}\rho SCCp(\lambda, \beta)v^3 \tag{2}$$

The theoretical maximum value of this co-efficient called as Beltz limit is 16/27. It is variable and depends on the characteristics of the turbine and wind speed. It is often represented by the ratio of the speed which depends on the mechanical speed of the turbine in (rad/s). Hence, it is possible to define the co-efficient Cp by a mathematical approximation for a high power wind turbine [11].

$$Cp(\lambda,\beta)=(0.5-0.00167(\beta-2))\sin\left[\frac{\pi(\lambda+0.1)}{18.5-0.3(\beta-2)}\right] \quad (3)$$

On representing the co-efficient in function for different values of pitch angle of the blades. The curve character for optimal point corresponding of the maximum power co-efficient Cp and therefore the maximum mechanical power is recovered. The deduction of characteristic that binds to a given wind speed, the power of the turbine as a function of its speed of rotation. Knowing the wind turbine speed, the aerodynamics torque is directly determined by,

$$T_{aer}=\frac{P_{aero}}{\Omega t}=\frac{1}{2\Omega t}C_p(\lambda).\rho\pi R^2 v^3 \quad (4)$$

The multiple adapts the slow speed of the blades for the first speed of machine by multiplication ratio G. This element defines the mechanical torque and speed of the machine as,

$$T_g=\frac{T_{aero}}{G} \text{ and } \Omega_{mech}=G\Omega_t \quad (5)$$

The fundamental equation of dynamics determines the evolution of the mechanical speed of the generator. The simplified model of this equation is given by,

$$J\frac{d\Omega_{mech}}{dt}=\frac{J}{P}\frac{d\omega_{mech}}{dt}=T_{mech}=T_s-T_{em}-f\,\Omega_{mech} \quad (6)$$

Where, J is the total inertia of the generator. Tem is electromagnetic torque.

B. Permanent Magnet Synchronous Machine

The equivalent circuit of PMSM with sinusoidal flux distortion is modelled in [07]. The equivalent circuit of PMSM is showing in Fig. 2

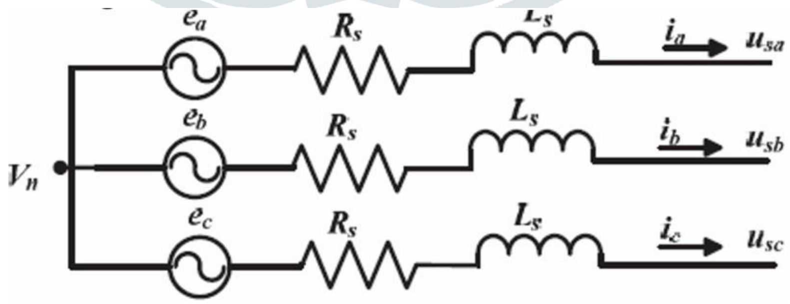


Fig.2 Equivalent circuit of PMSM

From Fig.2, the equivalent stator resistance Rs and equivalent stator inductance Ls including the mutual and leakage inductance. Ua is the phase to neutral terminal voltage, ea is the phase to neutral electromotive force generated by the permanent magnet.

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{R_s}{L_s}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} - \frac{1}{Ls}\begin{bmatrix} u_{as} \\ u_{sb} \\ u_{sc} \end{bmatrix} + \frac{V_n}{L_s} \quad (7)$$

The equivalent circuit for phase of PMSM is given by an expression

$$u_{sd} = -R_s i_{sd} + \omega_e \psi_{sq} - \psi_{sd} \quad (8)$$

$$u_{sq} = -R_s i_{sq} - \omega_e \psi_{sd} - \psi_{sq} \quad (9)$$

The flux induced in the stator i.e. in dq frame can be expressed as

$$\psi_{sd} = -L_d i_{sd} - \psi_{PM} \quad (10)$$

$$\psi_{sq} = -L_q i_{sq} \quad (11)$$

The PMSM used for low speed radial flux, multi-poles generation using permanent magnet. The electrical expression for the generator is represented in the rotating d-q reference frame, in which the d-axis is synchronized with the flux of the machine are

$$V_d = r_s i_d + L_d \, {}^{d_{iq}}\!/_{dt} - L_q \omega i_q \quad (12)$$

$$V_d = r_s i_d + L_d \, {}^{diq}\!/_{dt} - L_q \omega i_q + \phi_{m\omega} \quad (13)$$

Where, vdand vqare the d-q transformed voltage, idand iqare the d-q transformed stator current, rs is the stator resistance of the winding. The instantaneous electromagnetic torque is given by

$$T_e = \frac{3p}{2}\left\{\phi_m i_q + i_d i_q\left(L_a - L_q\right)\right\} \quad (14)$$

The surface mounted PMSG, Ld and Lq are very similar, hence it is considered that, Ld=Lq=L. Furthermore the magnetizing current reference (id) is fixed to zero because magnetization of machine is provided by the permanent magnet. The conventional system includes double feed induction generator based wind turbine generation system which will draw the reactive power from the grid [17].

C. Power Electronics Interfacing

The power electronics interfacing used between the generator and load/utility grid is a matrix converter. The unique advantage of matrix converter is the absence of bulky reactive element that are subjected to ageing and the system reliability. Furthermore, matrix converter provides bi-directional power flow nearby sinusoidal inputs and output. Hence, matrix converter has received considerable attention as a good alternative to voltage source inverter (VSI) topology. The development of matrix converter has started from early 1980x's. afterword's the research in this filed is continued to need of reliable bidirectional switch on the other hand the initial modulation strategy was abandoned in favor of more modern solution, allowing higher voltage transfer ratio and better current quality[18].

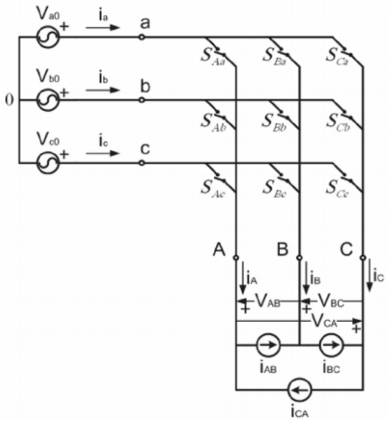


Fig.3 Schematic of matrix converter

The bidirectional switch for the matrix converter along with the capability of block the voltage and to conduct the current in both the directions is shown in Fig.3 the two main topologies for bi-directional switches, namely the common emitter antiparallel IGBT diode configuration and common collector antiparallel IGBT are configured. The diode provides reverse blocking capability. The complete connection of the common emitter arrangement is shown in Fig.4. The main advantage of this solution is that, the two IGBTs can be driven with respect to the same point, i.e. the same common emitter that can be considered as local ground for bidirectional switch. On other hand, each bi-directional switch requires an insulate power supply, in order to ensure the correct operation. Hence, total of nine insulated power supply are needed. The power supply must be insulated due to bidirectional switch is turned on the common emitter assumes the potential of an input phase. Therefore, it is not possible for all the bidirectional switch to be driven with respect to the same common point. The matrix controller includes the controls strategy as shown in Fig.4 in this, the matrix controller is connected with either side series resistor, and inductor filters are used to minimize the harmonics generated by the switching action. The closed loop control strategy uses the three phase voltage and current as time variant quantity to time invariant quantity parameter. The voltage Vabc, is used to generate the phase lock loop angle and Iabc to generate abc to α β.transformation.

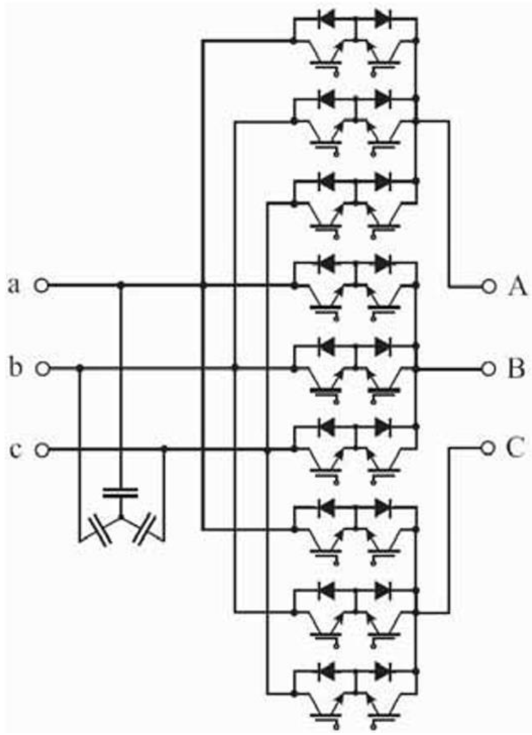
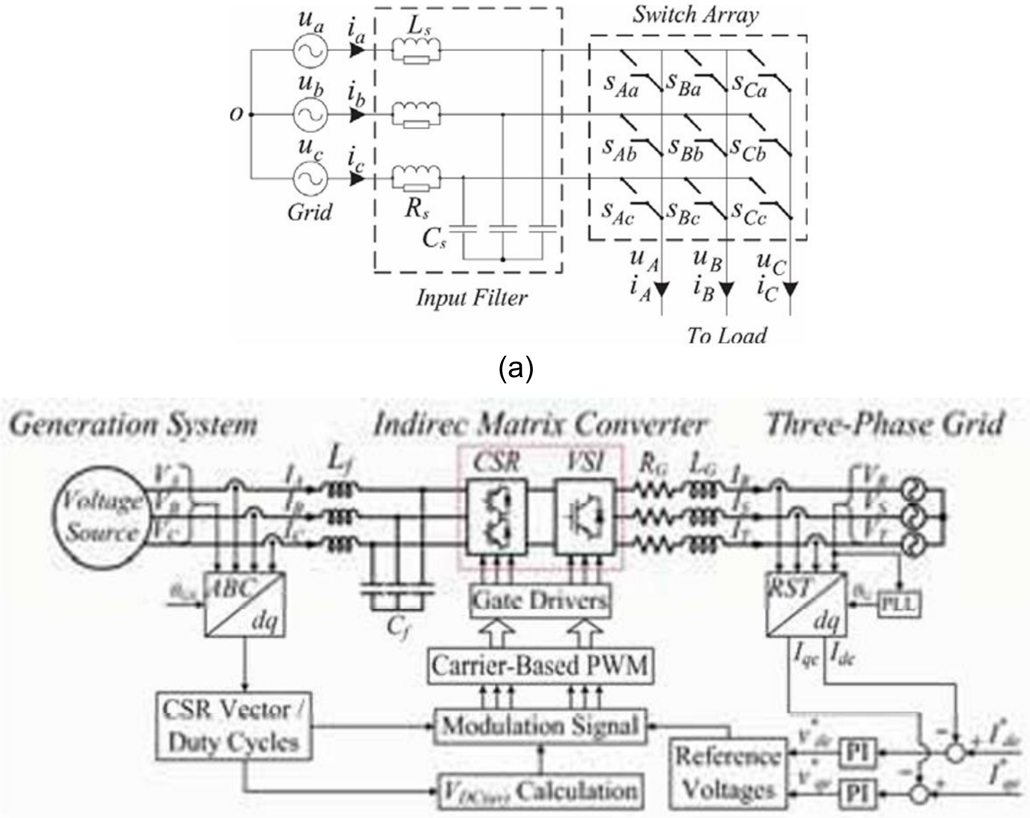


Fig. 4. Schematic of power stages in common emitter

Further the .to dq transformation to include the controlling quantity id, iq. The reference value of id and iqare compared with actual value of id and iqand are make error zero using a PI controller. The controller output is given to the modulation PWM which is nothing but a switch. The machine side is connected to PMSM variable power source driven by the wind turbine [18].



(a)

(b)

Fig. 5 (a) Matrix converter and (b) Control strategy

III. SIMULATION RESULTS AND DISCUSSION

The developed model in this research work is presented in Matlab/Simulink environment to obtain the performance for the variable wind velocities. The total time for the simulation is considered as 25sec to get the detailed parameter. A 10 kW installed capacity wind turbine connected with PMSM and power electronics interfacing as shown in Fig.1. The wind velocity for a different duration of time is shown in Fig.6. In this, the wind velocity is varied for the different stages of time. Between time t=0 to 5sec, the wind velocity is 5.25 m/sec, between time t=5 to 15sec, the wind velocity is 4m/sec and again it varies 6.25m/sec between t=15 to 25sec as depicted in simulation result which is considered as forecasting wind available at radius of wind turbine. Another forecasting parameter is load, which connected to other side of the wind turbine. Voltage remains constant for the entire duration of simulation time except small transients.

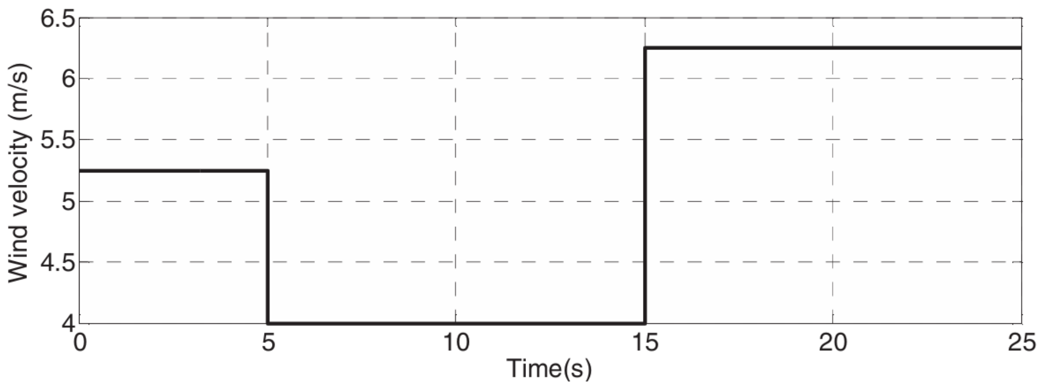


Fig. 6 Wind velocities

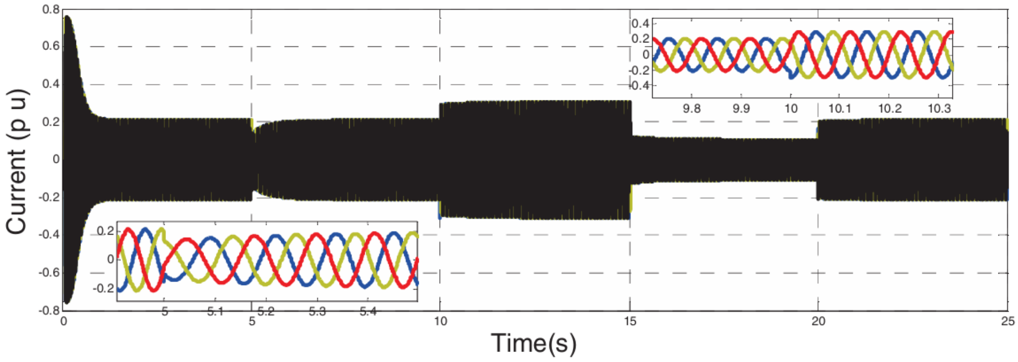


Fig.7 Current

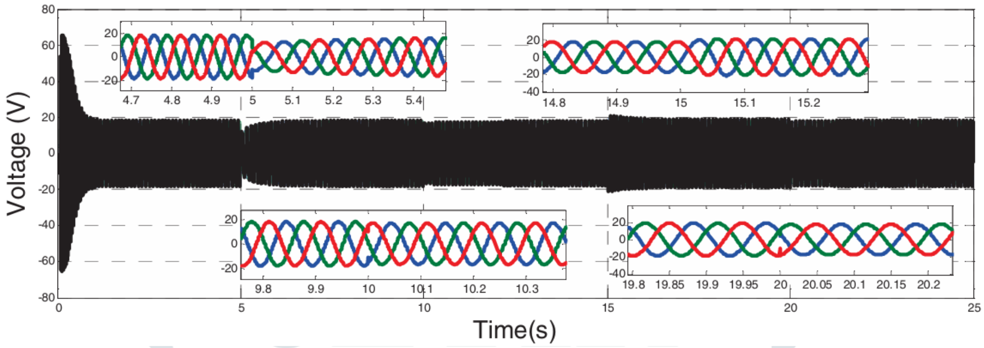


Fig.8 Voltage Variation

The variation of load current is shown in Fig.7, this variation of voltage is variation the nominal value of upper and lower. The voltage and transient due to the wind velocity variation is shown in Fig.8. These variation are due to frequent load changing and wind velocity deviation. However, the voltage remains same due to pitch angle control and to maintain a constant speed as shown in Fig.8. The wind turbine reference speed is kept as 100 rpm. The controller has to maintain the 100 rpm rotational speed even wind velocity varies and load changes. The turbine rotor speed is speed is shown in Fig.9. The error obtained at controller part, i. e. error between reference speed and actual speed is shown in Fig.10. From this simulated result, it is clearly observed, the error is zero except small transients during the load and wind variation. The turbine torque for different stages of load is shown in Fig.11. In this, torque is constant for direct velocity except transients but it is different for different electrical load. The torque here is negative, since machine is running in a generator mode. The variation of Vd and Vqvoltage at the terminals of generator is shown in Fig.12. Form all these simulated study. It is determined that, the wind turbine speed can be maintained constant to get the desired frequency power with pitch angle variation as per the signal given by the controller.

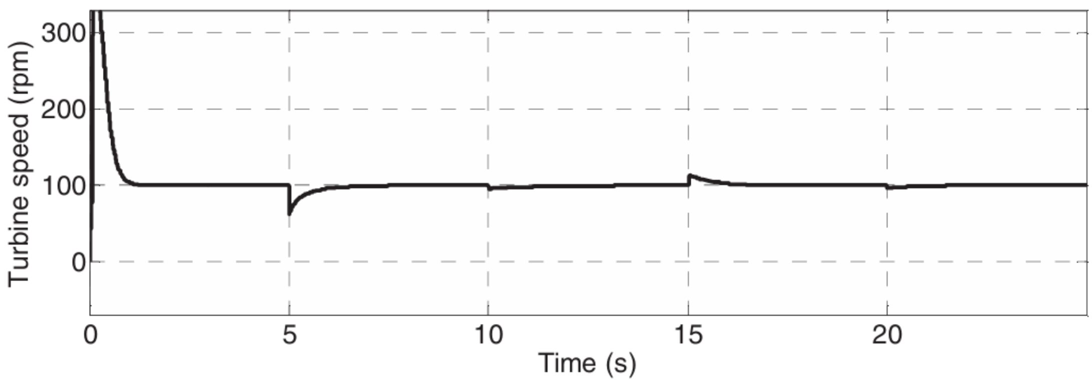


Fig. 9 Turbine speed

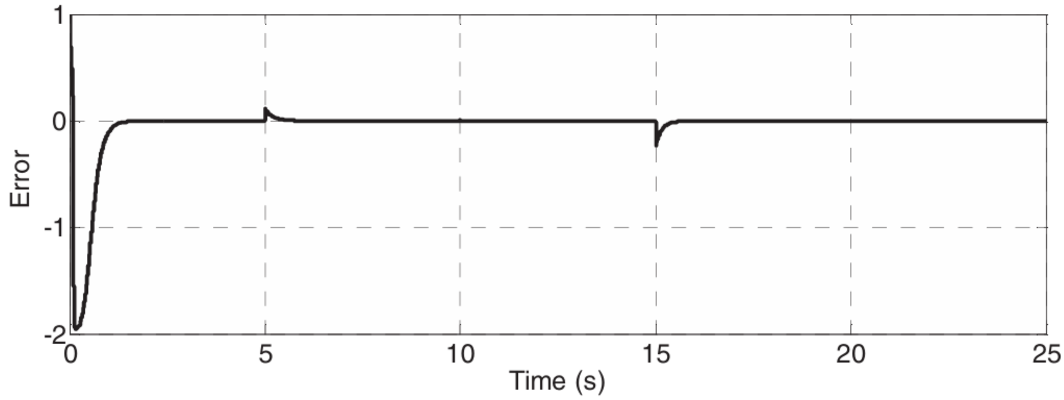


Fig.10 Error in speed

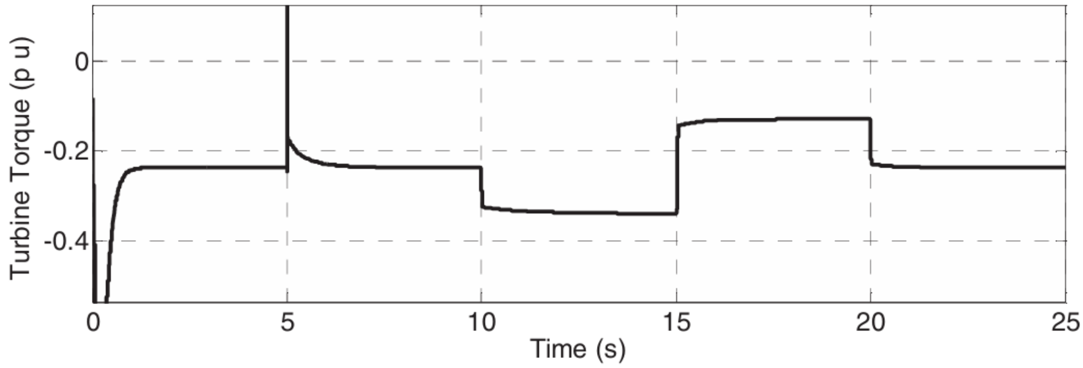


Fig. 11 Torque

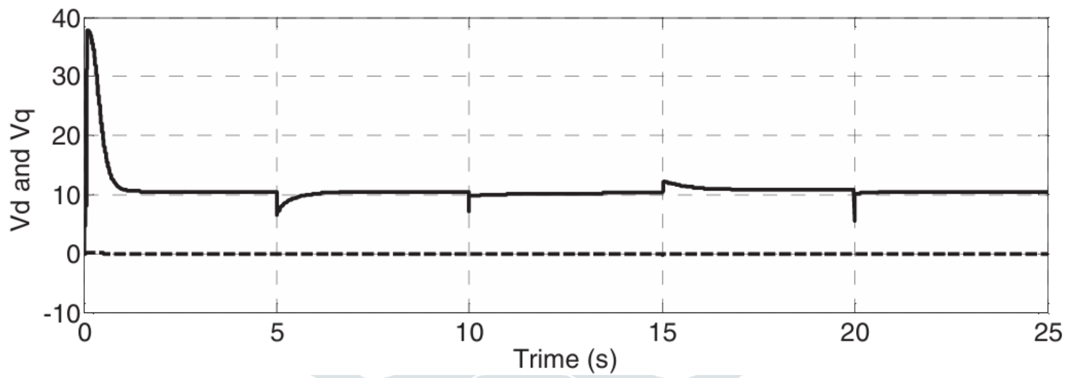


Fig.12 Vd and Vq of Generator

IV. CONCLUSIONS

The research works on variable wind, dynamic load and constant speed has been presented through a simulation model in Matlab/Simulink environment. The model consist of wind turbine generation system along with PMSM and power electronics interfacing circuit. The matrix converter are used in between a generator and load convert variable frequency AC power to fixed voltage and frequency AC power. The pitch angle controller include an equivalent transfer function for mechanical valve and PI controller. The entire model of wind turbine generation system is presented in Matlab/Simulink environment to obtain the dynamic performance. The simulation results shows, for a dynamic load and variable wind WTG system, the terminal voltage can be maintained constant within the limit even wind velocity and load are dynamically changing. This presented research model may become a tool before its real time application.

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