Dynamic Modeling and Control of Wind Turbine Scheme Based on Cage Machine for Power System Stability Studies

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Abstract--Among renewable sources, wind energy source is the most sympathetic and favorable source because it is free from pollution, global warming and no carbon dioxide emissions as it is assessed in conventional energy sources. At the same time, power demand is rapidly increasing and put the world on a verge of global crises. However, based on existing literature, the development of wind-generator dynamic model is of great interest nowadays. Besides that, with the nonlinear characteristics of cage-rotor wind turbine generator system and uncertainty of wind variations, the system becomes unstable. Therefore, in this paper, a complete dynamic wind-generator mathematically modeling approach of a wind energy system has been carried out, based on feedback control techniques via field oriented control concept, which plays a significant role in the power system. The proposed dynamic wind-generator system model consists of three phase cage rotor induction machine units, and it is intended in a Simulink software toolMatlab for the simulation purpose in order to regulate the generator output. The proposed system design, analysis, and control process have broadened prospectus of applications and developments.Finally,from the simulation outcomes, the output response of the proposed system yields a satisfactory damping and quick recovery.

Keywords: Nonlinear control systems, wind speed disturbances, wind-generator scheme modeling, and stability.

1. Introduction

During the last decade, questions have arisen about alternative energyfor the developmentof any country.Till date, the most of the countries like Pakistan have not utilized renewable energy sources such as the wind and solar,due to the fact that other conventional sources are easily accessible. At the same time, there are no any incentives to look for alternative forms of energy. In addition, protecting the environment should be the top priority. Moreover, among other renewable energy resources, the wind energy is the fastest growing, continuous, most dominant,worthwhile choice for power generation and to obstruct CO_2 emission from several conventional resources[1, 2]. Globally, an urgent attention is a prerequisite to exploit the wind energy in order to shelter the global energy crisis issues. It is well documented in the literature that several scientists, engineers and researchers from developing and developed countries have conducted research in the renewable energy issue, in which wind source is the most basic renewable source for power generation[2-10]. However, Fig. 01 illustrates the total world installed wind energy capacity[11]. In addition, several continents and their top three wind installed capacity are depicted in Fig. 02[11]. According to the collected literature, as referred in[12], Asia Continent and China has the cumulative installed capacity are around 142 GW and 115 GW in 2013 and 2014, respectively.

However, power generation, stability, and control of wind energy isthe hot research directionsfor researchers,due to the requirement of low capacity excitation converter, wide range, speed regulation, and independent control of active and reactive power[13]. Nonetheless, according to the design with respect to the wind direction, usually characterized into two classes such as horizontal axis wind turbine system (HAWTS)&vertical axis wind turbine system VAWTS, in which HAWTS have more advantages than VAWTS in many aspects[11, 13-15]. In addition, examining the category of generator among entire, the squirrel cage induction generator is more popular for wind energy applications dueto its simplicity, robust structure, low cost, and resistance in opposition to pulsation and interruption[16-18]. Therefore, control system, that produced power from an uncertain input such as the wind speed, presents terrible issues, because due to uncertain wind conditions, which produce disturbances. Further, due to gusts of air in the atmosphere, and interrupted which effects of turbine tower shadow. Challenges have been takenfor wind-generator which is nonlinear, multivariable and strong decoupling, so the stability and control analysis issues are more important[19]. In the last few decades, several researchers introduced various control algorithms for wind energy applications, and their main aim was tantamount to design a controller in order to pathway the reference signals at the output side. Even though these control algorithms are most popular for wind turbine systems, but unfortunatelythey suffer due to the disturbances with respect to the system parameters[20-22]. Furthermore, wind energy system configuration frequently exists in the nonlinear formation except feedback control concept which is low price schemes, sophisticated in operation, simpler, reliable, efficient and having an ideal performance for wind turbine system applications[23, 24]. In this paper, a general dynamic modeling and controller design of horizontal axis wind turbine cage rotor systems based on a feedback algorithmthrough the field oriented concept have been presented.

To the best of the author's knowledge, this is the first work in the literature where, a detailed dynamic analysis of wind-generator has been presented.The contribution of this paper ispreciseas follows:

In this paper, a dynamic wind-generator model is presented that can be employed to investigate the stability and performance analysis of the wind energy system.

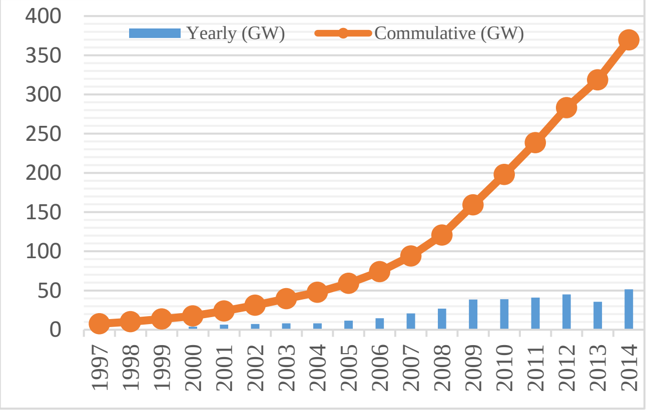

Fig. 01. The purple line shows cumulative and the blue line shows the annual total installed wind energy capacity of the world in [GW] in the F.Y. 1997-2014.

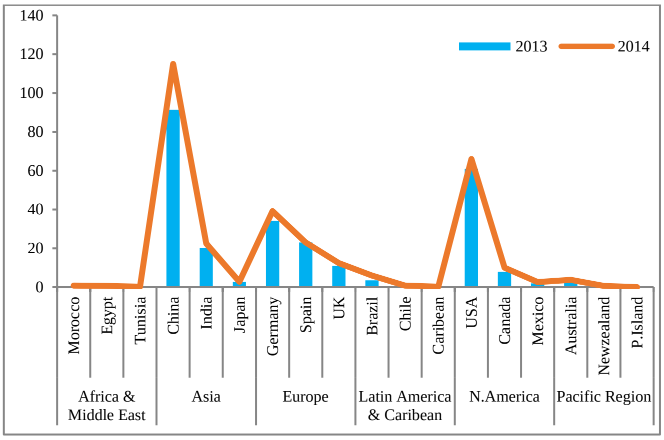

Fig.02 Shows the several continents and country wise total installed capacity of wind energy in [GW] in the F.Y 2013-2014 in which purple and the blue line shows the year 2014 and 2013 respectively.

2.Problem Description and Basic System Modeling

The wind turbine induction generator schematic model diagram is illustrated in Fig. 03. The model consists of HAWTS and a cage rotor induction generator, interfaced to the grid via an overhead transmission line. A fix control box is connected to the generator in order to regulate the system parameters.

However, the wind power produced at the critical edge impact area can be expressed as follows[25, 26]:

$$\langle P_{wind}\rangle = 0.5\rho\pi R^2 V_{wind}{}^3 \quad (1)$$

However, the turbine torque relation is illustrated as follows:

$$\langle \tau_{turbine}\rangle = \frac{1}{\Omega_t} P_{turbine}\left\langle \tilde{\theta}, \Omega_t, V_{wind}\right\rangle \quad (2)$$

where,

$$\begin{cases} P_{turbine} = 73\dfrac{\left(151\dfrac{1}{\langle\Gamma_{TSR}\rangle} - \dfrac{29}{50}\langle\tilde{\theta}\rangle - \dfrac{1}{500}\langle\tilde{\theta}^{2.14}\rangle - \dfrac{66}{5}\right)}{200 * \rho\pi R^2 V_{wind}{}^3 \exp\left(\dfrac{97}{5\Gamma_{TSR}}\right)}; \\ c_{power} = 0.73\left(151\dfrac{1}{\langle\Gamma_{TSR}\rangle} - \dfrac{29}{50}\langle\tilde{\theta}\rangle - \dfrac{1}{500}\langle\tilde{\theta}^{2.14}\rangle - \dfrac{66}{5}\right)e^{-\left\langle\frac{97}{5\Gamma_{TSR}}\right\rangle}; \end{cases}$$

basically, c_{power} is the power coefficient, expressing turbine efficiency, and it is a well-renowned factor for simulation, it 's theoretical and the practical limit is <0.6and <0.4, respectively[27-29].

The tip speed ratio ata zero degree pitch angle can be defined as follows(see[14, 30]):

$$\langle\Gamma_{TSR}\rangle = \left\langle \left(\frac{R\Omega_r}{V_{wind}} - \frac{1}{500}\tilde{\theta}\right)^{-1} - \frac{3}{1000\left(1+\tilde{\theta}^3\right)} \right\rangle^{-1}, \quad (3)$$

2.1 Turbine Model

As shown in Fig. 03, the wind turbine shafts and the mechanical gearbox dynamic mathematical model isdescribed as follows:

$$\begin{cases} \dfrac{d}{dt}\langle\varphi\rangle = \langle\Omega_t\rangle - \dfrac{1}{np}\langle\Omega_r\rangle; \langle\varphi\rangle = \langle\varphi_t\rangle - \dfrac{1}{np}\langle\varphi_r\rangle \\ \dfrac{d}{dt}\langle\Omega_t\rangle = -\dfrac{1}{J_t}\langle\tau_{urbine} + \tau_{load}\rangle; \\ \tau_{turbine} = P_{turbine}\dfrac{1}{\langle\Omega_t\rangle}; \tau_{load} = D_r\left\langle\Omega_t - \dfrac{1}{np}\Omega_r\right\rangle - Q_s\langle\varphi\rangle, \end{cases} \quad (4)$$

2.2 Generator Model

Among all electrical generators, the cage rotor induction generator is a well-renowned generator for wind energy conversion system applications, when operated vector control theory, a rapid response and exact torque control performance can be obtained (see[28]). According to the

Clerks transformation theory, the cage generator model equations can be written as follows[31]:

$$\frac{d}{dt}\langle\Omega_r\rangle=\frac{3p^2L_m}{2L_rJ}\langle i_\beta\lambda_\alpha-i_\alpha\lambda_\beta\rangle-\frac{pD_r}{nJ}\left\langle\Omega_t-\frac{1}{np}\Omega_r\right\rangle-\frac{pQ_s}{nJ}\langle\varphi\rangle \tag{5.1}$$

$$\frac{d}{dt}\langle\lambda_\alpha\rangle=c_3\langle i_\alpha\rangle-c_4\langle\lambda_\alpha\rangle-\langle\Omega_r\lambda_\beta\rangle; \tag{5.2}$$

$$\frac{d}{dt}\langle\lambda_\beta\rangle=c_3\langle i_\beta\rangle-c_4\langle\lambda_\beta\rangle+\langle\Omega_r\lambda_\alpha\rangle \tag{5.3}$$

$$\frac{d}{dt}\langle i_\alpha\rangle=-c_0\langle i_\alpha\rangle+c_1\langle\lambda_\alpha\rangle+c_2\langle\Omega_r\lambda_\beta\rangle+\frac{\langle V_\alpha\rangle}{\Upsilon L_s}; \tag{5.4}$$

$$\frac{d}{dt}\langle i_\beta\rangle=-c_0\langle i_\beta\rangle+c_1\langle\lambda_\beta\rangle-c_2\langle\Omega_r\lambda_\beta\rangle+\frac{\langle V_\beta\rangle}{\Upsilon L_s}. \tag{5.5}$$

At this instant, we summarize the Eq. (4)-(5) in the state-space wind-generator system model as follows:

$$\begin{cases}\dfrac{d}{dt}\langle\Omega_t\rangle=-\dfrac{D_r}{J_t}\left\langle\Omega_t-\dfrac{1}{np}\Omega_r\right\rangle-\dfrac{Q_s}{J_t}\langle\varphi\rangle-\dfrac{P_{turbine}}{J_t\langle\Omega_t\rangle}\\ \dfrac{d}{dt}\langle\varphi\rangle=\left\langle\Omega_t-\dfrac{1}{np}\Omega_r\right\rangle\end{cases} \tag{6.1}$$

$$\begin{cases}\dfrac{d}{dt}\langle\Omega_r\rangle=\begin{cases}\dfrac{3p^2L_m}{2L_rJ}\langle i_\beta\lambda_\alpha-i_\alpha\lambda_\beta\rangle-\dfrac{pD_r}{nJ}\left\langle\Omega_t-\dfrac{1}{np}\Omega_r\right\rangle\\ -\dfrac{pQ_s}{nJ}\langle\varphi\rangle\end{cases}\\ \dfrac{d}{dt}\langle\delta_{op}\rangle=\langle\Omega_{op}\rangle;\end{cases} \tag{6.2}$$

$$\begin{cases}\dfrac{d}{dt}\langle\lambda_\alpha\rangle=c_3\langle i_\alpha\rangle-c_4\langle\lambda_\alpha\rangle-\langle\Omega_r\lambda_\beta\rangle;\\ \dfrac{d}{dt}\langle\lambda_\beta\rangle=c_3\langle i_\beta\rangle-c_4\langle\lambda_\beta\rangle+\langle\Omega_r\lambda_\alpha\rangle;\end{cases} \tag{6.3}$$

$$\begin{cases}\dfrac{d}{dt}\langle i_\alpha\rangle=-c_0\langle i_\alpha\rangle+c_1\langle\lambda_\alpha\rangle+c_2\langle\Omega_r\lambda_\beta\rangle+\cos\langle\delta_{op}\rangle\dfrac{\langle V_{op}\rangle}{\Upsilon L_s};\\ \dfrac{d}{dt}\langle i_\beta\rangle=-c_0\langle i_\beta\rangle+c_1\langle\lambda_\beta\rangle-c_2\langle\Omega_r\lambda_\beta\rangle+\sin\langle\delta_{op}\rangle\dfrac{\langle V_{op}\rangle}{\Upsilon L_s}.\end{cases} \tag{6.4}$$

Here, we remind the readers that, Ω_{op} , V_{op} are the angle in degrees and amplitude in volts respectively, and can be calculated. In addition, wind speed is the undefined disturbance factor that produces the disturbances in the system and is said to be interrupted parameter of the wind turbine[23, 28]:

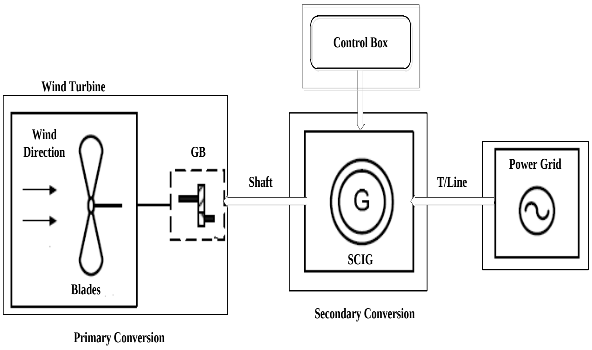

Fig. 03. Shows the block diagram of a wind generator system model which includes a primary conversion and a secondary conversion with the power grid.

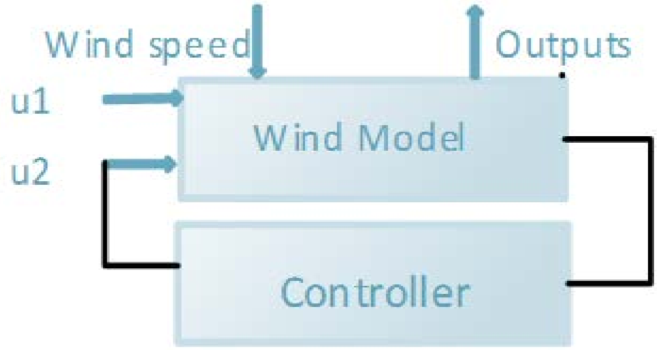

Fig. 04. Shows the wind energy system unit block diagram.

3. Controller Design

The block diagram of the proposed control system is illustrated in Fig. 04. In this paper, for the best performance a new approach has been employed in order to linearize the dynamic wind generator system parameters.However, in order to make the generator drive as a transducer wherein the electromagnetic torque can be identical to torque signal for various machine drive systems. In such a system, speed/position control is dramatically simplified because the electrical dynamics of the drive become irrelevant to the speed/position control issues. In the case of induction generator drive systems, such type of performance can be achieved via field oriented control technique.

We assume that Ω_t is a linear parameter, but due to the nonlinearity of the magnetic flux,which produces the disturbances. Therefore, in this way, the proposed approach is more suitable and having better performance than the conventional control schemes (see[32]). As referred to Eq. (6), and one more footstep of integration,extended in front of V_{op} [31]:

***Observation*:**however, wind speed and dimensionless coefficient is restricted function and considered as bounded C^3 derivative conditions. Therefore, $\tau_{turbine}$ is also bounded C^3 derivative state. The constant parameter values are given in (see Appendix).

Furthermore, the wind-generator dynamic design techniques used for the control systems are based on the state-space linear model. The nonlinear wind-generator model was linearized in the region at an operating situation.

The linearized dynamic model can be described as follows:

$$\begin{cases}\dfrac{d}{dt}\langle\chi\rangle=\langle f(\chi)\rangle_{k+i}+g_k\langle u_k\rangle+g_{k+1}\langle u_{k+1}\rangle+\partial\langle\Sigma\rangle,\\ \qquad k=1,\, i=0,1,2,3,4,\ldots\ldots.,\,8\end{cases} \tag{7}$$

where,

$$\langle\chi\rangle\in\Re^9=\left\langle\begin{bmatrix}\Omega_t & \varphi & \Omega_r & V_{op} & \delta_{op} & \lambda_\alpha & \lambda_\beta & i_\alpha & i_\beta\end{bmatrix}^T\right\rangle; \tag{8}$$

$$\begin{cases} \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=0}} = -\dfrac{D_r}{J_t}\left\langle \chi_k - \dfrac{1}{np}\chi_{k+2}\right\rangle - \dfrac{Q_s}{J_t}\left\langle \chi_{k+1}\right\rangle, \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=1}} = \left\langle \chi_k - \dfrac{1}{np}\chi_{k+2}\right\rangle, \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=2}} = \dfrac{3p^2 L_m}{2L_r J}\left\langle \chi_{k+8}\chi_{k+5} - \chi_{k+6}\chi_{k+7}\right\rangle - \dfrac{pD_r}{nJ}\left\langle \chi_k - \dfrac{1}{np}\chi_{k+2}\right\rangle \\ \qquad -\dfrac{pQ_s}{nJ}\left\langle \chi_i\right\rangle, \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=3}} = \left\langle \chi_{k+i}\right\rangle; \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=4}} = \left\langle \chi_{k+i}\right\rangle; \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=5}} = c_3\left\langle \chi_{k+7}\right\rangle - c_4\left\langle \chi_{k+i}\right\rangle - \left\langle \chi_{k+2}\chi_{k+6}\right\rangle; \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=6}} = c_3\left\langle \chi_{k+8}\right\rangle - c_4\left\langle \chi_{k+i}\right\rangle + \left\langle \chi_{k+2}\chi_i\right\rangle; \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=7}} = -c_0\left\langle \chi_{k+i}\right\rangle + c_1\left\langle \chi_{k+5}\right\rangle + c_2\left\langle \chi_{k+2}\chi_{k+i}\right\rangle \\ \qquad + \left\langle \chi_{k+5}\right\rangle \Upsilon \dfrac{1}{L_s}\cos\left\langle \chi_{i-2}\right\rangle; \\ \left\langle f(\chi)\right\rangle_{\substack{k+i\\ i=8}} = -c_0\left\langle \chi_{k+i}\right\rangle + c_1\left\langle \chi_{i-1}\right\rangle - c_2\left\langle \chi_{k+2}\chi_{i-1}\right\rangle \\ \qquad + \left\langle \chi_{i-2}\right\rangle \Upsilon \dfrac{1}{L_s}\sin\left\langle \chi_{k+4}\right\rangle; \end{cases}$$

$$\begin{cases} g_k = \left\langle \begin{pmatrix}0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0\end{pmatrix}^T\right\rangle; \\ g_{k+1} = \left\langle \begin{pmatrix}0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0\end{pmatrix}^T\right\rangle; \\ \left\langle u\right\rangle \in \Re^2 = \left\langle \left(u_k, u_{k+1}\right)^T\right\rangle \end{cases}$$

$$\partial \in \Re^9 = \left\langle \begin{pmatrix}1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\end{pmatrix}^T\right\rangle; \left\langle \Sigma\right\rangle = -\frac{1}{J_t}\tau_{turbine}.$$

and u_k is the electrical frequency, and u_{k+1} , Ω_{op} are the auxiliary input voltages.

However, we have verified that our investigative dynamic system model is stable, linearize and can be verified through the following proofs:

System proof: Consider the Eq. (7), the design techniques used for the control systems are constructed on the geometrical linearization and are said to bestable and can be described as follows:

Let us consider the nonlinear system which is additionally affected by an unknown bounded disturbance Σ .

$$\frac{d}{dt}\left\langle \Psi\right\rangle = A\left\langle \Psi\right\rangle + B_1\left\langle \Sigma\right\rangle + B_2\left\langle U\right\rangle, \tag{8.1}$$

if we find the linear feedback control, then $\left\langle U\right\rangle = -k\left\langle \Psi\right\rangle$, and $k \in \Re^{1\times 2}$ is a constant matrix, then we obtain,

$$\frac{d}{dt}\left\langle \Psi\right\rangle = \left(A - kB_2\right)\left\langle \Psi\right\rangle + B_1\left\langle \Sigma\right\rangle, \tag{8.2}$$

wetake $\left\langle \bar{A} = A\text{-}kB_2\right\rangle$, and substitute into Eq. (8.2), we get

$$\frac{d}{dt}\left\langle \Psi\right\rangle = \bar{A}\left\langle \Psi\right\rangle + B_1\left\langle \Sigma\right\rangle. \tag{8.3}$$

Let us consider a homogeneous time invariant system of Eq. (8.3), and can be characterized as follows:

$$\frac{d}{dt}\left\langle \Psi\right\rangle = \bar{A}\left\langle \Psi\right\rangle, \tag{8.4}$$

Now we integrate the Eq. (8.4) from the time limit t_0 to t , then we can comprise as follows:

$$\left\langle \Psi(t)\right\rangle = \left\langle \frac{1}{e^{-\bar{A}(t-t_0)}}q\left(t_0\right)\right\rangle, \tag{8.5}$$

where $q\left(t_0\right) = \Psi(t_0)$, therefore, the homogeneous time invariant system Eqs. (8.4) is said to be asymptotically stable if and only if the eigenvalues of the matrix $\bar{A}$ satisfy $\mathrm{Re}\lambda\left(\bar{A}\right) < 0$, then the solution of Eq. (8.3) can be rewritten as follows:

$$\left\langle \Psi(t)\right\rangle = \frac{1}{e^{-\bar{A}(t-t_0)}}\left\langle \Psi\left(t_0\right)\right\rangle + B_1\left\langle \Sigma\right\rangle \int_{t_0}^{t} \frac{1}{e^{-\bar{A}(t-\tau)}d\tau}. \tag{8.6}$$

Furthermore, the Eq. (8.6) can assure the subsequent inequality:

$$\left\langle \left\| \frac{1}{e^{-\bar{A}(t-t_0)}}\left\langle \Psi\left(t_0\right)\right\rangle \right\| \right\rangle + \Upsilon \int_{t_o}^{t} \left\langle \left\| \frac{1}{e^{-\bar{A}(t-\tau)}} \right\| \right\rangle d\tau \ge \left\langle \left\| \Psi(t)\right\| \right\rangle. \tag{8.7}$$

However, it should be noted and reminds the readers that, we assumed $\Upsilon = \max\left\langle \left\| B_1\Sigma\right\| \right\rangle$, where $\Upsilon > 0$ is bounded constant, in view of the fact that, $\mathrm{Re}\left\langle \lambda\left(\bar{\mathrm{A}}\right)\right\rangle < 0$ and $\left\langle \Psi\left(t_0\right)\right\rangle$ is the initially bounded significance, then we can recognize that $\left\langle \Psi(t)\right\rangle$ is said to be asymptotically bounded stable.

Additionally, for steady state circumstances at medium to high momentums, the flux-linkage manages the resistive factor which puts forward to sustain the flux-linkage at the constant level; the stator voltage magnitude should be directly proportional to the electrical frequency (avoiding magnetic saturation [31]).

In the next section, we utilize our proposed controller in order to stabilize the wind turbine system parameters under numerous wind speedcontexts. However, as referred to (see [31]), generator torque versus speed characteristics is relatively abrupt in the vicinity of the synchronous speed, which is nearly equal to Ω_{r} , resulting in by controlling the stator frequency, and is able to roughly control the wind turbine speed and vice versa.

It is a reminded to the readers that, in this study, we propose to employ the nonlinear control algorithm concept in order to obtain the desired performance by avoiding magnetic saturation. In this way, we suppose that the wind turbine speed and stator voltage are set to be at a constant level. Moreover, at any rotating speed, the dq coordinate system of two phases mathematical model of the wind generator system is more convenient, rather than abc(3-phase) static system. In this transformation, the model order is minimized, but does not alter the characteristics of nonlinearities.

The wind energy dynamics system model can be more simplified as follows:

$$\frac{d}{dt}\left\langle \chi\right\rangle = f\left\langle V_{wind}, \chi, \varepsilon, U_{op}\right\rangle, \tag{9}$$

where, $\left\langle \chi\right\rangle \in \Re^5 = \left\langle \left(i_d, i_q, \lambda_d, \lambda_q, \Omega_r\right)^T\right\rangle, u \in \Re^1 = \left\langle \Omega_{op}\right\rangle = \varepsilon$

$$\frac{d}{dt}\left\langle \chi\right\rangle = f\left\langle \chi\right\rangle + g\left\langle \chi\right\rangle u + h\left\langle \zeta\right\rangle,$$

$$g \in \Re^5 = \left(\left\langle \chi_1 \quad \chi_2 \quad \chi_3 \quad \chi_4 \quad \chi_5\right\rangle\right)^T,$$

$$h \in \Re^5 = \left(\left\langle 0 \quad 0 \quad 0 \quad 0 \quad 1\right\rangle\right)^T, \chi_5 = 0;$$

where,

$$\zeta = \frac{1}{J\Omega_r}\left(55.115\rho\pi R^2 V_{wind}{}^3 \frac{\left\langle \dfrac{np}{R\chi_5}V_{wind} - 0.09\right\rangle}{\exp\left(\left\langle \dfrac{np}{R\chi_5}V_{wind} - 0.09\right\rangle\right)^{-1}}\right)p^2.$$

The dynamic system model can be rewritten as follows:

$$\begin{cases} F = \begin{pmatrix} F_1 & F_2 & F_3 & F_4 & F_5 \end{pmatrix}^T + \begin{pmatrix} \chi_2 & -\chi_1 & \chi_4 & -\chi_3 & \chi_5 \end{pmatrix}^T \Omega_{op} \\ \quad + \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \end{pmatrix}^T \zeta; \end{cases} \tag{10}$$

where,

$$F_1 = -\left\{\frac{{M_m}^2 R_r + {L_r}^2 R_s}{\delta L_s {L_r}^2}\right\}\langle \chi_1 \rangle + \left\{\frac{M_m R_r}{\delta L_s {L_r}^2}\right\}\langle \chi_3 \rangle + \left\{\frac{M_m}{\delta L_s L_r}\right\}\langle \chi_5 \chi_4 \rangle + \left\{\frac{\Upsilon^{-1}}{L_s}\right\}\langle U_{op} \rangle;$$

$$F_2 = -\left\{\frac{{M_m}^2 R_r + {L_r}^2 R_s}{\delta L_s {L_r}^2}\right\}\langle \chi_2 \rangle - \left\{\frac{M_m}{(\Upsilon) L_s L_r}\right\}\langle \chi_3 \chi_5 \rangle + \left\{\frac{M_m R_r}{(\Upsilon) L_s {L_r}^2}\right\}\langle \chi_4 \rangle;$$

$$F_3 = \left\{\frac{M_m R_r}{L_r}\right\}\langle \chi_1 \rangle - \left\{\frac{R_r}{L_r}\right\}\langle \chi_3 \rangle - \langle \chi_4 \chi_5 \rangle;$$

$$F_4 = \left\{\frac{M_m R_r}{L_r}\right\}\langle \chi_2 \rangle - \left\{\frac{R_r}{L_r}\right\}\langle \chi_4 \rangle + \langle \chi_3 \chi_5 \rangle;$$

$$F_5 = \left\{\frac{1.5 p^2 M_m}{J L_r}\right\}\langle \chi_2 \chi_3 \rangle - \left\{\frac{1.5 p^2 M_m}{J L_r}\right\}\langle \chi_1 \chi_4 \rangle;$$

Basically, cage rotor induction generator dynamic model is presented in a synchronous reference framework. It is again reminds to the reader that in this situation, $\Omega_r = \Omega_t \times np$ and we suppose that, at symmetry conditions the stator voltage magnitude of the generator and wind speed is predetermined at the unvarying position. What is more, by the symmetry conditions, the negative incline of the torque and speed characteristics makes the dynamic system exponentially stable as exposed in (see Sec. 8.5 [31]).

4. Simulation Result

In this Manuscript, a controller has been designedfor a wind-generator system based on the feedback linearization concept through vector control conceptsin order to stabilize the system. Through the Matlab tool, we simulated a random wind speed, a rotor speed, currents and the magnetic fluxes in the*dq*synchronous frame atthe time frame of 8 sec.However, the random wind speed signal applied to the wind-generator system as shown in Fig. 05; where the average winds speed is around 6.8 m/sec,the regime wind speed upper and the lower limit is around 7.8 m/s after 6 sec and 5.8 m/s after 2.4 sec, respectively, and is presumed to be stable. The generated rotor speed is supposed to be stable after 3 sec and can be easily visualizedin Fig. 06. Whereas, asfluxes in the*dq*synchronous frame are bounded and is said to be fully stable after4 sec as shown in Fig. 07 (a)& Fig. 07 (b), respectively. On the other hand, two currents in*dq* frame are depicted in Fig. 07 (c) & Fig.07 (d) respectively, and are said to be linearized and stable after around 4.5 sec and 4 sec respectively. Nevertheless, simulated clarification is supposed to stay at bounded stable circumstances and creates perfect effective consequence with a realistic performance at randomwind speed. However, we put our model into practice convolution of the proposed schemes, clearly higher dynamic system performance was our main aim and to this end, in view of the fact that, wind generator system operates for the long duration of a time, a small improvement in stability guarantees a higher level and leads to price subsiding.

It is reminded to the readers that the good damping performances have been obtained throughout the rigorous wind speed, and have reasonably well in practice and undoubtedly demonstrated the proposed controller design.

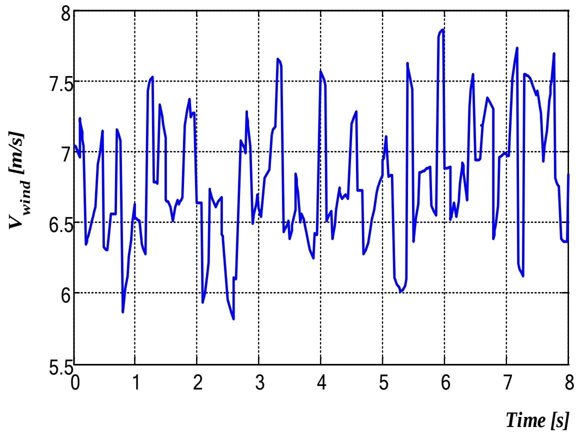

Fig. 05. A real wind speed response versus time.

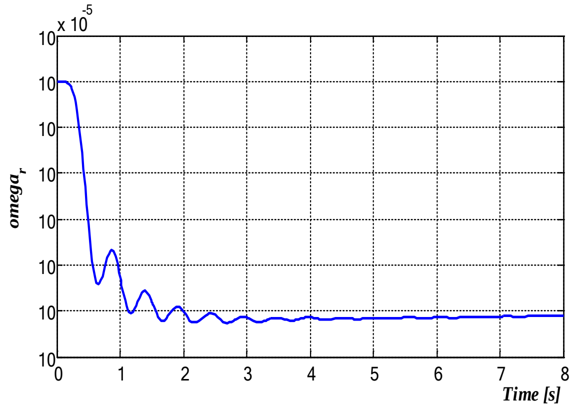

Fig. 06. A rotor speed component response versus time.

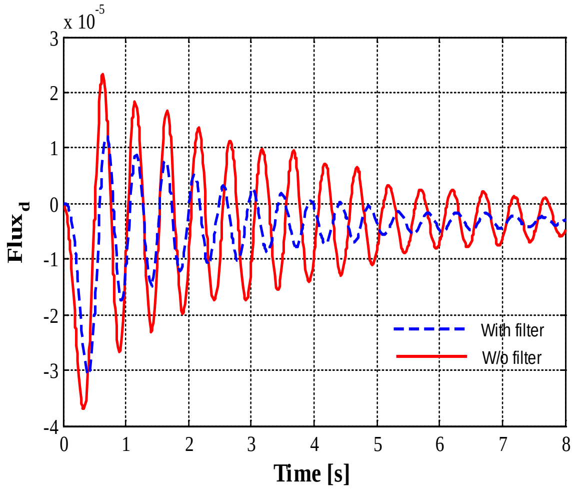

Fig. 07 (a)

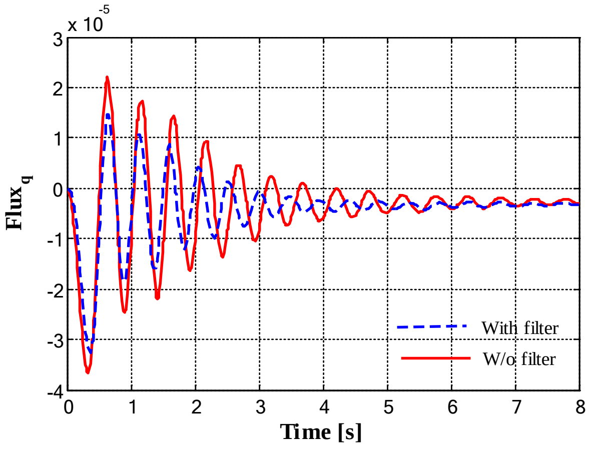

Fig. 07 (b)

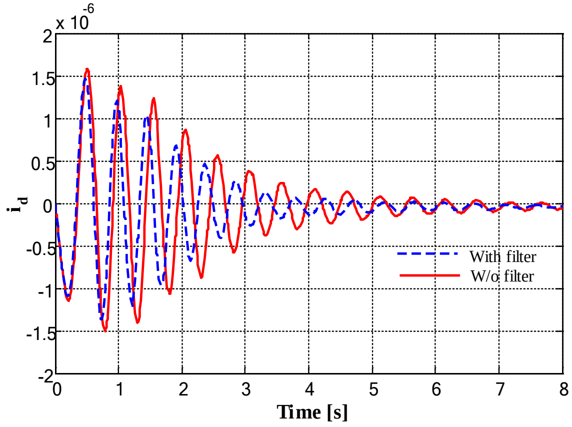

Fig. 07 (c)

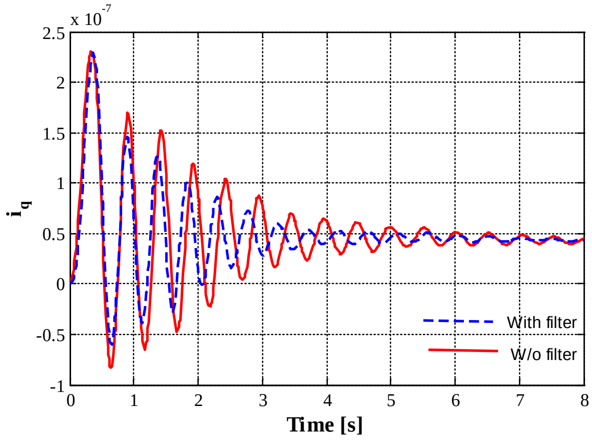

Fig. 07 (d)

Fig 7. Throughout the proposed techniques, robustness analysis with a small percent increment in the stability is our primary aim and to this end, in order to scarify the simplicity in the case of stability. Therefore, the smaller scale improvement in damping/oscillation improves the wind-generator system performance regarding stabilitywhere (blue dashed line) shows with the filter (low pass filter), and higher damping (solid red line) shows without the filter.

5. Conclusion

In this paper, a nonlinear control dynamic wind-generator system model has been simulated in order to stabilize the system parametersthrough feedback control concept based on FOC concept. The anticipated concept is a low cost and is more suitable for wind energy applications. The proposed study can readily be expanded to other classes of wind energy systems without major changes.

Furthermore, though the proposed control design concept is easy to design, efficient and we achieve the desired outcomes. Finally, the future recommendations are described as follows:

- The future growth of the wind generator system requires an operational research which must constitute for stability and control.
- The proposed wind generator dynamic system still required some state of art endeavors in order to compact with the authentic instance for stability &control with the support of intelligent coordination's.
- Smart wind-generator systems, monitoring, safety, security, and maintenance should be an opportunity for advanced study.
- Continuing for future directions of the proposed approach can readily be extended to supplementary categories of wind energy conversion system without chief amendments.

Appendix: Standard values and their units.

$$\begin{cases} \text{R}=0.01\times10^{3}\text{m};\rho=1250\times10^{-3}\text{kg/m}^{3};\text{J}_{\text{t}}=0.1\times10^{3}\text{kgm}^{2}. \\ \text{n}=0.02\times10^{3};\text{Q}_{\text{s}}=2\times10^{6}\text{Nm/rad};\text{J}=0.0111\times10^{3}\text{kgm}^{2}. \\ \text{J}_{\text{t}}\text{- Inertia of turbine.Stator resistance R}_{\text{s}}=262\text{m}\Omega. \end{cases}$$

$$\begin{cases} \text{c}_{\text{o}}=\text{c}_2\text{c}_3+\left\langle 1\text{-M}_{\text{m}}{}^{2}/\text{L}_{\text{s}}\text{L}_{\text{r}}\right\rangle^{-1}\text{R}_{\text{s}}/\text{L}_{\text{s}}.\ c_1=\text{c}_2\text{c}_4.\text{M}_{\text{m}}=0.14336\text{H}. \\ \text{c}_2=\left\langle 1\text{-M}_{\text{m}}{}^{2}/\text{L}_{\text{s}}\text{L}_{\text{r}}\right\rangle^{-1}\text{M}_{\text{m}}/\text{L}_{\text{s}}\text{L}_{\text{r}}.\ \text{J-Inertiaof cage-rotor IG.} \\ \text{c}_3=\text{L}_{\text{m}}\text{R}_{\text{r}}/\text{L}_{\text{r}};\text{c}_4=\text{R}_{\text{r}}/\text{L}_{\text{r}}.\ \text{Rotor resistance R}_{\text{r}}=187\text{m}\Omega; \\ \text{L}_{\text{s}}=\text{L}_{\text{ls}}+\text{M}_{\text{m}}.\text{L}_{\text{r}}=\text{L}_{\text{lr}}+\text{M}_{\text{m}}.\ \text{U}_{\text{op}}=1880\text{V}. \\ \text{L}_{\text{lr}}=\text{L}_{\text{ls}}=0.0032\text{H};\text{D}_{\text{r}}=500\text{k-Nms/rad. }\rho\text{-Wind density.} \\ \text{R- Length of turbine blade.}\Upsilon=1-M_m{}^{2}/L_sL_r. \\ \alpha,\beta\text{- Reference frame work.V}_{\text{wind}}\text{- Wind speed }(\text{m/s}). \\ \text{i}_{\alpha},\text{i}_{\beta}\text{- Stator currents.}\lambda_{\alpha},\lambda_{\beta}\text{- Rotor fluxes.} \\ \tilde{\theta}\text{-Pitch angle.V}_{\alpha},\text{V}_{\beta}\text{- Stator voltages.V}_{\text{op}}\text{- Peak input voltage.} \\ \tilde{\theta}\text{- Blade pitch angle }(\text{rad}).\text{ p- No. of pair of poles.} \\ \text{n-Gearbox ratio. }\Omega_{\text{r}}\text{-Elec. angular frequency }(\text{rad/s}). \\ \varphi_{\text{t}}\text{-Turbine angle radians.}\Omega_{\text{t}}\text{-Wind turbine speed }(\text{rad/s}). \\ \text{L}_{\text{s}},\text{L}_{\text{r}},\text{M}_{\text{m}}\text{- Stator, rotor \& mutual inductance, respectively.} \\ \varphi_{\text{r}}\text{-Rotor angle.Q}_{\text{s}}\text{-Spring stiffness coefficient.D}_{\text{r}}\text{- Damping factor.} \end{cases}$$

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