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LQR and Observer based controller design performance analysis of the wind energy system based on induction generator

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Abstract: Pakistan is currently amid an energy crisis and the same is to be expected to be in future coming years. Renewable energies have played an important role in overcoming energy crises. Besides all renewable energy resources, wind energy is the most well-known source for power generation and it offers enormous benefits such as it is clean, naturally cordial, and financially practicality sustainable power source asset. This manuscript presents a novel application of LQR/observer-based controller that will provide a robust analysis of the wind energy conversion system (WECS) to get efficient production of wind energy from available resources. The proposed design scheme uses the squirrel cage induction generator. The linear quadratic regulator controller implements a full-state observer for estimation of state variables. Furthermore, in this research study the control strategy is used to linearize the non-linear wind energy conversion system (WECS) through feedback linearization techniques by regulating voltage and frequency Induction Machine). The validity of the LQR controller based scheme is verified by the simulation results which are performed using MATLAB tool.

***Index Terms*— Linear Quadratic Regulator (LQR), Observer-Based Controller, Robust, Wind Energy Conversion System (WECS).**

I. INTRODUCTION

Beside all renewable energy resources, wind energy is the most well-known source for power generation and it offers enormous benefits such as it is clean, naturally cordial and financially practicality sustainable power source asset, and is planned by many created and creating nations as a promising intends to give electrical energy. However, for achieving an actual sustainable system it is important to consider the environmental impact of wind energy conversion systems. [1]. Extensive research has been carried out to employ various control strategies in modern WECSs to resolve technical issues related to a wind turbine. In this stance, detailed modelling of wind turbines is required for analyzing the performance of a wind energy conversion system under any grid-side fault condition and also for power system stability studies. The use of modern wind energy technology with large scale wind turbine system, variable speed wind turbine play a vital role in power system due to low cost, flexibility and reliability and it is also one of the most preferred technology. Whenever the disturbances occur in the wind system, the wind turbine does not take part either in voltage control or frequency control [2]. As the wind velocity is not constant and wind turbine requires a rotation speed at which it produces maximum output, therefore, wind turbine system is operated at different variable speeds to maintain wind velocity by changing rotation speed [3]. Mathematical modelling plays an integral part in understanding the behaviour of WT over its operating region and enables the control of wind turbines performance. Much attention has been paid for designing various control techniques. Referring to (see [4-7]), to form a complete control system they combined several observers with controllers for tracking the reference optimal speed of generators. [8] used a polynomial observer by sum-of-square (SOS) technique to estimate aerodynamic torque of WECS. [9] Proposed MIMO LQR damping controller for DFIG based wind farms. [11] presents a linear quadratic regulator algorithm-based controller scheme for improving the characteristics of wind turbine generator systems.

In this manuscript, a robust control model is designed for analyzing non-linear variable speed wind turbine system. The general model provides aid to study the impacts of those advanced control strategies on a systematic level on wind turbines.

II. WIND ENERGY CONVERSION SYSTEM MODELING

The overall block diagram of a WECS structure is shown in Fig. 1. The wind turbine is the fundamental device in the wind energy conversion system that converts kinetic energy into mechanical energy that can be further used for electricity generation.

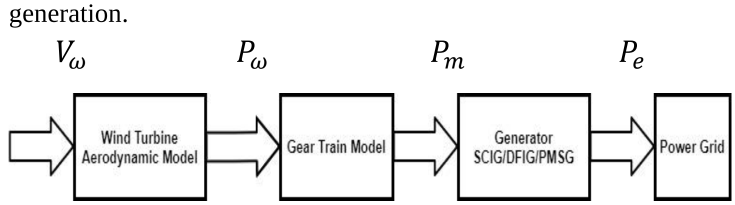

Fig. 1. Block diagram of general WECS.

The output power of a wind turbine can be computed using the following equations [2,8,10-11].

$$P_\omega = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v_\omega^3 \qquad (1)$$

Where ρ = density of wind in (kg/m^3), R=radius of a wind turbine in (m), v_ω=wind speed in (m/sec),

C_p=power co-efficient which is function of tip speed ratio λ and blade angle Θ. The tip-speed ratio λ is defined as:

$$\lambda = \frac{\omega_t R}{v_\omega} \tag{2}$$

Here ω_t =rotor speed of the turbine.

The wind turbine torque can be calculated by [12]:

$$T_\omega = \frac{P_\omega}{\omega_t} = \frac{1}{2}\rho\pi R^3 C_q(\lambda,\beta)v^3 \tag{3}$$

where $C_q(\lambda,\beta) = C_p(\lambda,\beta)/\lambda$ is torque coefficient.

III. Squirrel Cage Induction Generator

A general wind turbine model is shown in Fig. 2. research uses squirrel cage induction generator that is commonly used for variable speed wind energy conversion system because of enormous advantages such as it is economical, robust, rugged, provides exact torque control and it can produce useful power at varying rotor speeds.

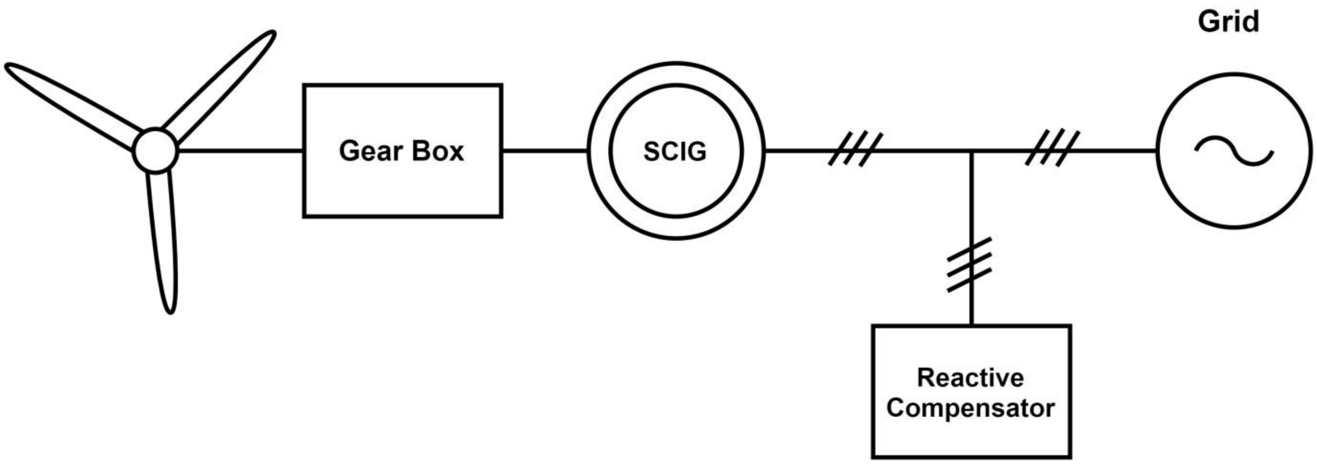

Fig. 2. A wind turbine system model including SCIG

The dynamic model of SCIG in (α, β) coordinate systems is expressed as [3,13-14]

$$\dot{\omega}_{r=1.5p^2 Lm\frac{1}{L_r j}(i_\beta\psi_\alpha - i_\alpha\psi_\beta)-\eta,} \tag{4}$$

$$\psi_\alpha = C_3 i_\alpha - C_4\psi_\alpha - \omega_r\psi_\beta; \tag{5}$$

$$\psi_\beta = C_3 i_\beta - C_4\psi_\beta + \omega_r\psi_\alpha; \tag{6}$$

$$i_\alpha = v_\alpha\frac{1}{\gamma L_s} - C_0 i_\alpha + C_1\psi_\alpha + C_2\omega_r\psi_\beta; \tag{7}$$

$$i_\beta = v_\beta\frac{1}{\gamma L_s} - C_0 i_\beta + C_1\psi_\beta - C_2\omega_r\psi_\beta; \tag{8}$$

Here

$$\eta = pD_r\frac{1}{gJ}\left(\omega_t - \frac{1}{gp}\omega_r\right) - \frac{1}{gJ}pQ_s 0; \tag{9}$$

Where iα and iβ are stator currents in (α,β) coordinate system, vα and vβ are stator voltages in (α,β) coordinate system, ψ_α and ψ_β are the rotor flux in (α,β) coordinate system, , Ls is the inductance of stator, Lm is mutual inductance, g is gearbox ratio, J is the inertia of induction machine, P shows the no. of pole pairs of SCIG.

IV. Controller Design

Wind turbines having random wind speed give variable values of frequency and voltage without the usage of the controller element. The research study uses an observer based controller and linear quadratic regulator (LQR). However, modelling and control of WECS system connected to the AC grid supply have been presented. The linear quadratic regulator is a robust controller, which provides less computational complexity and realistic responses for variable wind speed data. The controller design strategies depend on state-space mathematical modelling and can be accomplished through the dynamic simulation software MATLAB.

V. Results and discussion

The mathematical modelling of WECS wind turbine dynamics, controller and generator modelling is linearized and simulated in MATLAB by generating a MATLAB code. The initial step responses at variable speed WECS of non-linearized systems are observed. Finally, the controllers are used and response curves are shown in fig. 3. The simulation results prove LQR gives optimal and stable response as compared to an observer based controller.

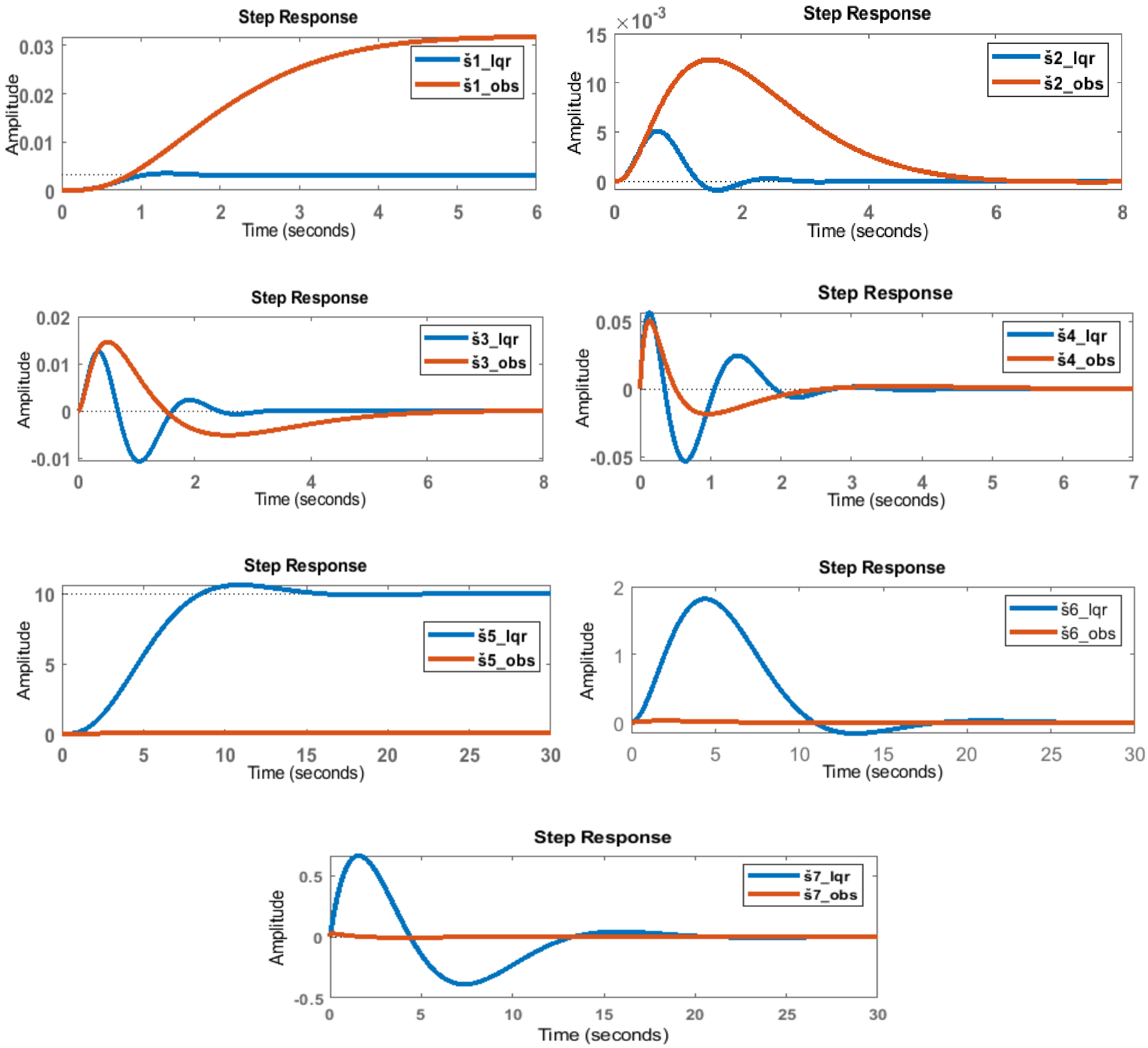

Fig. 3. State variable response of (š1-**š**7) using LQR and observer.

VI. CONCLUSION

Various control methods have been proposed and implemented due to the complexity of the wind turbine system. The research presents a novel approach of LQR and Observer Based Controller. A general mathematical model for variable speed wind turbine has been (Coded) analytically derived and simulated. This proposed LQR control design is then validated with the optimized observer-based controllers. The performance of the LQR controller is tested under different operating conditions. The proposed control design is then validated with the optimized observer-based controllers. The performance of the LQR controller is tested under different operating conditions. The analysis given by simulation proves that the system variable performances using LQR controller are superior to those achieved by the observer-based controller. It can be claimed that the LQR controller is an efficient approach that guarantees the system stability. Besides, this proposed LQR controller applies to various control schemes to achieve satisfactory responses.

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