A PROJECT REPORT ON

“Comparative Performance Analysis of SFIG and DFIG Wind Turbines through simulation ”

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Abstract

Wind energy is gaining popularity as an alternative to traditional energy sources due to growing concerns about environmental degradation and resource depletion. Wind energy, created by wind turbines properly located in wind-rich places, provides an infinitely renewable and clean alternative for reducing greenhouse gas emissions and combating climate change. Furthermore, wind energy fosters economic growth by lowering dependency on imported fossil fuels and increasing energy independence. Although intermittency difficulties exist, advances in energy storage and grid integration technologies are resolving these concerns. Wind energy adoption is becoming more competitive as costs continue to fall and economies of scale are realized. Global adoption of wind energy has the potential to create a sustainable and environmentally responsible future.

Wind Energy Conversion Systems

A wind turbine with rotor blades that capture the kinetic energy of the wind and transform it into rotational mechanical energy makes up a wind energy conversion system (WECS). The gearbox, generator, and control systems are housed in the nacelle, which is at the top of the tower. Power electronics then modify and manage the electrical energy for effective grid integration once the generator converts mechanical energy to electricity. The performance is enhanced by control systems while the tower provides structural support.

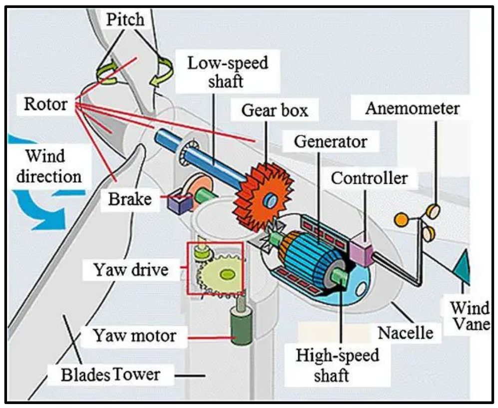


Fig 1- Various Parts of a Wind Turbine

Generators used in WT

Fixed-speed and variable-speed wind turbines are the two categories for the rotating speed of wind turbines, respectively. In addition, variable-speed wind turbines may be divided into those that employ partial-scale power converters and those that employ full-scale power converters.

(i) **Fixed-speed wind turbine generator:** It increases the speed of the low-speed shaft to the high-speed shaft using a multistage gearbox and a squirrel cage induction generator (SCIG). A capacitor bank is positioned between the grid and the SCIG to serve as reactive power compensation since the SCIG is directly linked to the grid through a coupling transformer and uses reactive power.

(ii) **Wind turbines with variable speed and partial scale power converters:** The partial scale power converter, which is made up of two IGBTs, supplies electricity to the rotor of the variable speed wind turbine, earning it the moniker "Doubly-Fed Induction Generator" (DFIG). A grid side converter (GSC) and a rotor side converter (RSC) make up the partial scale converter. While the RSC regulates the generator's active and reactive power, the GSC controls the DC-link voltage. In order to function at subsynchronous or super synchronous speeds, the power converter regulates the rotor frequency.

(iii) **A wind turbine with variable speed and full-scale power converters:** There are two types of full-scale power converters that may be used with variable speed wind turbines.

- A synchronous generator that is electrically energized
- Synchronous permanent magnet generator (PMSG)

A full-scale converter refers to the connection of the generator's stator and rotor to the grid via a power converter. The power converter at the generator side may fully adjust the amplitude of the voltage and frequency to make sure that the generator can be fully controlled throughout a broad range of wind speeds.

The EESG is typically constructed using a wound-rotor synchronous generator, and the generator's rotor carries the field system that is excited by a DC signal.

Given that it possesses the self-excitation feature, which enables the generator to run at high efficiency and power factor, the PMSG is a viable alternative to take into account in WECS. Because permanent magnets are included within the rotor, PMSG does not require a separate power source for excitation.

Singly Fed Induction Generator Wind Turbine

An induction generator wind turbine, also known as a fixed-speed wind turbine, is a type of wind turbine that uses an induction generator to convert wind energy into electrical energy. Unlike doubly fed induction generators (DFIG) or synchronous generators, induction generators have a fixed rotational speed that is directly linked to the frequency of the grid to which they are connected. This fixed-speed operation is a characteristic feature of induction generator wind turbines.

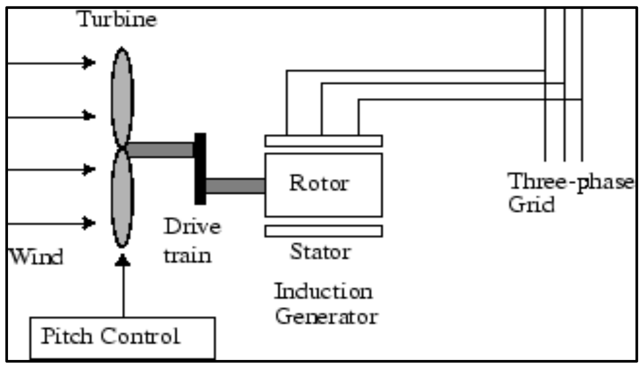


Fig. 2- SCIG Wind turbine (Singly Fed)

Here's how an induction generator wind turbine generally works:
1. Wind Capture: The wind turbine blades capture the kinetic energy from the wind, causing them to rotate.

2. Mechanical Power: The rotational motion of the wind turbine blades is transferred to the rotor of the induction generator. The rotor is typically connected directly to the wind turbine shaft, meaning that the rotational speed of the generator is the same as the rotational speed of the wind turbine blades.

3. Induction Effect: The rotor of the induction generator has windings or coils, and as it rotates, it interacts with the stator's magnetic field, which induces an electric current in the stator windings.

4. Electrical Output: The electric current generated in the stator windings is collected and transmitted through power lines to the electrical grid.

5. Grid Synchronization: Induction generators in wind turbines require the electrical grid to provide a constant frequency (e.g., 50 Hz or 60 Hz). The rotational speed of the generator is synchronized to match the grid frequency. Since the grid frequency is fixed, the generator's rotational speed is also fixed, which is why it is called a fixed-speed wind turbine.

Doubly Fed Induction Generator Wind Turbine

DFIG stands for "Doubly Fed Induction Generator," and it is a type of electrical generator used in modern wind turbines. DFIG is also known as a variable-speed generator. It is an evolution from the fixed-speed induction generators used in older wind turbine designs.

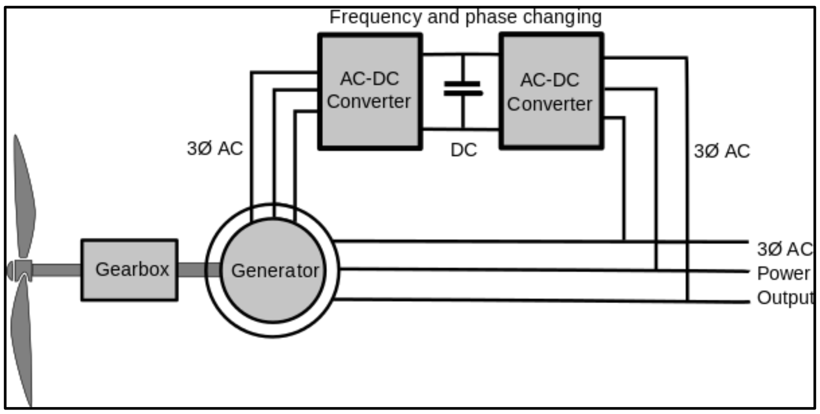


Fig. 3- Doubly fed induction generator wind turbine

DFIG wind turbines are one of the most common types of wind turbines used in the wind energy industry today. Here's how a Doubly Fed Induction Generator works in a wind turbine:

1. Wind Capture: The wind turbine blades capture the kinetic energy from the wind, causing them to rotate.

2. Mechanical Power: The rotational motion of the wind turbine blades is transferred to the rotor of the DFIG. Unlike a synchronous generator that is directly connected to the wind turbine shaft, the rotor of the DFIG is driven by a separate gearbox, allowing it to rotate at a different speed than the wind turbine blades. This enables variable-speed operation, which is one of the key features of DFIG-based wind turbines.

3. Induction Effect: The rotor of the DFIG consists of wound coils or windings. When the rotor rotates, the interaction with the stator's magnetic field induces an electric current in the rotor windings.

4. Stator and Power Conversion: The stator of the DFIG is connected to the grid and provides the fixed-frequency electrical output. The induced current in the rotor windings is converted to direct current (DC) through a power converter. The power converter, often equipped with power electronics like insulated-gate bipolar transistors (IGBTs), allows for bidirectional power flow between the rotor and the grid.

5. Variable-Speed Control: The ability to control the rotor speed independently from the wind turbine's rotational speed enables DFIG wind turbines to optimize power production. By adjusting the power converter's settings, the generator can extract maximum power from the wind over a range of wind speeds.

Comparison Table between SFIG and DFIG

Aspect	SFIG	DFIG
Principle of Operation	Induction generator	Induction generator with partial power conversion (rotor-side converter)
Speed Regulation	Fixed speed	Variable speed
Power Electronics	No power electronics are used; only AVRs are used.	Partial power converter (rotor-side converter) and full power converter (grid-side converter)
Grid Connection	Limited grid compatibility	Full grid compatibility
Starting Torque	Low	Low
Efficiency	Moderate	Moderate
Power Factor Control	The power factor depends on grid conditions	Can be actively controlled
Reactive Power Control	No reactive power control	Can be actively controlled
Mechanical Complexity	Simple	More complex
Maintenance	Low	Moderate
Cost	Lower cost	Moderate cost
Suitable Applications	Small-scale applications	Medium to large-scale wind farms
Grid Stability	Has limited impact on grid stability	Can help improve grid stability

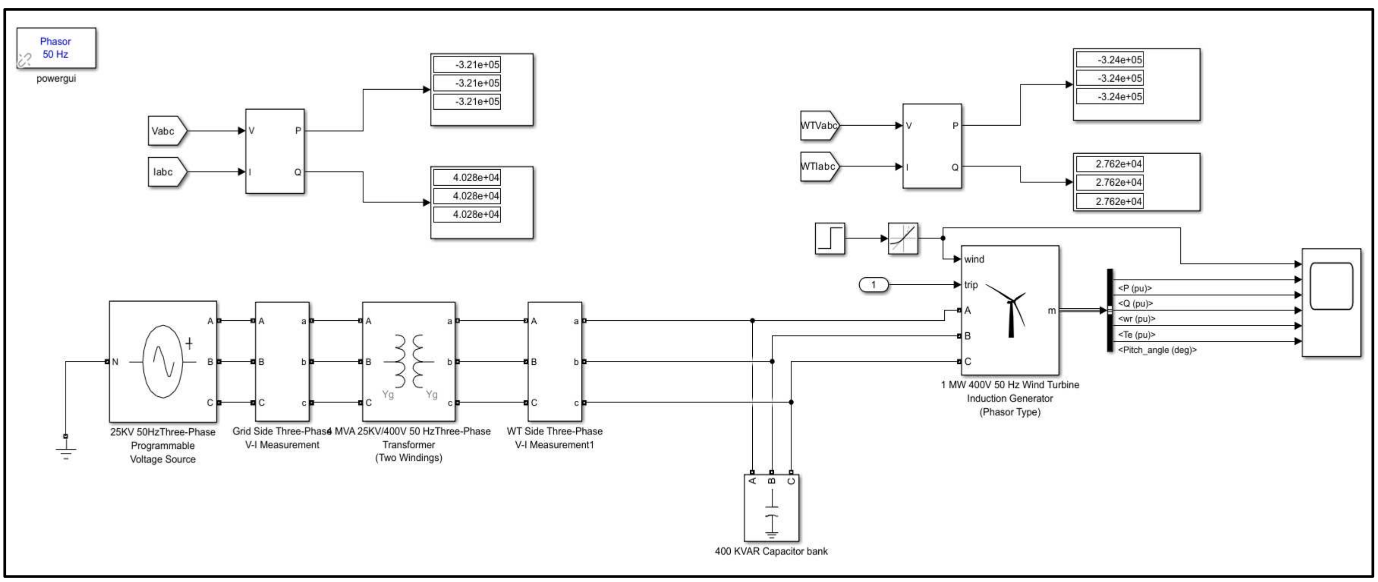
Simulation and Modeling

Using the software MATLAB/Simulink, the wind turbine models are created to simulate and achieve the desired results. For this project, two models are created to be compared against each other. The first model is the conventional Fixed Speed Induction Generator wind turbine or SFIG, and the second model is the Doubly-fed Induction Generator wind turbine or DFIG.

For the wind turbine, two wind conditions are modeled. First, they are simulated at base speed to achieve the rated output of the turbine, and second, above base wind speed is simulated to obtain the results of how it affects the turbine output.

The models for the same are shown below:

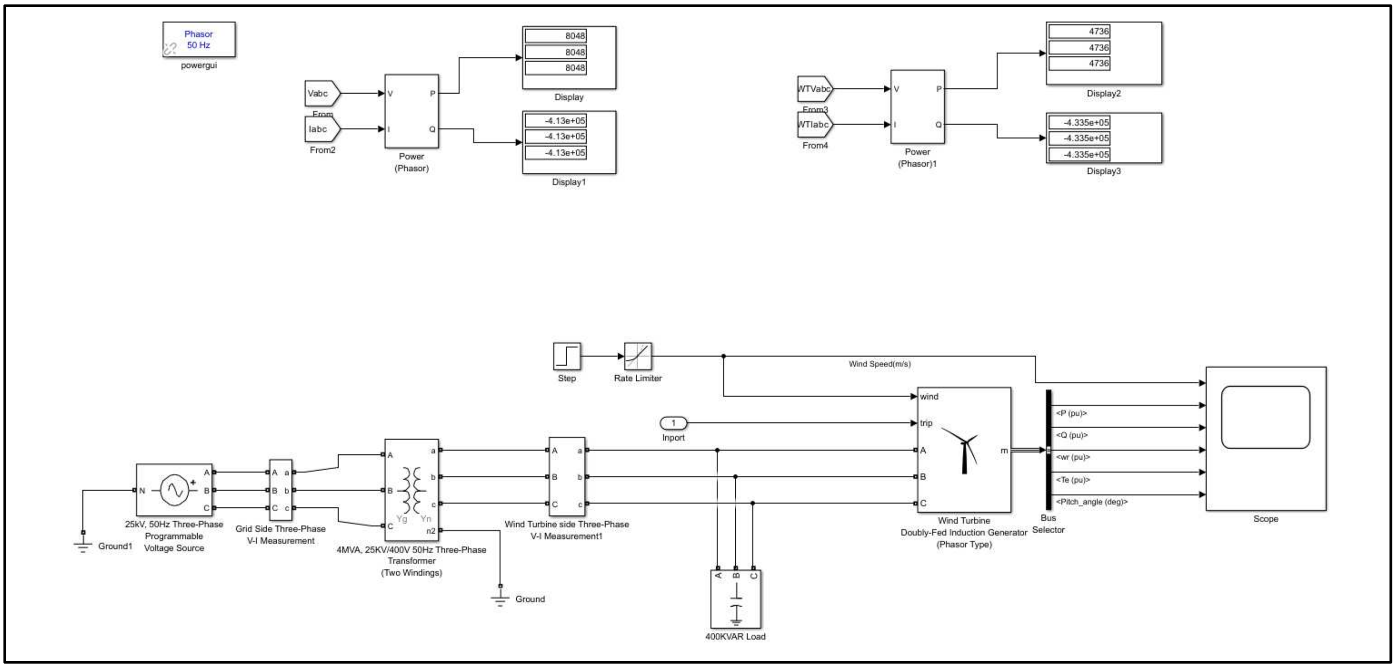
1. **SFIG Wind Turbine Model**



A 1 MW wind turbine block is used in this model for ease of modeling purposes. The wind turbine output is 400 V (line-to-line) at a frequency of 50 Hz, connected to a bus. The 400V bus is then connected to a step-up transformer that increases the voltage level to 25 kV, which is the grid voltage. A capacitor bank with a capacity of 400 kVAR is also connected to supply reactive power to the induction generator, which is required to establish the air gap magnetic flux needed to produce torque.

The real and reactive powers on both the grid side as well as the turbine side are displayed with the scopes. The induction generator-based wind turbine's output parameters, such as electromagnetic torque (Te) and pitch angle, are also shown.

2. DFIG Wind Turbine Model

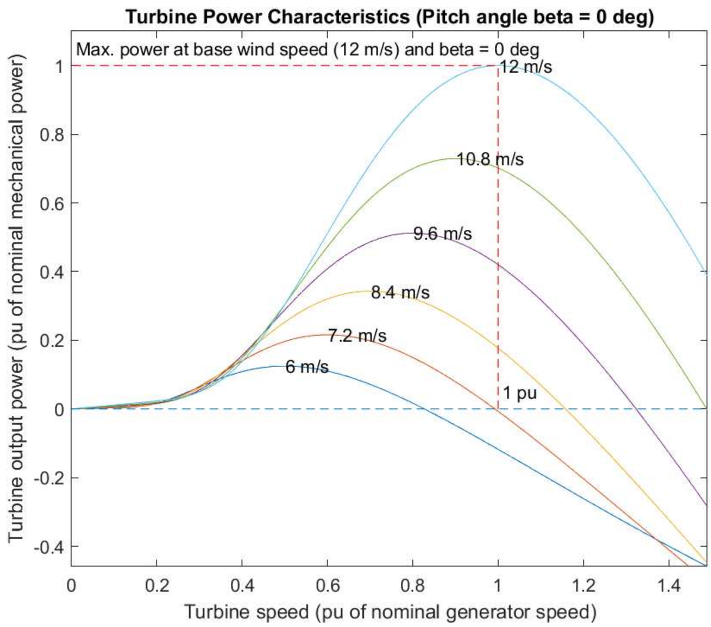


This model employs a 1 MW DFIG wind turbine block with the same bus voltage and grid voltage setup as previously described. The reactive power in a DFIG is mostly supplied by the power grid via the stator windings. As a result, the DFIG does not need to generate reactive power to establish the flow.

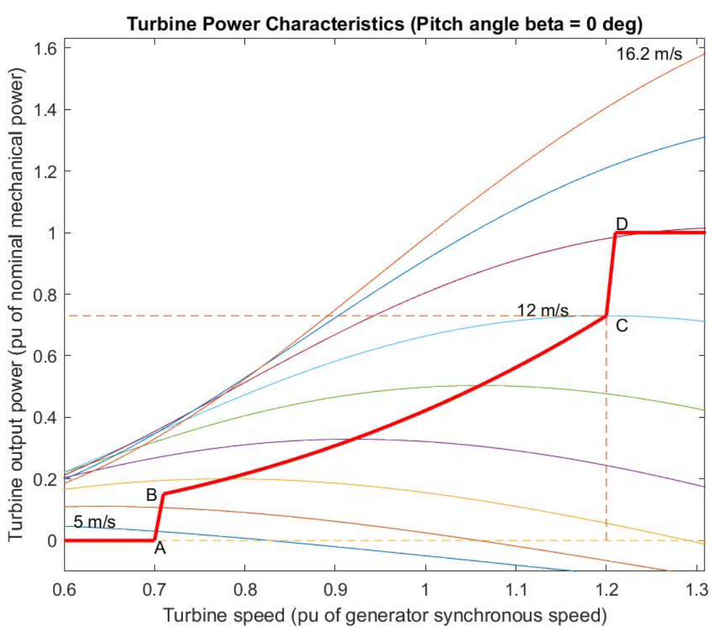
The scopes display the real and reactive powers on both the grid side and the turbine side. The output parameters of the DFIG-based wind turbine, such as electromagnetic torque (Te) and pitch angle, are also shown.

The turbine power characteristics of both wind turbines are as follows:

1. The SFIG-based wind turbine gives an output power of 1 pu at a wind speed of 12m/s and a turbine speed of 1 pu.

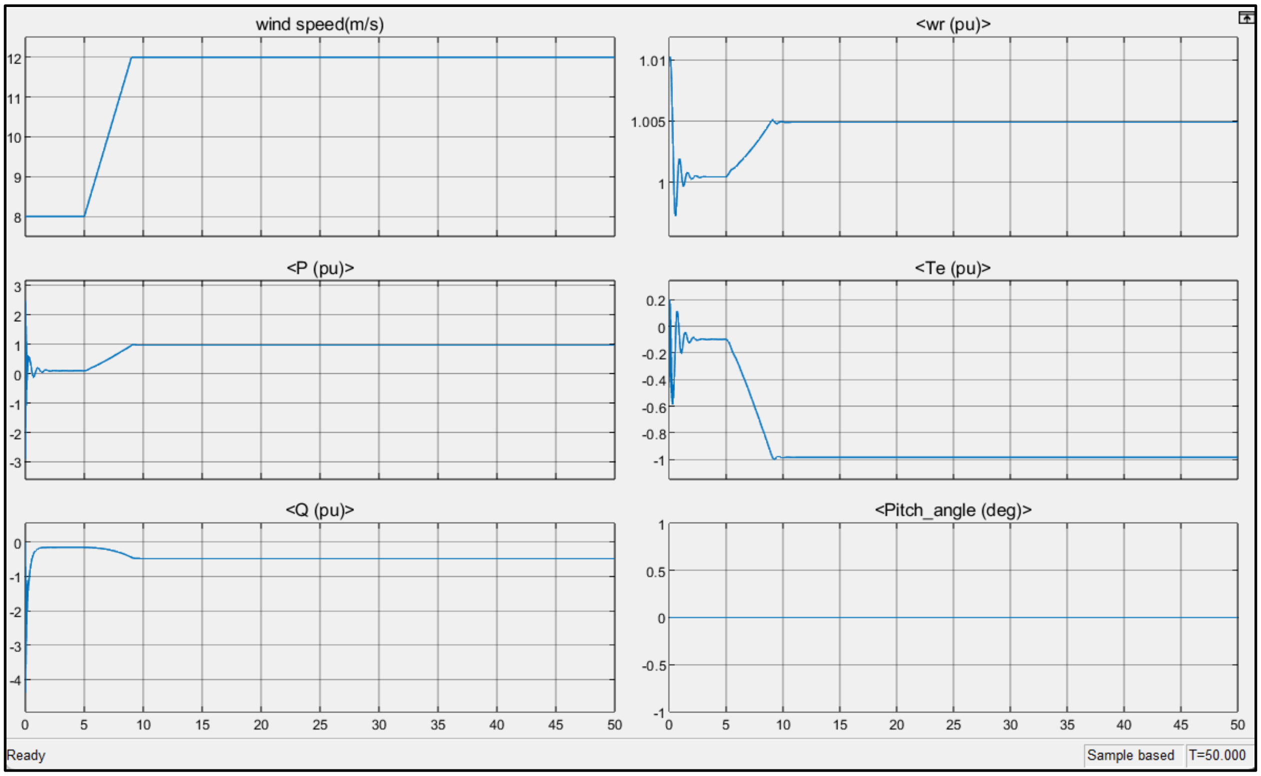


2. The DFIG-based wind turbine gives an output power of 1 pu at wind speeds around 14m/s and turbine speed of 1.2 pu



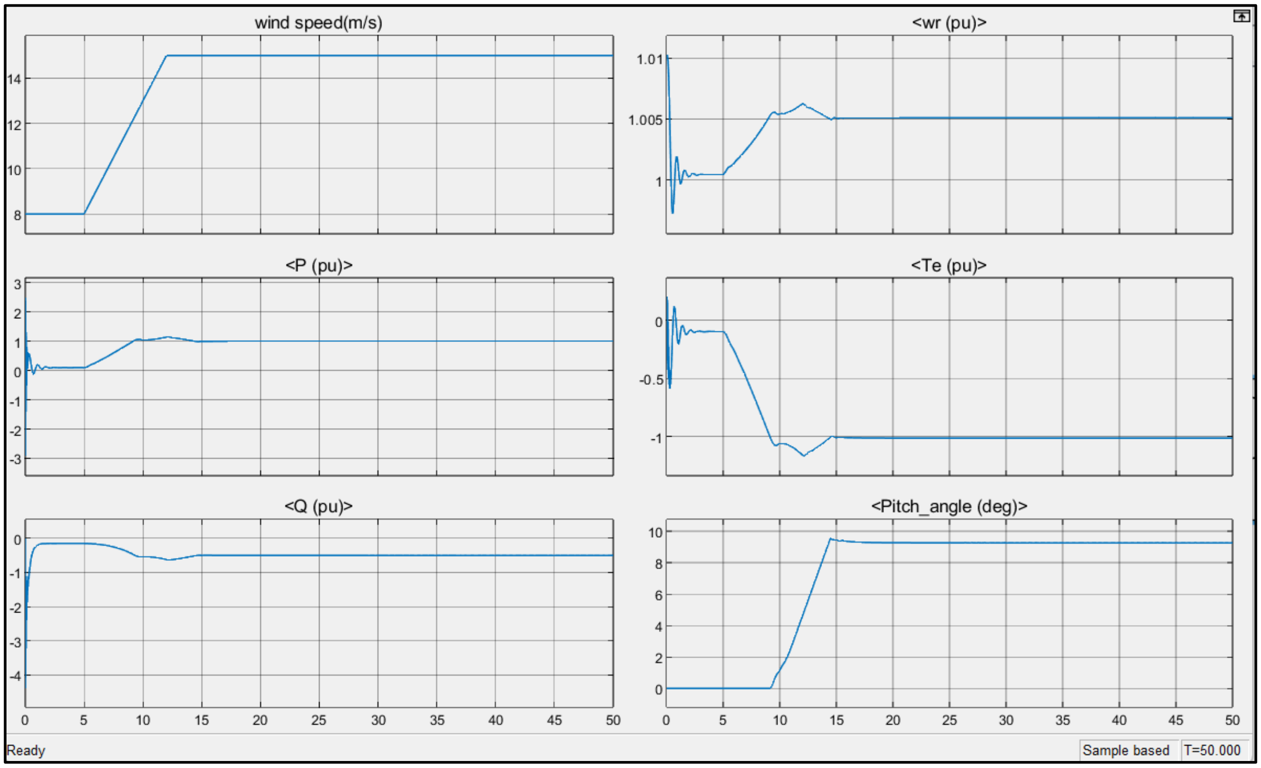
Results and Discussions

1. **Normal operation of SFIG at 12m/s base wind speed.**



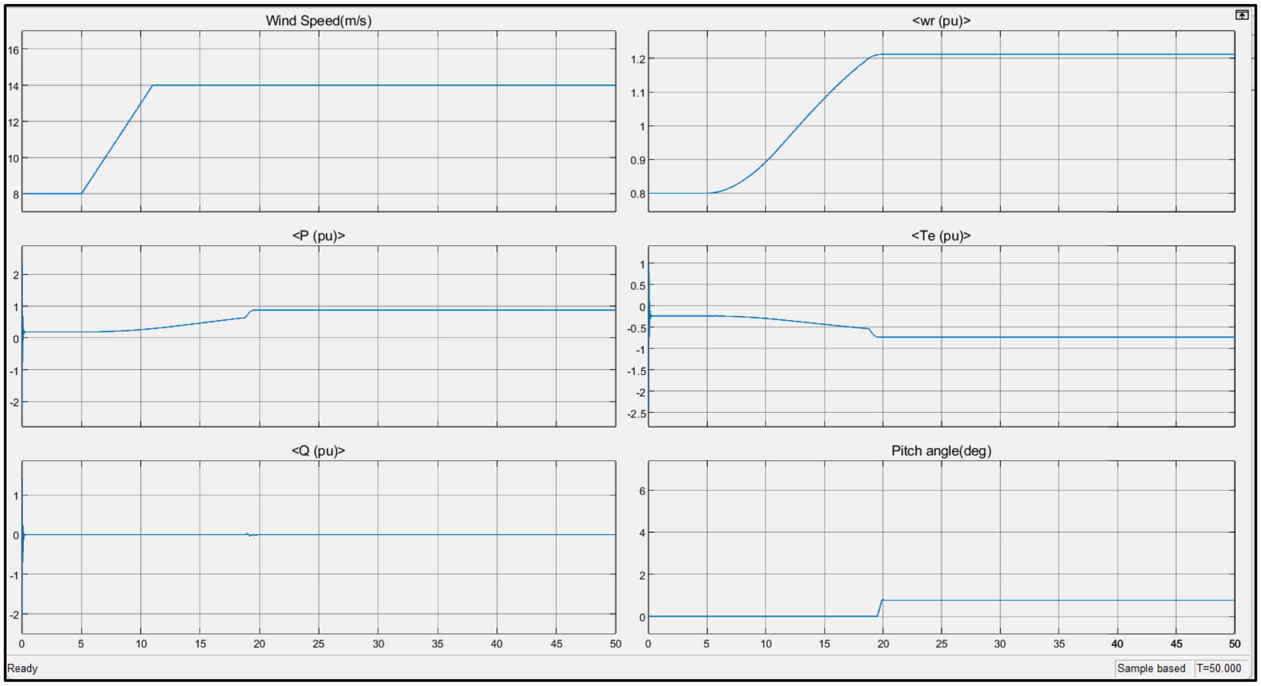
- At a base speed of 12 m/s, the turbine generates a real power output of around 0.972 pu.
- The reactive power absorbed by the grid is 0.12 pu, and the reactive power absorbed by the turbine, including the 400 KVAR from the capacitor bank, is 0.483 pu. The remaining reactive power is used by the transformer to establish flux.
- After some losses in the transformer, approximately 0.963 pu is supplied to the grid.
- The rotor speed is slightly greater than 1 pu as it is acting as an induction generator.
- As the wind speed is at base speed and the real power also does not exceed 1 pu, the pitch angle is constant at 0 degrees.

2. Normal operation of SFIG at above base wind speed.



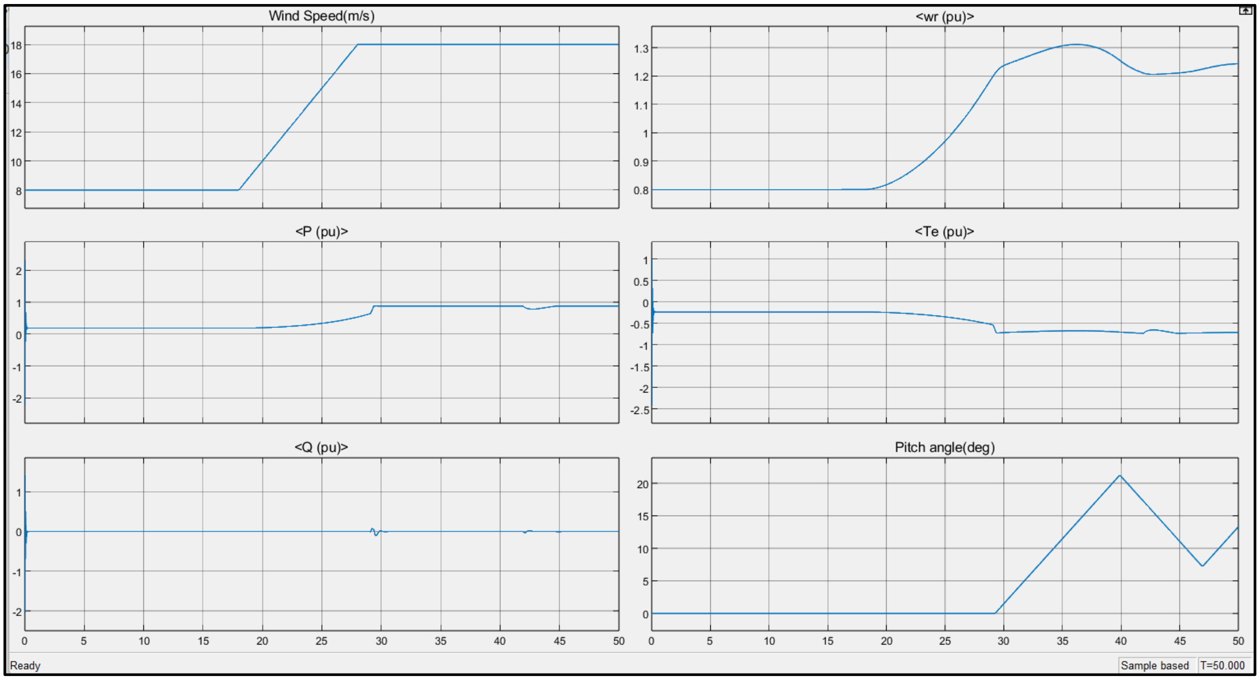
- When the turbine exceeds the base speed, real power output crosses 1 pu; however, due to yawing mechanism available, the pitch angle changes and real power output comes back to 1 pu.
- It absorbs reactive power of around 0.5 pu.
- The rotor speed is around 1.005 pu as it is acting as an induction generator.
- The pitch angle increases and then settles at around 9.4 degrees to adjust the turbine with the wind direction for optimum output.

3. Normal operation of DFIG at 14m/s base wind speed.



- At a base speed of around 14 m/s, the turbine generates a real power output of around 0.969 pu.
- The reactive power absorbed by the grid is 0.041 pu, and the reactive power absorbed by the turbine is 0.0037 pu. The remaining reactive power is used by the transformer to establish flux.
- After some losses in the transformer, approximately 0.963 pu is supplied to the grid.
- The rotor speed is greater than rated at around 1.2 pu . The DFIG matches the wind turbine's fluctuating wind speed by modifying the rotor speed, increasing power extraction from the wind.
- To increase the power output to its nominal value, the pitch angle is slightly increased to 0.76 degrees.

4. **Normal operation of DFIG at above base wind speed.**



- At a wind speed of around 18 m/s, the turbine generates a real power output of around 0.969 pu.
- The reactive power absorbed by the grid is 0.0409 pu, and the reactive power absorbed by the turbine is 0.00357 pu.
- After some losses in the transformer, approximately 0.962 pu is supplied to the grid.
- The rotor speed exceeds 1.3 pu and finally settles at around 1.25 pu to extract maximum power from the varying wind speeds.
- To increase the power output up to its nominal value, the pitch angle changes heavily to 20 degrees and then drops and rises back to 13 degrees.

Conclusion

In conclusion, the choice between fixed-speed and DFIG wind turbine generators depends on various factors, including project requirements, grid code compliance needs, and budget considerations. Fixed-speed turbines are simpler and more cost-effective but they may be less efficient and lack grid support capabilities. DFIG turbines offer better efficiency and grid support but come with higher upfront and maintenance costs, making them a favorable choice for projects aiming for optimal energy capture and grid code compliance. The decision will ultimately depend on the specific needs and goals of the wind power project.

The wind energy industry is continuously evolving, and newer technologies and advancements may influence the comparison between these two types of turbines. Therefore, it is essential for project developers and stakeholders to stay up-to-date with the latest innovations and industry trends when making informed decisions about wind turbine selection.

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