International Seminar On Non-Conventional Energy Sources for Sustainable Development of Rural Areas,
IJAERD- International Journal of Advance Engineering & Research Development
e-ISSN: 2348-4470, p-ISSN:2348-6406
Impact Factor: 4.72, DOI:10.21090/ijaerd

Simulation of Power Control of a Wind Turbine Permanent Magnet Synchronous Generator System

Mr. Biswa Bhusan Dash
Department of Electrical Engg
University of CSVTU, Bhilai

Mr. Murlidhar
Department of Electrical Engg
University of CSVTU, Bhilai

Abstract - ***This thesis presents a control system for a 2MW direct-drive permanent magnet synchronous generator wind turbine system with the objectives to capture the optimal power from the wind and ensure a maximum efficiency for this system. Moreover, in order to eliminate the electrical speed sensor mounted on the rotor shaft of the PMSG to reduce the system hardware complexity and improve the reliability of the system, a sliding mode observer based PM rotor position and speed sensor less control algorithm is presented her***

Keywords- WECS, PMSG, DTC, FOC.

I. INTRODUCTION

Electrical and hybrid vehicles, which are considered as the best replacement of conventional fossil fuel internal combustion engine based vehicles, have been greatly evolving and significantly commercialized during the recent years. Accordingly, there will be a growing demand for electrical energy when these vehicles become part of the electric grid load. Conventional electrical energy sources depend heavily on fossil fuels burning. However, burning of the fossil fuels causes environmental issues such as global warming, acid rain and urban smog, etc. by releasing carbon dioxide, sulfur dioxide, and other pollutants into the atmosphere [1]. Based on the issue, the renewable energy, which includes photovoltaic energy, wind energy, and geothermal energy, etc., has been heavily investigated and rapidly developing [2].

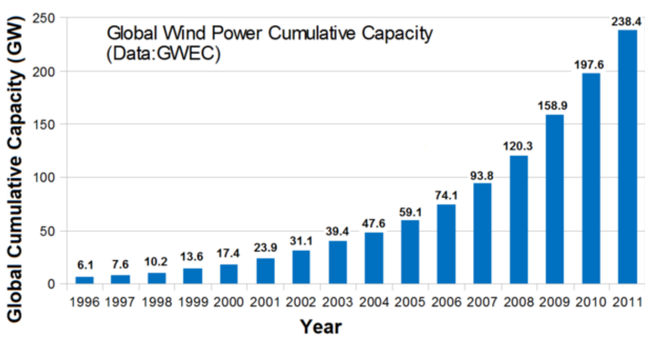


Figure 1.1 Global cumulative wind power capacity [5]

The direct-drive wind turbine PMSGs do not have the gearbox between the wind turbine and the PMSG rotor shaft, which avoids the mechanical power losses caused by the gearbox. Moreover, the removal of the gearbox also helps in reducing the cost of the system. The overall configuration of a direct-drive wind turbine PMSG system is shown in Figure 1.2. As can be seen in this figure, this system is composed of a wind turbine PMSG, a rectifier, and an inverter. The wind turbine PMSG transforms the mechanical power from the wind into the electrical power, while the 4 rectifier converts the AC power into DC power and controls the speed of the PMSG. The controllable inverter helps in converting the DC power to variable frequency and magnitude AC power. With the voltage oriented control algorithm, the inverter also possesses the ability to control the active and reactive powers injecte into the grid.

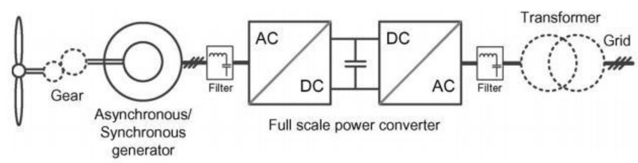


Figure *1.2* Wind turbine generators with full-scale power converters [8]

II. Control of Generator-Side Converter

In wind turbine PMSG systems, three system variables need to be strictly controlled [6]: (1) the optimal power generated by the PMSG at different wind speed levels; (2) the active and reactive power injected into the grid; (3) the DC bus voltage of the back to back converter. Figure 3.1 shows a direct-drive wind turbine PMSG fed by a back-to-back converter. In this system, the generator-side converter regulates the speed of the PMSG to implement the MPPT control. Meanwhile, the grid-connected converter controls the active and reactive power injected into the grid.

The optimal tip speed ratio based maximum power point tracking (MPPT) control is analyzed in this chapter. Two important PMSG control algorithms, the direct torque control (DTC) and the field oriented control (FOC), are analyzed and compared. Then, the simulation results of the generator-side converter control are given to validate the principles of control algorithms.28

III. Field Oriented Control based Generator-Side Converter Control

this thesis, the *d*-axis and *q*-axis inductances are equal (4). Thus, the torque expression can be simplified and rewritten as follows:

(3.1) In order to achieve the maximum torque per ampere, the *d* axis current is set at zero. In expression (3.1), is the flux linkage due to the permanent magnets which is a constant. Thus, there will be a linear relationship between the electromagnetic torque and the *q* axis current, such that the electromagnetic torque can be easily controlled by regulating the *q*-axis current. The phasor diagram for the FOC approach .

IV. Maximum Power Point Tracking Control

Direct-drive PMSGs have the capability to work in a wide speed range. According to the intensity of the wind, the wind turbine generators need to be controlled

1. Parking Mode: when the wind speed is lower than the cut-in speed which is (9mph) in this system, the wind turbine will not rotate but stay in parking status due to the fact that the electrical power generated by the PMSG system is insufficient to compensate for the internal power losses in this system. Therefore, the wind turbine is kept in parking mode by a mechanical brake; 29

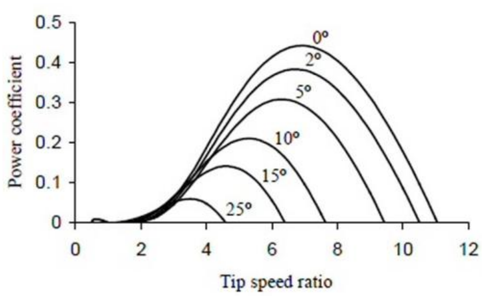


Figure 1.3 Power coefficient characteristics

2. MPPT mode: when the wind speed is greater than the cut-in speed, the wind turbine system starts to work and generate electrical power. Because the wind speed is in a relatively low range in the MPPT mode, the power captured by the wind turbine is below its rated value, the MPPT control needs to be applied to ensure a maximum efficiency of power capture. The MPPT mode ends when the wind speed is greater than the rated wind speed, (29mph), for this case-study system. 3. Constant power region: when the wind speed becomes greater than the rated value, the power generated by the system will be larger than its rated power if the MPPT control is still applied. This will increase the electrical stress on the PMSG and the power processing devices, and would further damage them. Therefore, the blade angle of the wind turbine blades needs to be properly controlled in the strong wind range to keep the system operating within its rated output condition. As its name implies, this is constant power region. In Chapter 2, the expression of the mechanical power captured by the wind turbine has been expressed as: (2.7) the power coefficient, , can be expressed in Figure 1.3.30

V. Comparison between Direct Torque Control and Field Oriented Control

Direct torque control (DTC) and field oriented control (FOC) are two of the most commonly applied algorithms for the control of PMSMs. The DTC approach was first developed and presented by I. Takahashi from Japan [43]. The basic principle of the DTC approach is that the stator flux linkage and the electromagnetic torque are estimated and compared with their reference values. Based on the control algorithm of mitigating the errors between the reference and estimated values, the reference torque and flux can be achieved by controlling the inverter states. The FOC approach was pioneered by F. Blaschke in 1970s [44]. The FOC approach has been and continues to be a significant factor in PMSMs control, which makes it possible that PMSMs can be controlled as 32 easily as DC machines. In the FOC approach, the *dq*-axes are rotating at the rotor electrical angular speed with the *d*-axis aligned with the rotor flux direction. Thus, the flux producing current component, , and the torque producing current component, , are along the *d*-axis and *q*-axis, respectively. Thus, the *dq*-axes currents can be controlled independently by two closed loop controls in the FOC approach, which indirectly controls the speed and the torque of the PMSMs. When choosing one control strategy of either DTC or FOC for the generator-side converter control, their merits and drawbacks need to be analyzed and compared according to the operation requirements of the direct-drive PMSG systems.

VI. Simulation Results and Analysis

Simulation studies were carried out in MATLAB-Simulink to validate the chosen case-study system. In order to approximate the performance of the discrete-time 36 microcontrollers which are commonly used in industrial control systems, such as the digital signal processors (DSPs), the chosen simulation type in Simulink is set as a discrete-type with a sample time of 2 microsecond. The parameters of the case-study wind turbine and the associated PMSM are shown in Table 3.1. Figure 3.7 shows the circuit diagram of the system built in Simulink, and Figure 3.8 shows the control scheme of the FOC approach in Simulink. Table 3.1 Parameters and operating conditions of the generator side control system [6]

Simulation results of the proposed system are shown in Figures 3.9 through 3.17. Figure 3.9 show.

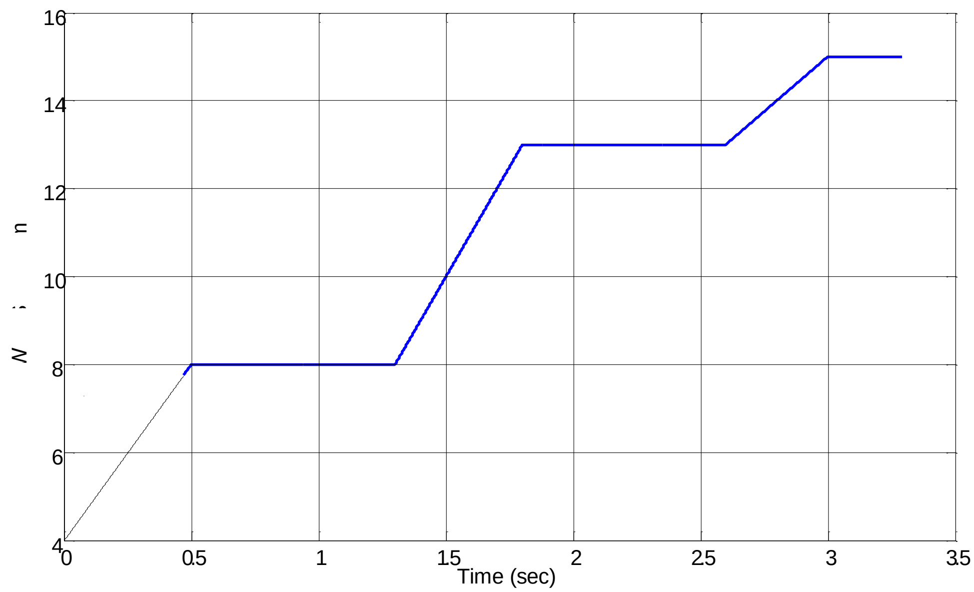


Figure 3.9 Wind speed input for the wind power generation system

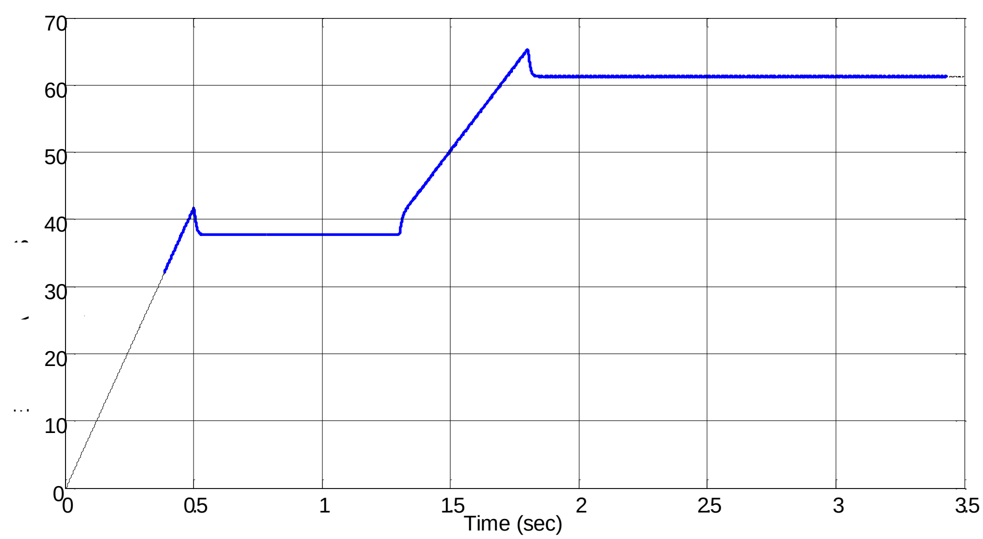


Figure 3.10 Actual electrical angular speed of the PMSG

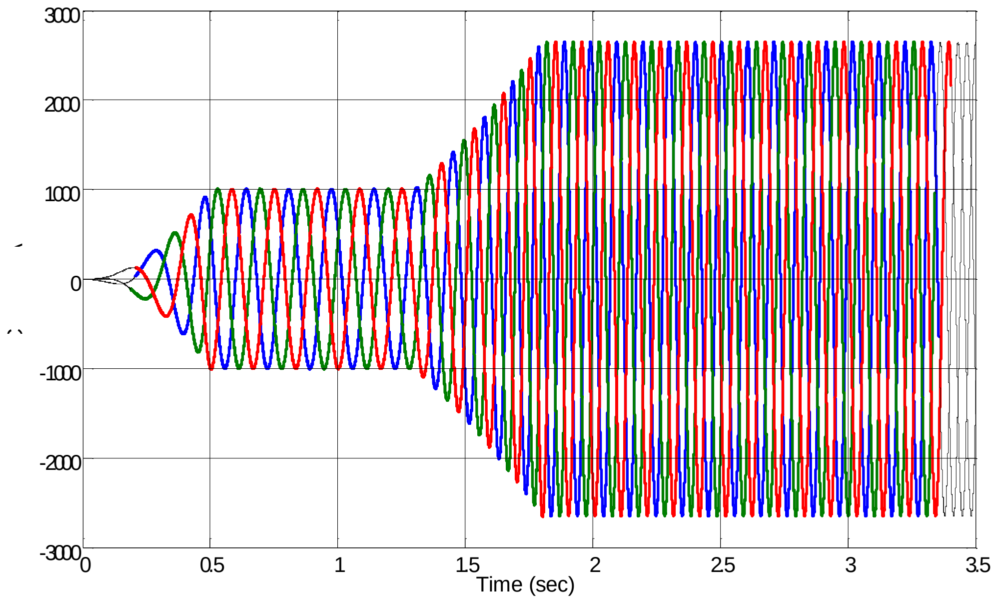


Figure 3.11 Three-phase stator currents of the PMSG

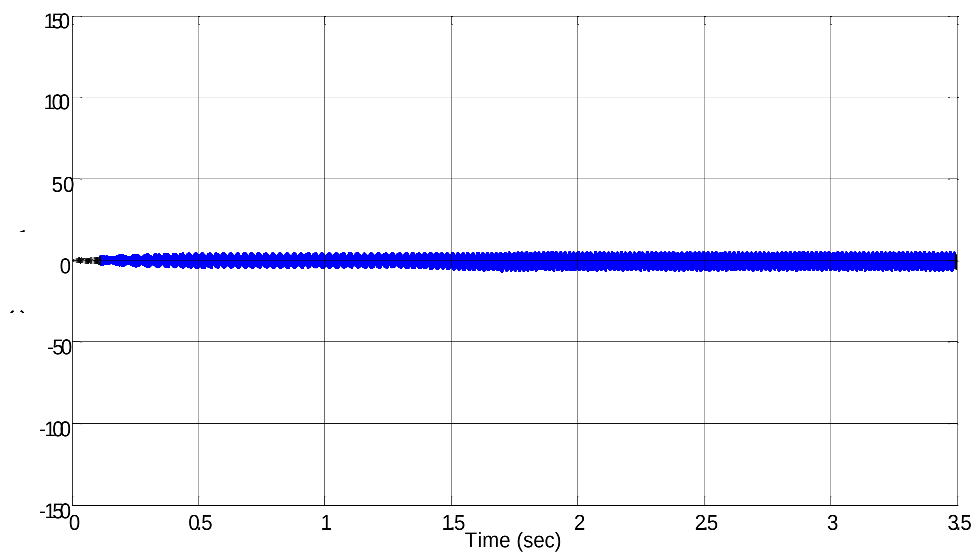


Figure 3.12 *d*-axis current of the PMSG

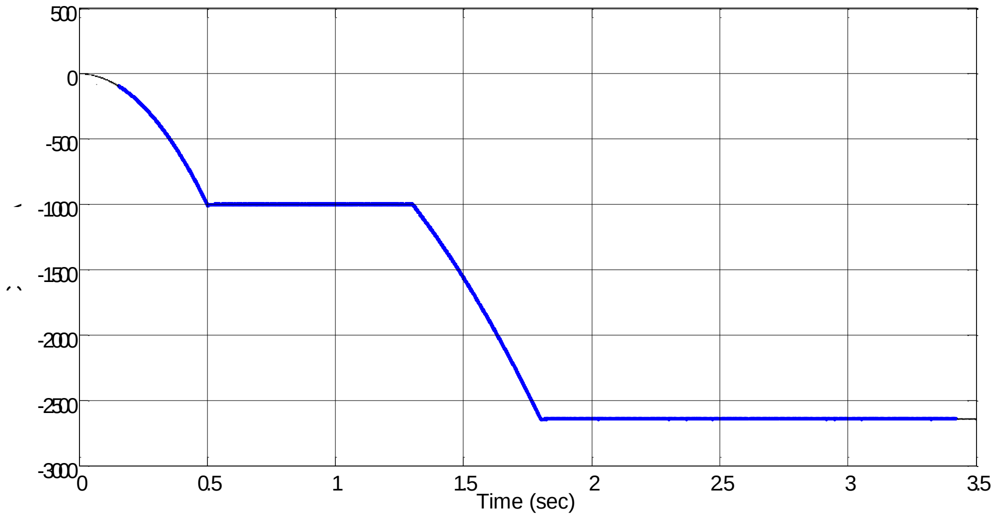


Figure 3.13 *q*-axis current of the PMSG

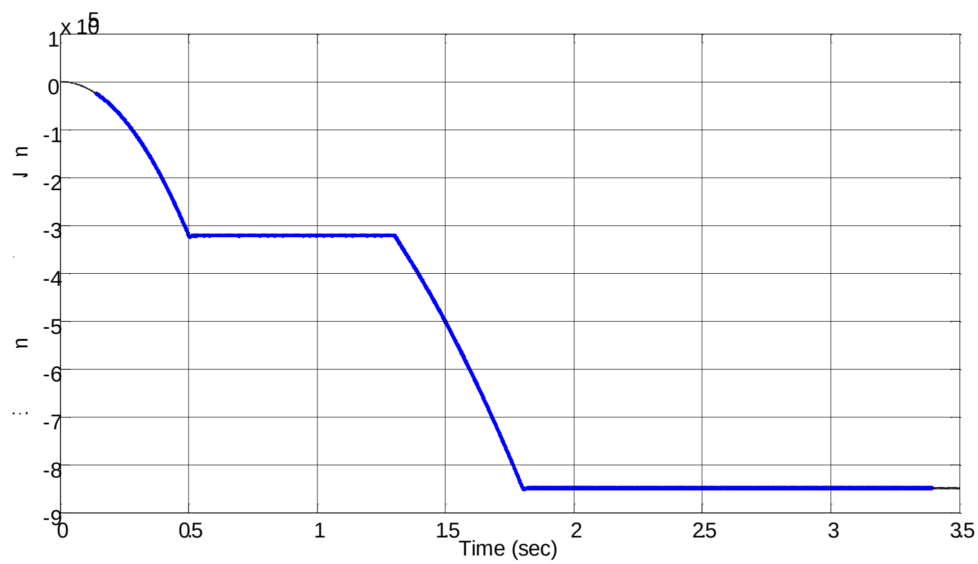
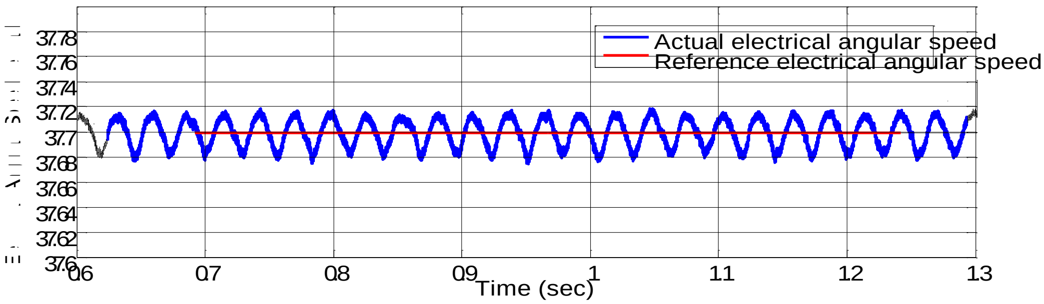
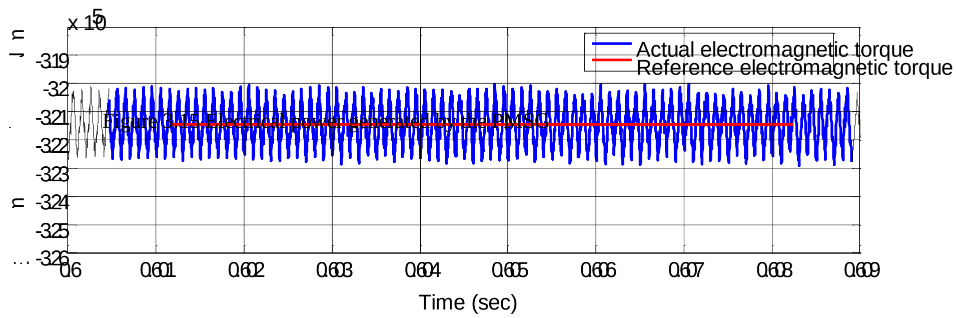


Figure 3.14 Electromagnetic torque developed by the PMSG



(a) Actual generator electrical angular speed vs. analytical value

(b)



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(b) Actual electromagnetic torque vs. analytical value

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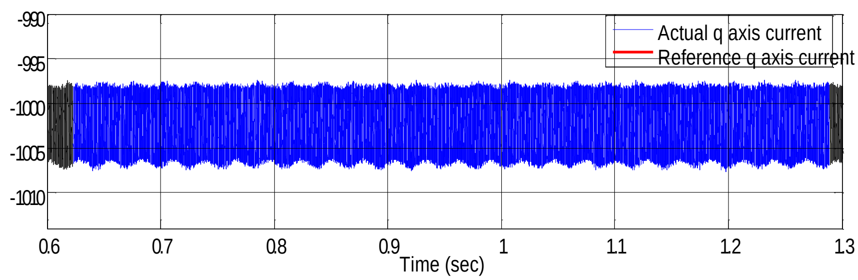
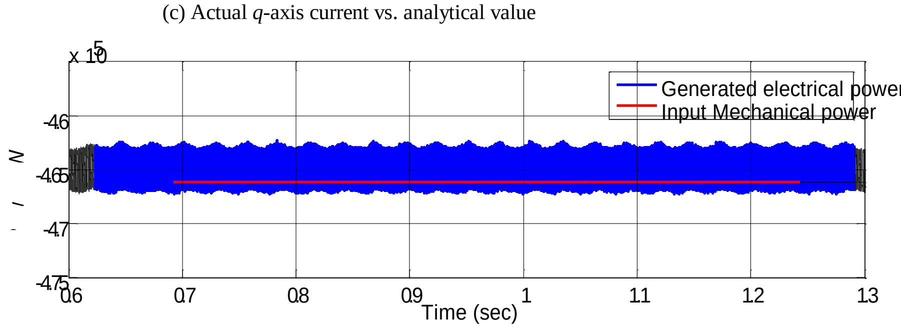
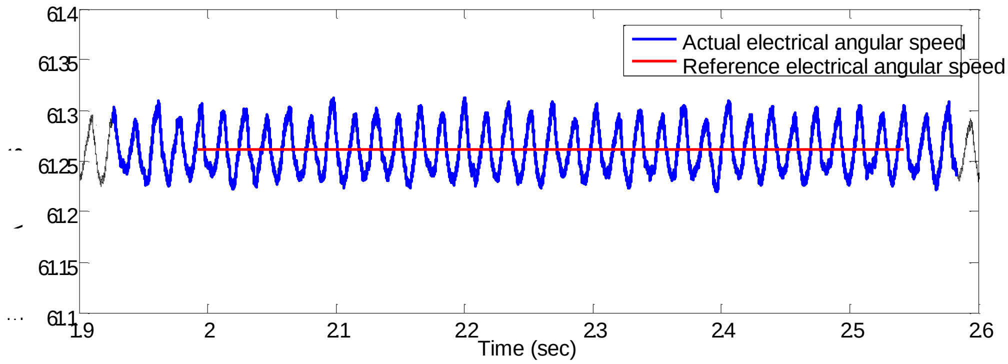


(c) Actual *q*-axis current vs. analytical value

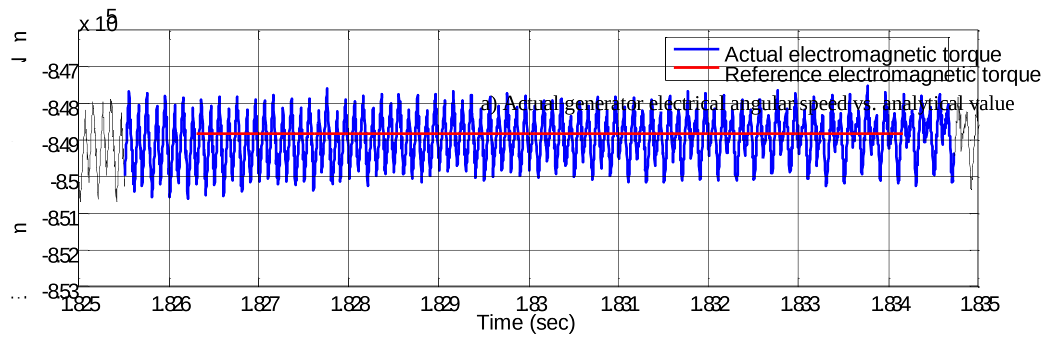


(d) Actual generated electrical power vs. input mechanical power

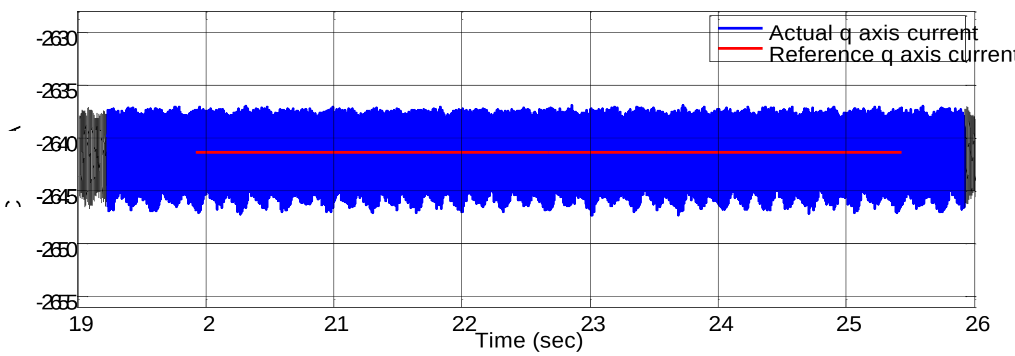
Figure 3.16 System Parameters in Static States with Wind Speed of zIO



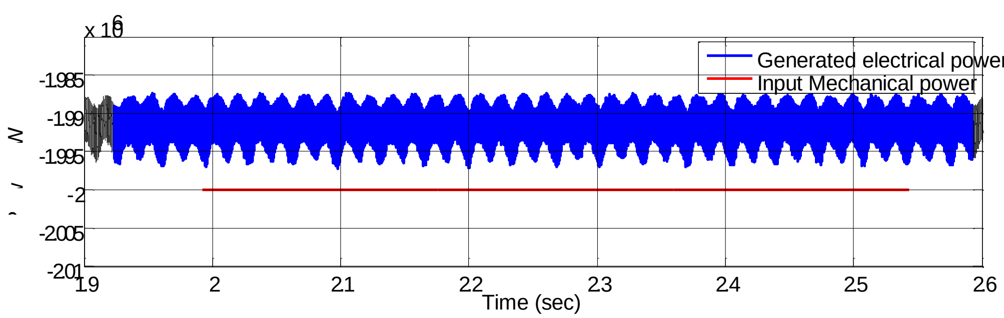
a) Actual generator electrical angular speed vs. analytical value



(b) Actual electromagnetic torque vs. analytical value



(c) Actual *q*-axis current vs. analytical value



(d) Actual generated electrical power vs. input mechanical power

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Try to avoid the stilted expression, “One of us (R. B. G.) thanks …” Instead, try “R.B.G. thanks …” Put sponsor acknowledgments in the unnumbered footnote on the first page.

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