Wind generation model (Assignment 3)

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Contents

List of Figures

List of Tables

Chapter 1

Wind Turbine Model

1.1 General Overview of the Wind TURBINE Model

The figure 1.1 illustrates a wind turbine system where the wind turns the turbine blades, which have a pitch angle (θ_{pitch}) set to zero. This means the blades are positioned to capture maximum wind energy. The rotational motion (ω_t) generated by the turbine is transferred to a gearbox, which adjusts the rotational speed (ω_g) before transferring it to the rotating load, typically a generator. This setup optimizes the conversion of wind

Wind Turbine model is represented as:

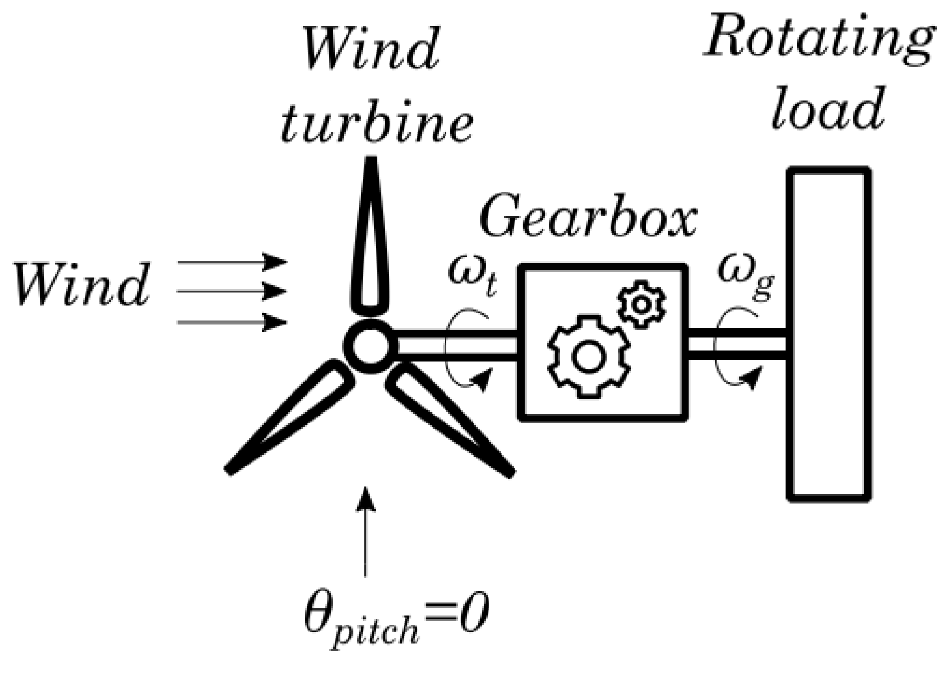

Figure 1.1: Wind Turbine Model

energy into mechanical energy and subsequently into electrical energy.

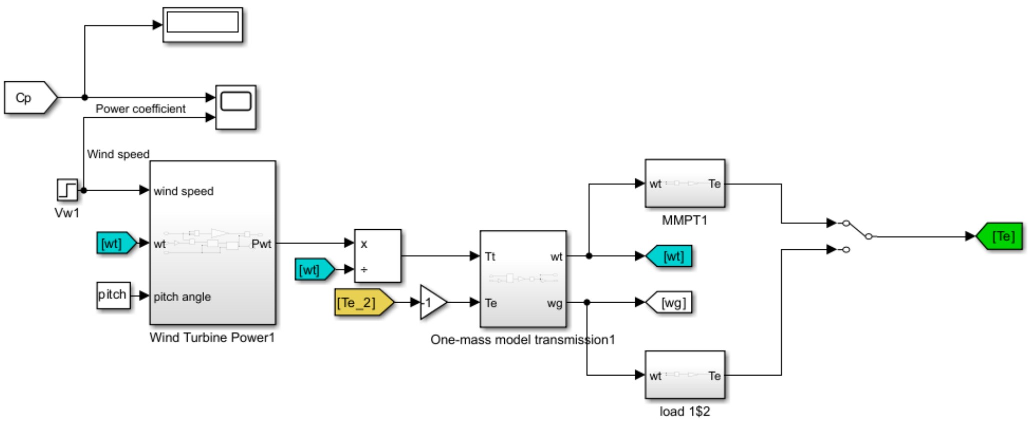

FIGURE 1.2: Wind Turbine Simulink Model

To obtain the power from the wind, the equation below can be used:

$$P_{wt} = \frac{1}{2} A \rho V_w^3 C_p$$

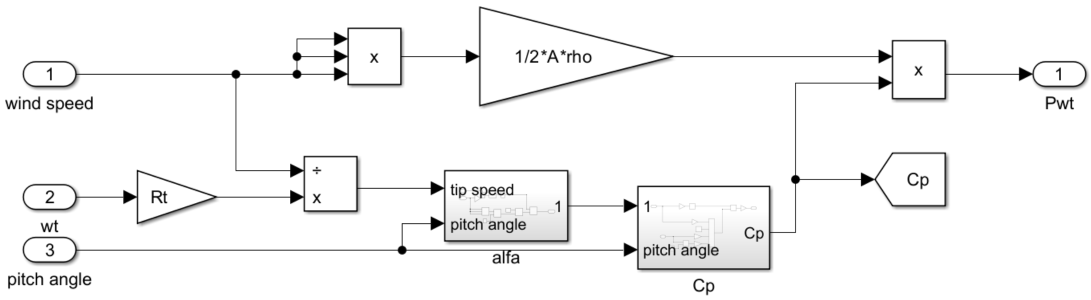

FIGURE 1.3: Power from the wind turbine

One-mass model mechanical transmission:

$$T_t - T_g' = J_{jot}\frac{d\omega_t}{dt}$$

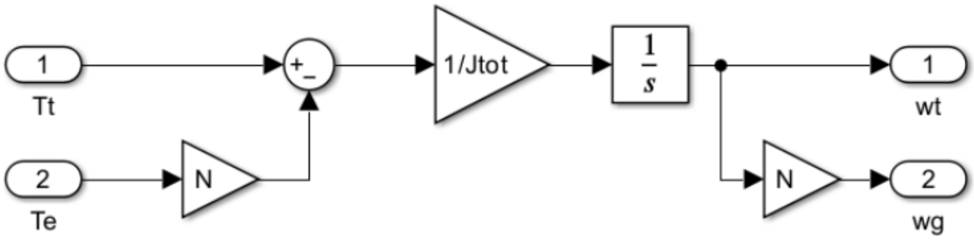

FIGURE 1.4: Torque Calculations

For this task, we have 3 load characteristics:

$$T_{load1,g} = K_1\omega_g; \quad T_{load2,g} = K_2\omega_g^2; \quad T_{max,g} = \frac{K_{cp}}{N}\omega_t^2$$

where

$$K_1 = 20, \quad K_2 = 1, \quad K_{cp} = P(cp_{max})$$

Blocks of the load characteristics are:

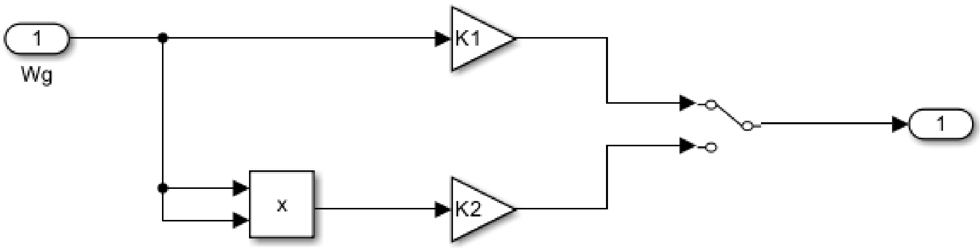

FIGURE 1.5: Load characteristics 1 and 2

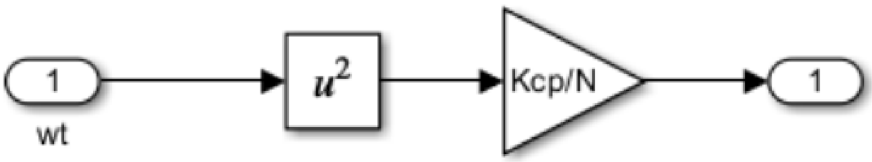

FIGURE 1.6: Optimal Load Characteristics

The graphs of rotor speed, electrical torque and power coefficient are represented below:

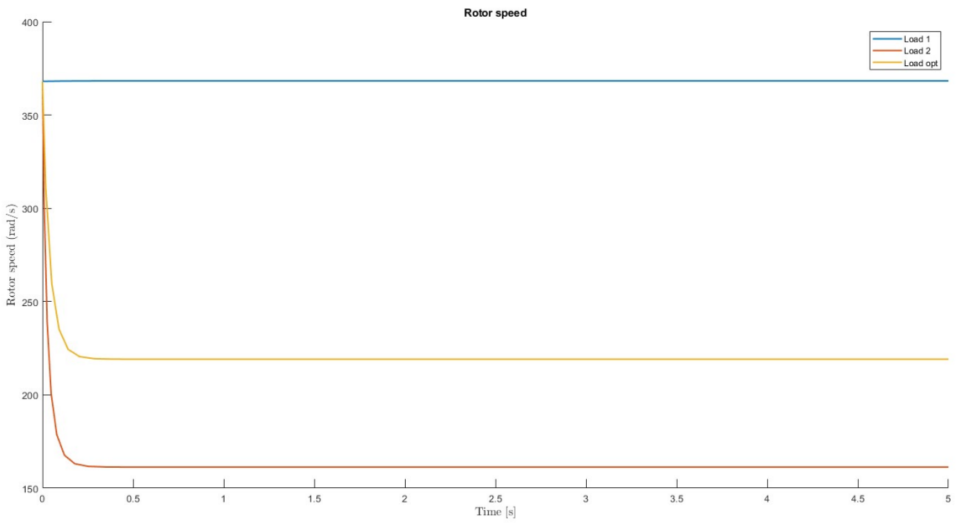

Figure 1.7: Rotor Speed

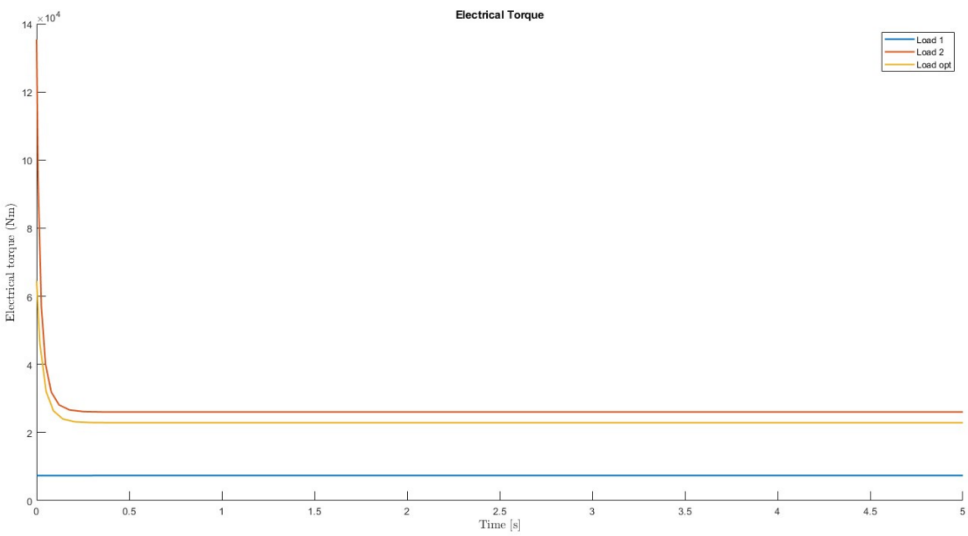

Figure 1.8: Electrical Torque

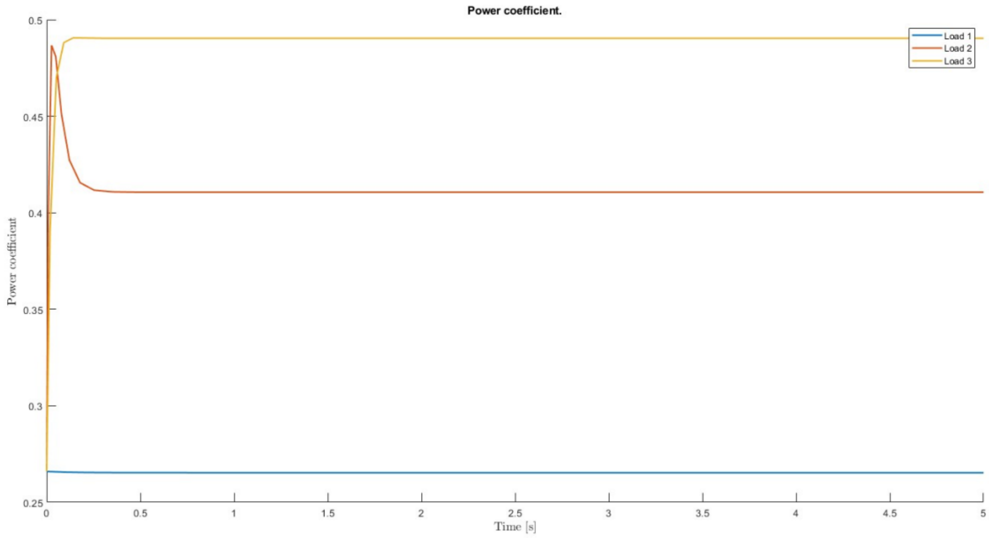

FIGURE 1.9: Power Coefficient
As shown in the graph, the power coefficient of the optimal load quickly reaches its maximum value and remains constant throughout the time. Since wind power is proportional to the power coefficient, we can conclude that the optimal load provides better wind power extraction.

Chapter 2

Permanent Magnet Synchronous Generator Operation

2.1 PMSG OPERATION

The PMSG operates as a motor with a constant rotor speed ($\omega_g = \omega_n/p$) and very low inertia. It converts mechanical power (P_{mech}) into three-phase AC voltage (v_s^{abc}) and current (i_s^{abc}). This AC power is rectified to a DC voltage (V_{dc}) using a rectifier.

The system includes two main control units:

- **Generator Side Control**: This unit optimizes the generator's performance by adjusting the torque (T_m^*) and reactive power (Q_s^*) based on the measured AC voltage (v_s^{abc}), current (i_s^{abc}), and rotor speed (ω_g).
- **Grid Side Control**: This unit manages the DC voltage (V_{dc}^*) and reactive power (Q_g^*), ensuring the power delivered to the grid is stable and within required parameters. It uses the grid AC voltage (v_g^{abc}), current (i_g^{abc}), and the DC link voltage (V_{dc}) for regulation.

The controlled DC power is then inverted back to AC to match the grid's voltage and frequency requirements, ensuring smooth and efficient power integration with the grid.

Scenario 1: For the machine side VSC, the reactive power reference is set to zero, and the torque reference is adjusted so that the load absorbs $P_{\text{load}} = 5$ MW.

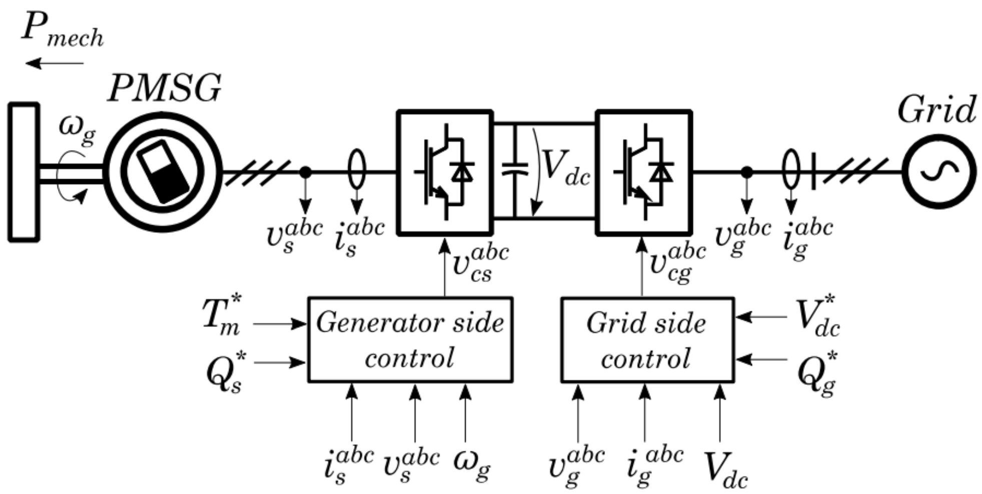

Figure 2.1: PMSG Control Structure

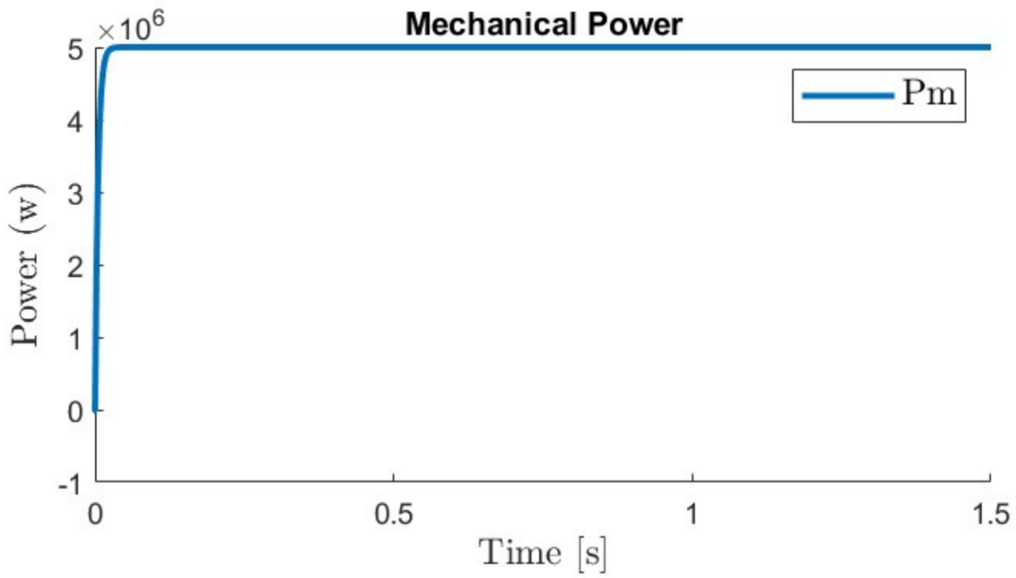

Figure 2.2: Power from the wind turbine

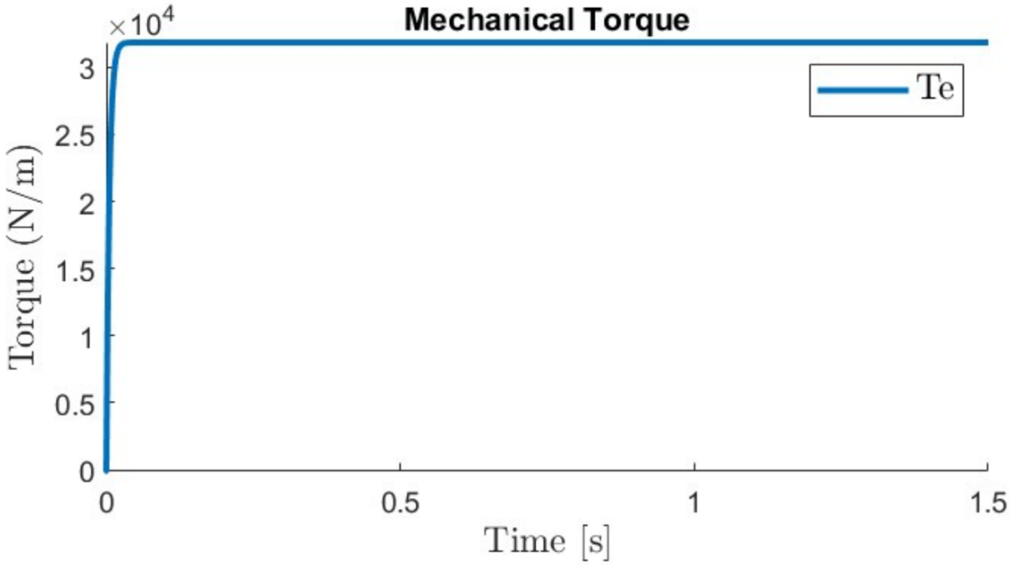

FIGURE 2.3: Torque from the wind turbine

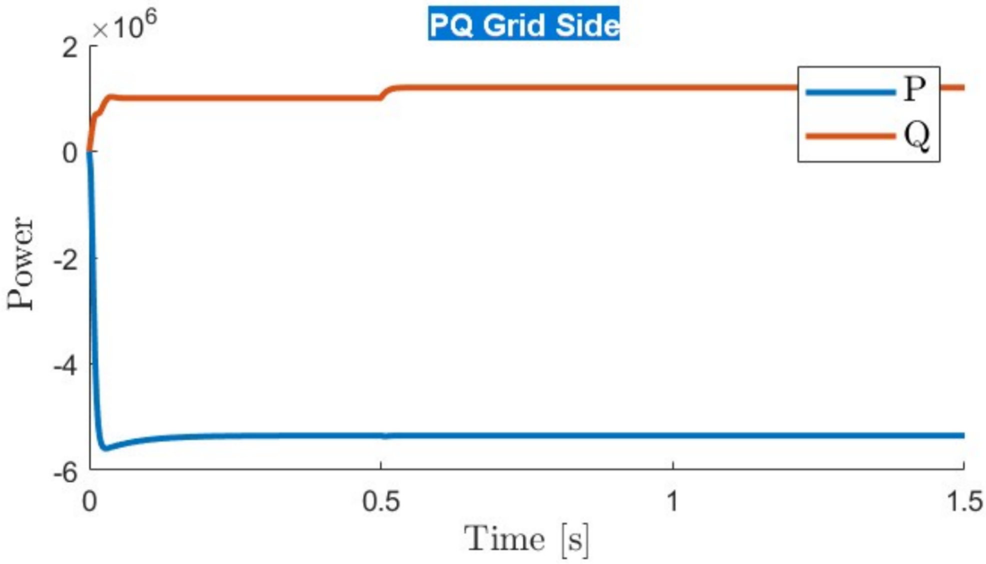

FIGURE 2.4: Active and Reactive power from the grid

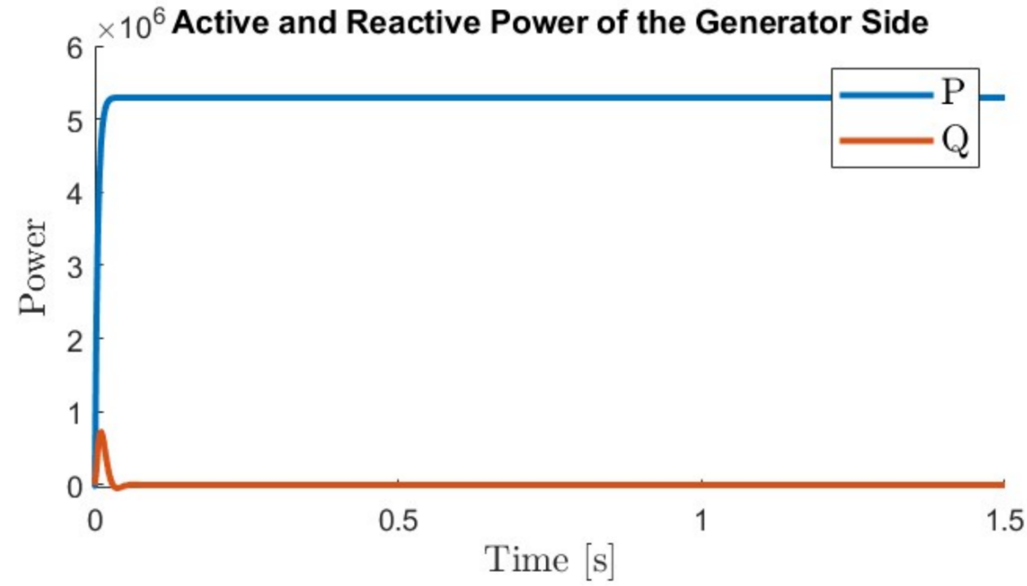

FIGURE 2.5: Active and Reactive power from Generator side

Result: The active power from the grid is 5.352 MW. After passing through the back-to-back converters, this power is reduced to 5.293 MW, resulting in losses of 59 kW. Ultimately, the generator receives 5 MW as specified by the torque reference signal, with total losses amounting to 352 kW.

Scenario 2: For the machine side VSC, make a step variation of reactive power reference from 0 to 0.5 Mvar and at a different time another step variation of torque from 1 MW to 5 MW.

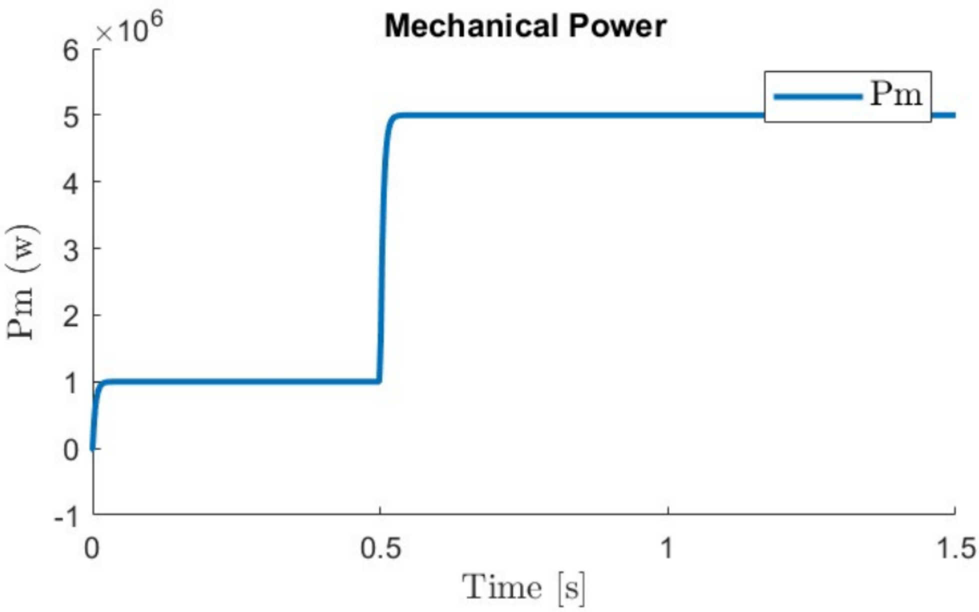

FIGURE 2.6: Power from the wind turbine

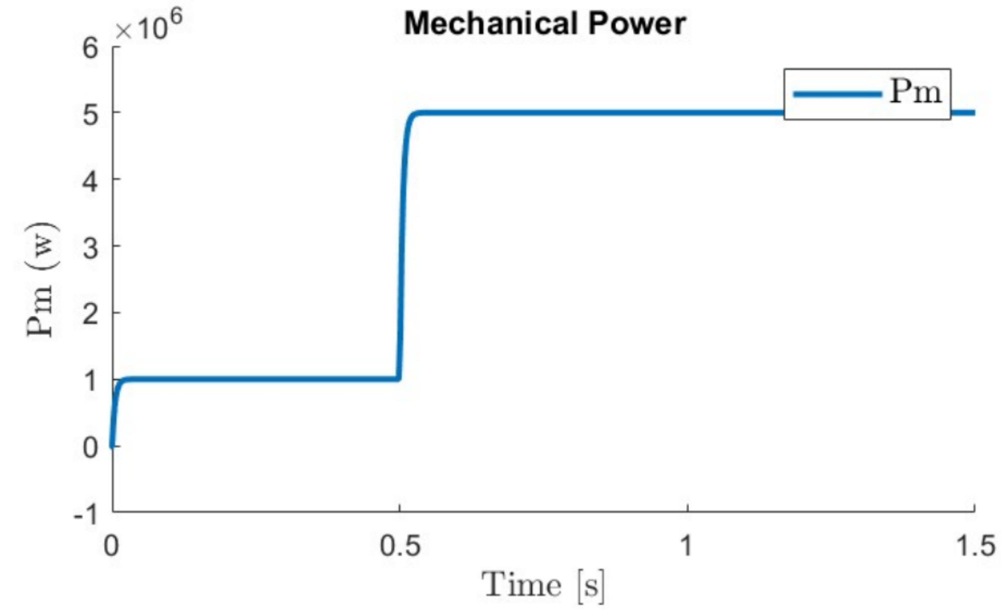

FIGURE 2.7: Torque from the wind turbine

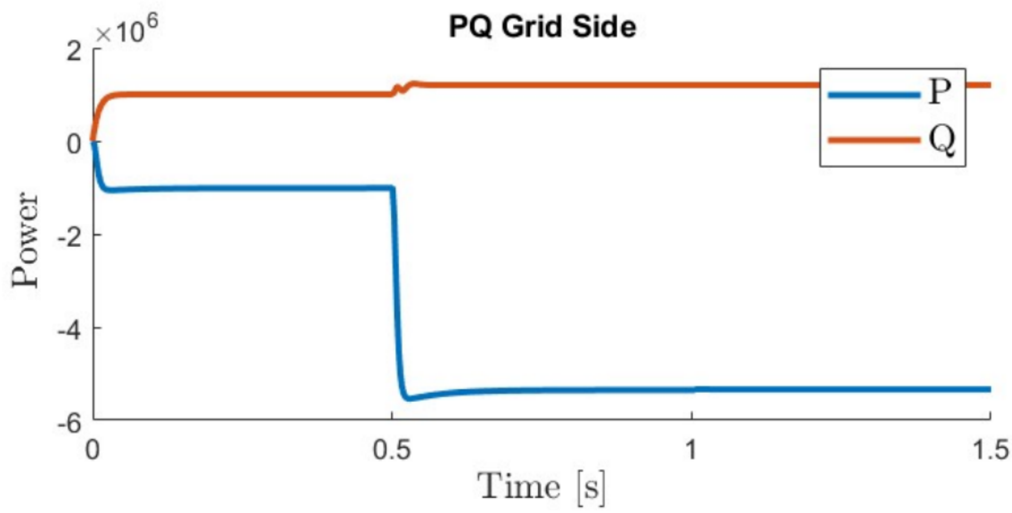

FIGURE 2.8: Active and reactive power from the grid

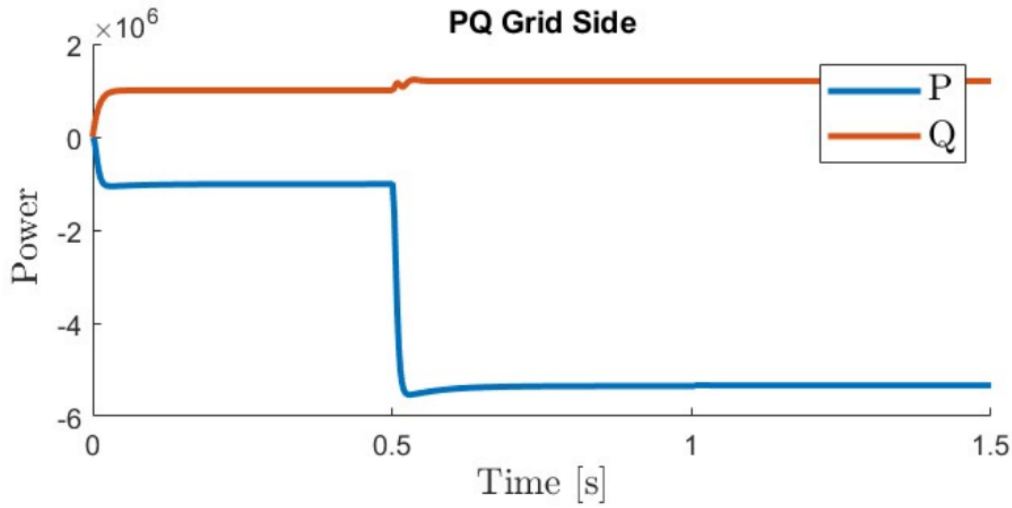

FIGURE 2.9: Active and reactive power from the grid

Result: The active power from the grid is 5.336 MW. After passing through the back-to-back converters, the power is reduced to 5.279 MW, resulting in losses of 59 kW. Ultimately, the generator receives 5 MW as specified by the torque reference signal, with total losses amounting to 336 kW, which is slightly less (by 16 kW). The time response for active power, following a step change in torque, is approximately 3 ms. To modify the time response, we can adjust the time constant of the current loop, as the torque applied is governed by the converter's current control.

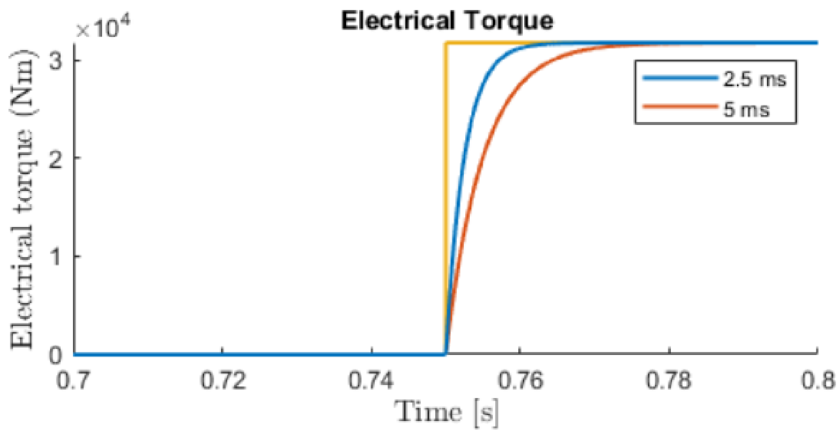

FIGURE 2.10: Electrical torque for different time response of current control

Tau for initial case equals 5 ms, for 2-nd case 2.5 ms

Chapter 3

Type 4 model of Wind Turbine

3.1 Type 4 model

In this section, the wind turbine model and the PMSG with back-to-back converters are combined to create the Type 4 wind turbine model. This integrated model includes several key modifications to optimize performance:

- **Reactive Power Control**: The reactive power reference of the machine side VSC (Voltage Source Converter) is set to zero. This ensures that the VSC only manages the active power flow, simplifying the control strategy.
- **Torque Reference**: The torque reference is derived from the MPPT (Maximum Power Point Tracking) block. The MPPT ensures that the turbine operates at the optimal load condition, maximizing the power extracted from the wind.
- **Back-to-Back Converters**: The model includes back-to-back converters, which consist of a machine side converter and a grid side converter. These converters are crucial for managing the power conversion and ensuring that the power generated by the PMSG (Permanent Magnet Synchronous Generator) is efficiently transferred to the grid.
- **Control Integration**: The control signals for active power, reactive power, and DC link voltage are integrated into the system, ensuring coordinated operation between the wind turbine and the grid.
- **PMSG Dynamics**: The PMSG is modeled to accurately reflect its dynamic behavior, including the effects of mechanical power input, rotor speed, and electromagnetic torque.

The complete Type 4 wind turbine model, incorporating these elements, is illustrated below:

Scenario 2: Wind speed variation from 5 m/s to 14 m/s.

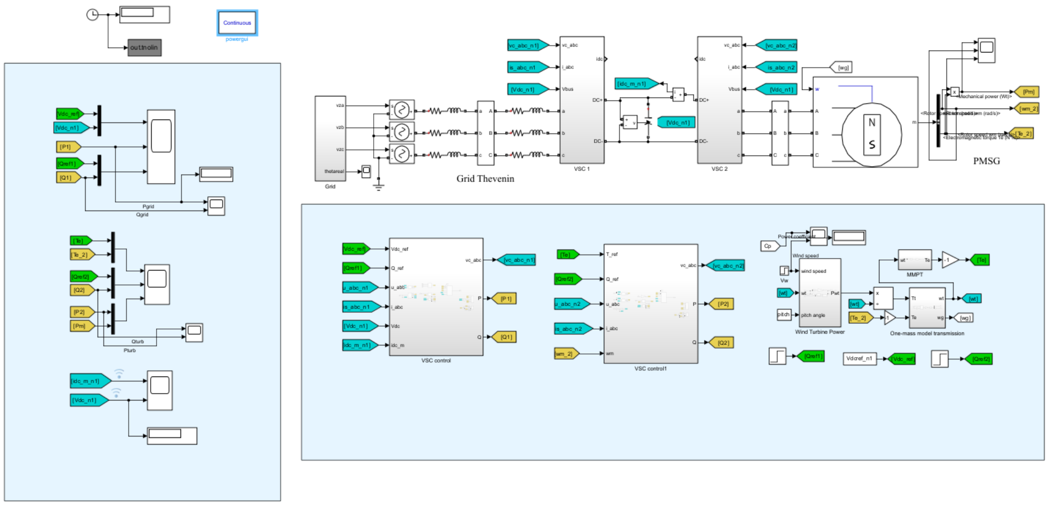

FIGURE 3.1: Type 4 model of Wind Turbine

Scenario 1: Wind speed variation from 5 m/s to 8 m/s.

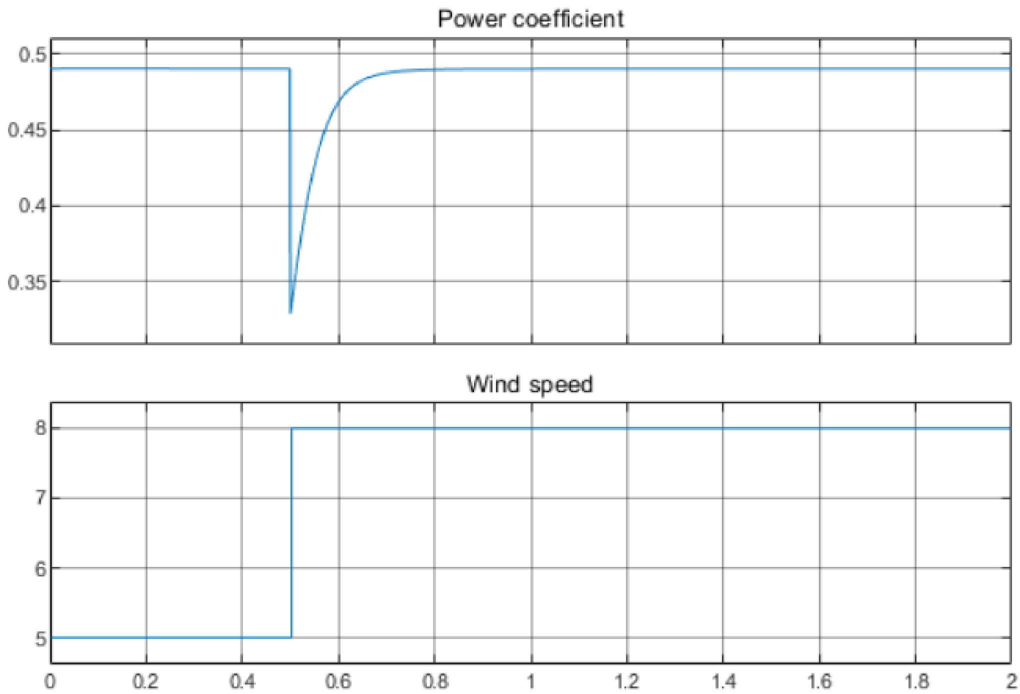

FIGURE 3.2: Power coefficient and variation of wind speed

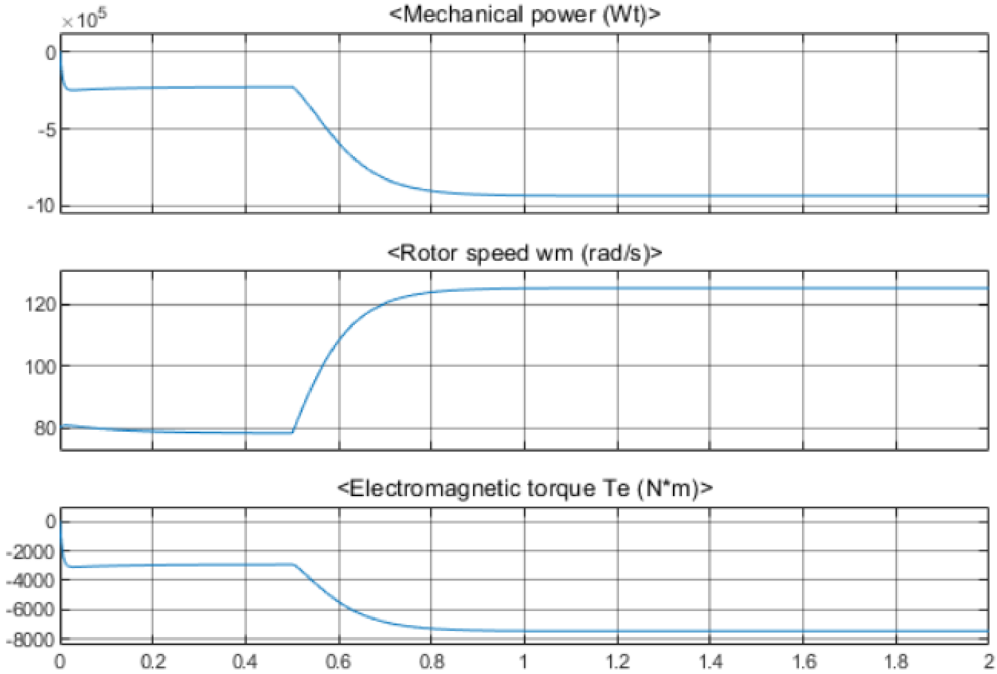

FIGURE 3.3: Variables from the PMSG

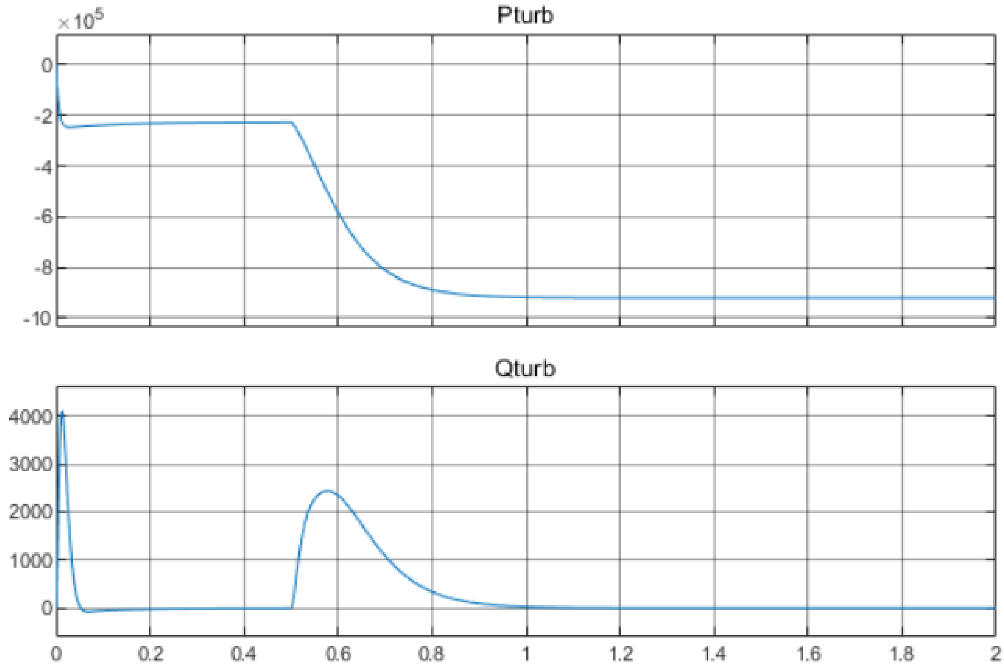

FIGURE 3.4: Active and reactive powers from the wind turbine

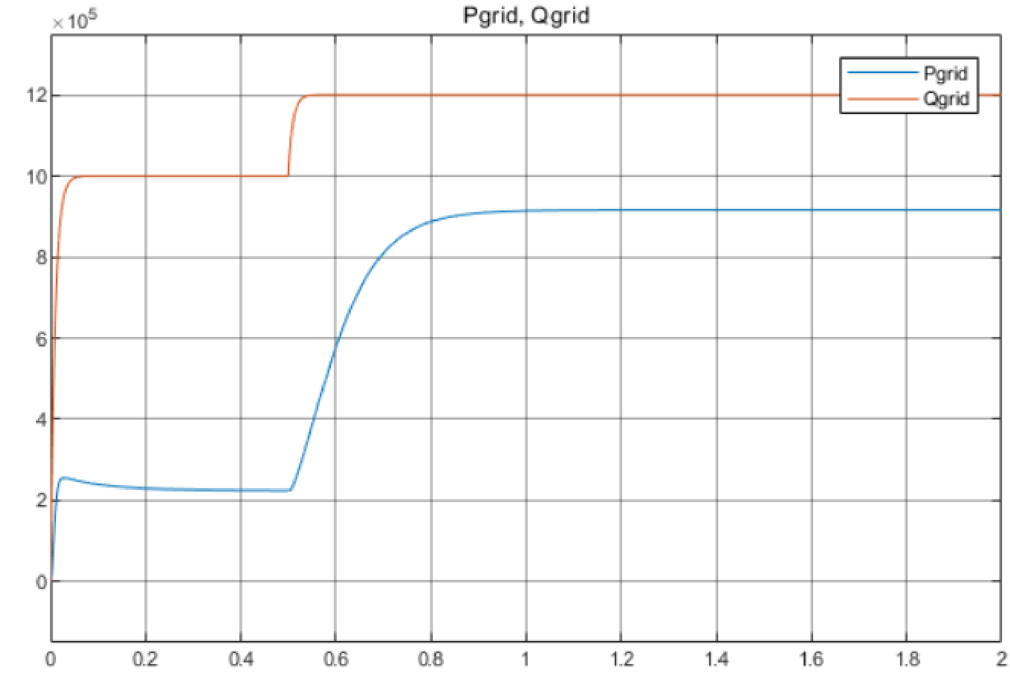

FIGURE 3.5: Active and reactive powers from the grid

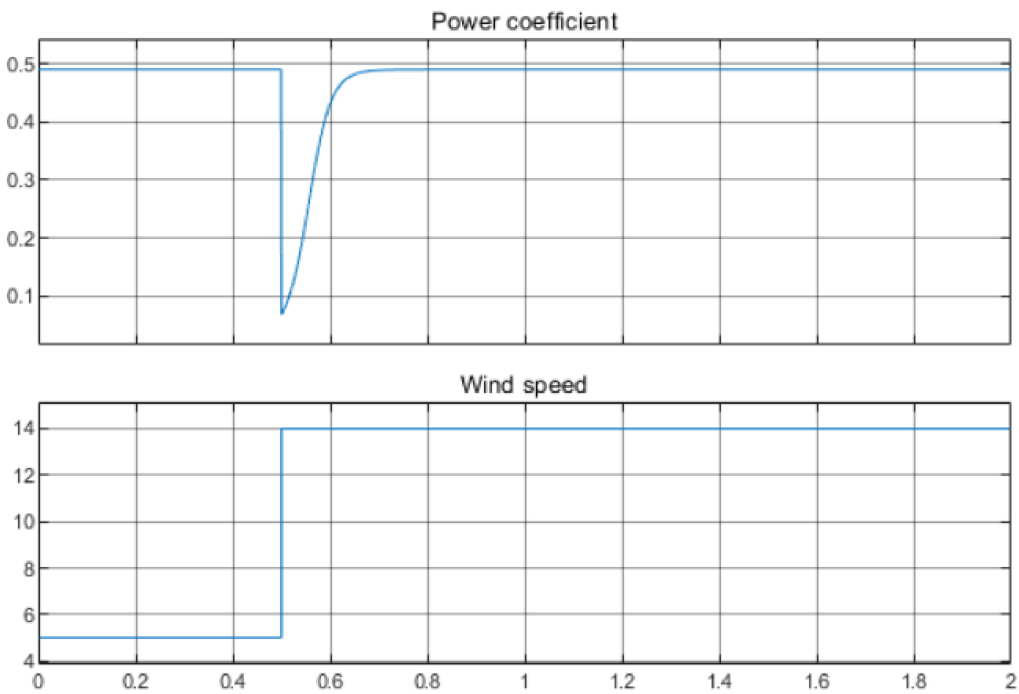

FIGURE 3.6: Power coefficient and variation of wind speed

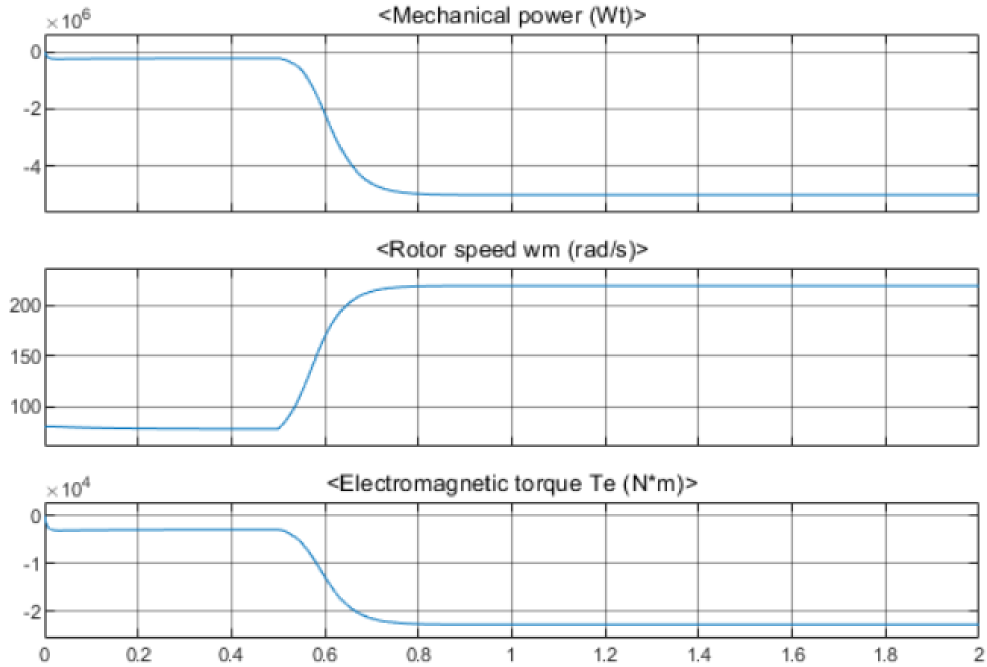

FIGURE 3.7: Variables from the PMSG

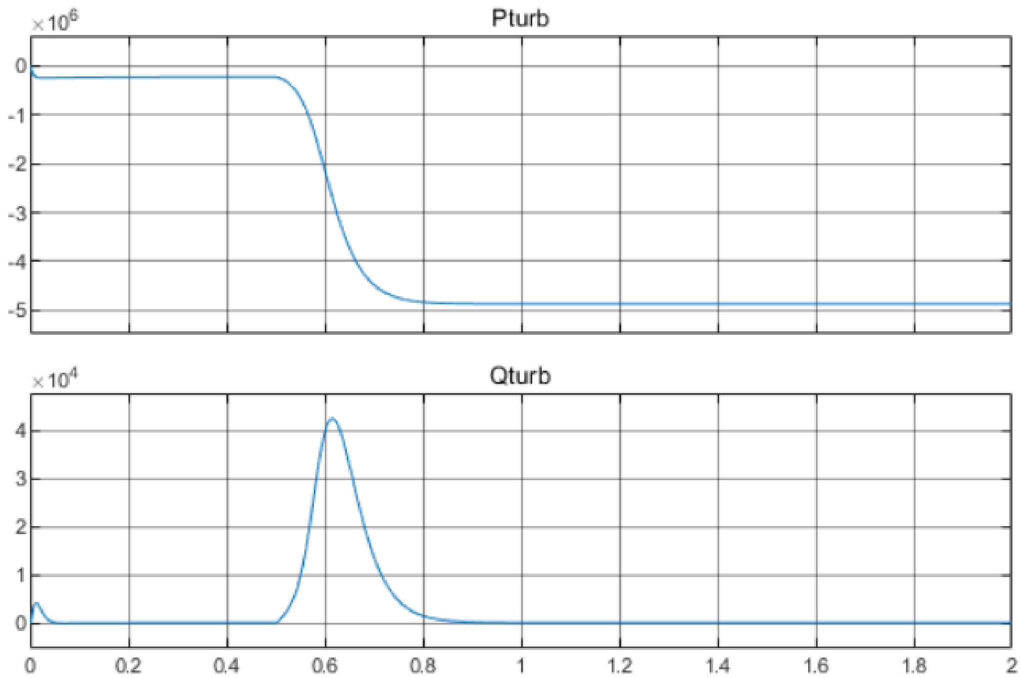

FIGURE 3.8: Active and reactive powers from the wind turbine

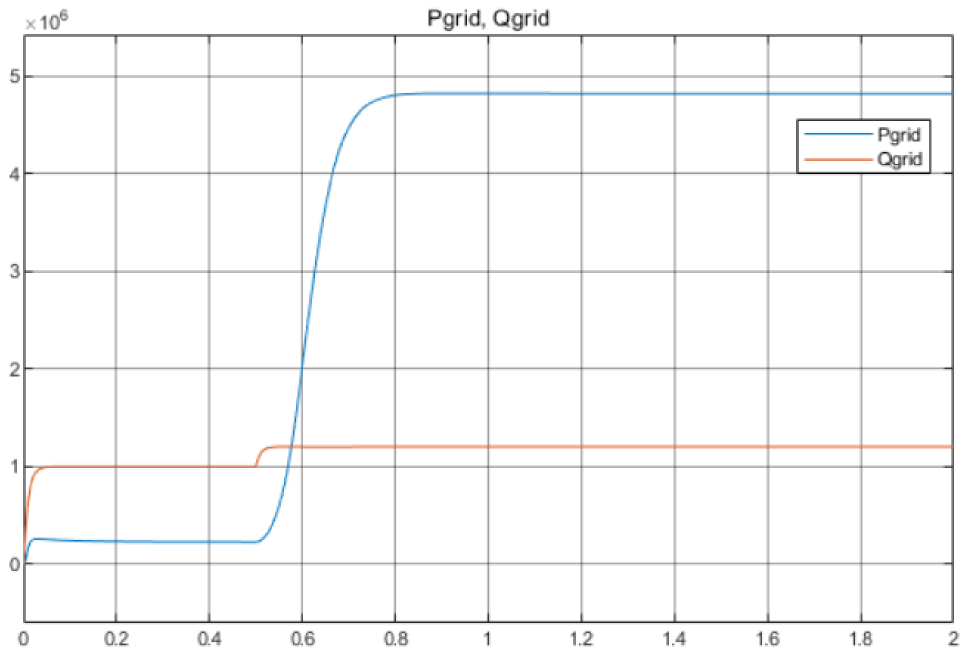

FIGURE 3.9: Active and reactive powers from the grid

Conclusions: The optimal load ensures that variations in wind speed do not affect the power coefficient, keeping the remaining time and value consistent in both scenarios. Higher wind speeds result in greater mechanical power, torque, and rotor speed. Consequently, the power transferred from the wind turbine to the grid is significantly lower in the first case (0.9 MW) compared to the second case (5 MW). The grid's reactive power remains the same in both cases, at 1.2 MW. However, higher wind speed variations lead to a higher initial amplitude of reactive power for the wind turbine, with 2.5 kVAR compared to over 40 kVAR.