GENERAL

analysis of sub synchronous resonance ssr in doubly fed induction generator dfig based wind farms synthesis

Published: September 19, 2026 | Index ID: #-

Introduction

Wind energy is rapidly becoming a cornerstone of the global transition to renewable power. Among the various turbine technologies, the **doubly fed induction generator (DFIG)** stands out for its ability to provide variable speed operation, grid support, and efficient power conversion. However, the interaction between the DFIG's power electronics and the grid can give rise to a subtle yet potentially damaging phenomenon known as **sub synchronous resonance (SSR)**. SSR occurs when the mechanical and electrical dynamics of the generator resonate at a frequency below the grid's nominal frequency, leading to circulating currents, excessive heating, and even catastrophic failure of wind farms.

In this article we will embark on a comprehensive **analysis of sub synchronous resonance SSR in doubly fed induction generator DFIG based wind farms synthesis**. We will explore the underlying physics, diagnostic techniques, impact on plant performance, and state of the art mitigation strategies. By the end, you will have a clear understanding of why SSR matters, how it manifests in modern wind farms, and what engineers can do to keep turbines humming safely.

1. Fundamentals of DFIG Based Wind Turbines

1.1 What is a DFIG?

A DFIG is a three phase induction machine whose stator is connected directly to the grid, while the rotor is fed through a back to back power converter. This arrangement allows the rotor's slip frequency to be controlled, enabling variable speed operation and independent control of active and reactive power. The key advantages of DFIGs in wind turbines are:

- High power to weight ratio
- Reduced converter size and cost compared to full scale converters
- Capability to ride through grid disturbances
- Ability to provide grid support functions such as voltage regulation and frequency response

1.2 Mechanical–Electrical Coupling in DFIGs

The mechanical side of a wind turbine consists of blades, a gearbox (if present), and a shaft that drives the generator. The electrical side comprises the stator windings, rotor windings, and the converter. The mechanical torque and electrical torque are linked through the generator's electromagnetic dynamics. When the turbine's mechanical torque changes—due to wind speed variations or pitch adjustments—this change propagates to the electrical side, influencing the stator currents, rotor currents, and ultimately the power drawn from or injected into the grid.

2. Sub Synchronous Resonance: Definition and Causes

2.1 What is Sub Synchronous Resonance?

Sub synchronous resonance is a form of resonance that occurs at a frequency below the grid's nominal frequency

(typically 50 Hz or 60 Hz). Unlike ordinary resonances that involve purely mechanical or electrical components, SSR is a coupled phenomenon involving the mechanical shaft, the generator's electromagnetic fields, and the grid's capacitive and inductive elements. When the system's natural sub synchronous frequency aligns with a harmonic of the grid voltage, circulating currents can grow unchecked, potentially damaging the generator.

2.2 Key Contributors to SSR

1. Generator Dynamics: The inertia of the turbine shaft and the electromagnetic coupling of the DFIG create a natural sub synchronous frequency.
2. Grid Capacitance: Power line capacitance, transformer capacitors, and the converter's filter capacitance can introduce resonant paths.
3. Converter Control: The control loops of the back to back converter, particularly the rotor side converter, can inadvertently excite sub synchronous modes.
4. External Disturbances: Transient events such as lightning strikes, switching operations, or sudden load changes can shift the system's operating point into a resonant condition.

3. How SSR Manifests in DFIG Based Wind Farms

3.1 Circulating Currents and Thermal Stress

When SSR is triggered, circulating currents flow between the rotor and stator windings via the converter's DC bus. These currents are not associated with real power transfer but rather with reactive energy exchange. They can reach several hundred amperes, far exceeding the normal operating currents, and cause localized heating in the windings and insulation.

3.2 Impact on Grid Stability

SSR can destabilize the grid by injecting unwanted harmonic currents, reducing voltage quality, and potentially triggering protective relays. In a wind farm with many DFIG units, the cumulative effect can lead to widespread voltage sags, frequency deviations, or even cascade failures.

3.3 Diagnostic Symptoms

- Unexplained voltage dips or spikes at sub synchronous frequencies
- Unexpected heating in the rotor or stator windings
- Unusual noise or vibration in the turbine shaft
- Triggering of protective devices without clear cause

4. Detection and Measurement Techniques

4.1 Power System Monitoring

High frequency voltage and current transducers, coupled with advanced signal processing, can capture sub synchronous oscillations. Frequency domain analysis (FFT) helps identify peaks at the resonance frequency.

4.2 Rotor Side Converter Diagnostics

Monitoring the DC bus voltage and rotor side converter currents provides early warnings of circulating currents. Modern DFIGs often incorporate internal diagnostics that flag abnormal current patterns.

4.3 Field Test Methods

Controlled excitation tests, such as injecting a small sinusoidal current at a sub synchronous frequency, can be used to map the resonance characteristics of a wind farm. The results guide the design of mitigation measures.

5. Modeling and Simulation for SSR Synthesis

5.1 Mathematical Representation

SSR analysis typically involves solving a set of differential equations that describe the mechanical, electromagnetic, and converter dynamics. The model must capture:

- Generator inertia and damping
- Stator and rotor inductances and resistances
- Converter control loops and filter parameters
- Grid impedance and line capacitance

5.2 Simulation Tools

Popular platforms include MATLAB/Simulink, PSCAD, DIgSILENT PowerFactory, and PSS®E. These tools allow engineers to:

- Simulate the full DFIG model in a grid environment
- Introduce perturbations and observe system response
- Run parametric sweeps to identify worst case scenarios
- Validate mitigation strategies before deployment

5.3 Case Study: Synthetic SSR Analysis

In a recent study, a 3 MW DFIG wind turbine was modeled in Simulink. The simulation introduced a 40 Hz harmonic injection to mimic a grid disturbance. The results showed a resonance peak at 42 Hz, leading to a 500 A circulating current. By adjusting the converter's low frequency filter and adding a series capacitor across the stator, the resonance peak was reduced by 85 /%, demonstrating the power of simulation driven synthesis.

6. Mitigation Strategies

6.1 Passive Filters

Installing series or shunt capacitors and inductors can shift the resonance frequency away from the grid's harmonic range. The design of these filters must consider the turbine's operating conditions and the grid's impedance profile.

6.2 Active Control Adjustments

- Rotor Side Converter Loop Tuning: Adjusting the bandwidth and damping of the converter's current control loop can dampen the resonant oscillations.
- Stator Current Control: Implementing sub synchronous filtering in the stator current controller helps suppress unwanted currents.
- Dynamic Reactive Power Management: By actively managing the reactive power output, the DFIG can counteract the effects of line capacitance.

6.3 Grid Side Solutions

Upgrading the grid infrastructure—such as adding series reactors or modifying transformer tap settings—can reduce the overall grid capacitance, thereby lowering the likelihood of SSR.

6.4 Structural and Mechanical Measures

Increasing shaft stiffness, adding dampers, or installing vibration absorbers can raise the mechanical natural frequency, moving it away from the sub synchronous resonance region.

7. Operational Guidelines for Wind Farm Operators

7.1 Routine Monitoring

Operators should monitor key parameters such as DC bus voltage, rotor side converter currents, and grid voltage harmonics on a continuous basis. Automated alarm thresholds help detect early signs of SSR.

7.2 Maintenance of Converter Filters

Regular inspection of filter capacitors and inductors ensures they remain within tolerance. Aging components can shift the filter characteristics, potentially re introducing resonance.

7.3 Firmware and Software Updates

Converter controllers often receive updates that refine control loop parameters. Keeping firmware up to date helps maintain optimal damping characteristics.

8. Future Trends and Research Directions

8.1 Advanced Control Algorithms

Machine learning based adaptive control schemes are being explored to predict and counteract SSR in real time, adjusting filter settings dynamically based on operating conditions.

8.2 Integrated System Level Design

Designing wind farms with SSR in mind from the outset—by co optimizing turbine layout, grid infrastructure, and converter control—can drastically reduce the risk of resonance.

8.3 Standardization Efforts

Industry bodies are working on guidelines for SSR testing and mitigation, aiming to provide a unified framework for designers and operators.

Conclusion

Sub synchronous resonance is a complex, multi faceted challenge that sits at the intersection of turbine mechanics, power electronics control, and grid dynamics. For DFIG based wind farms, SSR can lead to significant economic losses and safety risks if left unchecked. However, through rigorous modeling, proactive monitoring, and the deployment of both passive and active mitigation strategies, operators can keep resonance at bay.

By embracing a holistic approach—combining advanced simulation tools, robust control design, and vigilant operational practices—wind farms can harness the full potential of DFIG technology while safeguarding the grid and ensuring long term reliability.

Baca Juga (Artikel Terkait)

- **advanced engineering electromagnetics solution manual edition hardcover by balanis constantine a published by wiley**
  URL: http://denniswildberger.com/advanced-engineering-electromagnetics-solution-manual-edition-hardcover-by-balanis-constantine-a-published-by-wiley.pdf
- **advanced engineering electromagnetics solutions manual**
  URL: http://denniswildberger.com/advanced-engineering-electromagnetics-solutions-manual.pdf
- **advanced engineering electromagnetics wiley 1989 grading**
  URL: http://denniswildberger.com/advanced-engineering-electromagnetics-wiley-1989-grading.pdf
- **advanced engineering fluid mechanics by biswas**

URL: http://denniswildberger.com/advanced-engineering-fluid-mechanics-by-biswas.pdf

Tags: #analysis #sub #synchronous