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Enhancing Wind Turbine and Fuel Cell Voltage Stability with Distribution Static Compensator

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Abstract

Integrated wind farms face significant challenges due to strict grid code requirements. Maintaining voltage stability is especially important for wind farms that are connected to the electrical grid. This research paper examines how FACTS devices, specifically Static Synchronous Compensators (STATCOMs), can be used to resolve voltage stability issues in wind farms and fuel cell power plants that employ Double Fed Induction Generators (DFIGs) and are connected to both loads and the power grid. During fault ride-throughs and power outages, wind farms face challenges such as voltage dips and fluctuations, which can negatively impact the grid. As a result, wind turbines require a stable grid to function effectively. In the absence of voltage stability measures, wind farms may experience reduced productivity, equipment failure, and downtime. As a dynamic voltage restorer, FACTS devices will be used. Thus, stable voltage levels are maintained, and power interruptions are prevented at DFIG-based wind farms. Three-phase impedance faults on load buses and 25% voltage sags on high voltage buses were examined in this study. STATCOMs were implemented as dynamic voltage restorers during fault ride-throughs and power grid disruptions in the MATLAB/SIMULINK simulations to mitigate voltage dips and fluctuations experienced by wind farms and fuel cells. Simulation results showed that STATCOMs significantly reduced downtime, increased power output, and minimized equipment failures in wind farms.

Objectives

The main objective of this research is to investigate the voltage stability of a medium-power wind park (9MW) connected to a distribution grid, incorporating a hydrogen-based storage system. The key goals are:

- Modeling a wind energy conversion system operating at variable speeds and employing a Doubly Fed Induction Generator (DFIG) as a power generation unit.
- Modeling, controlling, and operating a Solid Oxide Fuel Cell (SOFC) Power Plant within a grid-connected system.
- Modeling a microgrid system (wind turbine/fuel cell) integrated with the grid.
- Examining the impact of grid faults on the dynamic performance of a variable-speed wind-driven DFIG when connected to the grid.
- Investigating the effect of a Static Synchronous Compensator (STATCOM) on enhancing transient voltage stability in the proposed hybrid system.

MODELING OF POWER SYSTEM COMPONENTS

A. Modeling of Wind Power Plant

The power that the turbine is able to

$$P_m = \frac{1}{2}\rho A U^3 c_p(\beta,\lambda) \quad (1)$$

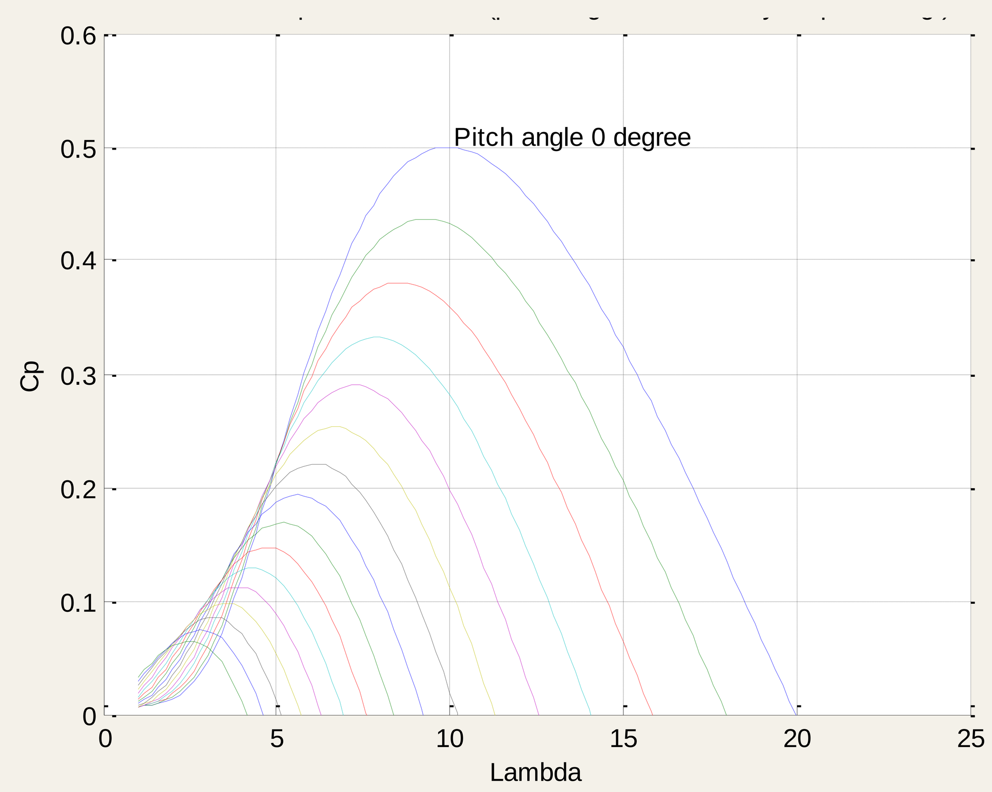

Figure 1: Cp as function of λ.

Based on this principle the voltages appeared on the stator and rotor terminals are written as follows

$$V_{qs} = R_s I_{qs} + \frac{d\psi_{qs}}{dt} + \omega_e \psi_{ds} \quad (3)$$

$$V_{ds} = R_s I_{ds} + \frac{d\psi_{ds}}{dt} - \omega_e \psi_{qs} \quad (4)$$

$$V_{qr} = R_r I_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_e - \omega_r)\psi_{dr} \quad (5)$$

$$V_{dr} = R_r I_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_e - \omega_r)\psi_{qr} \quad (6)$$

MODELING OF POWER SYSTEM COMPONENTS

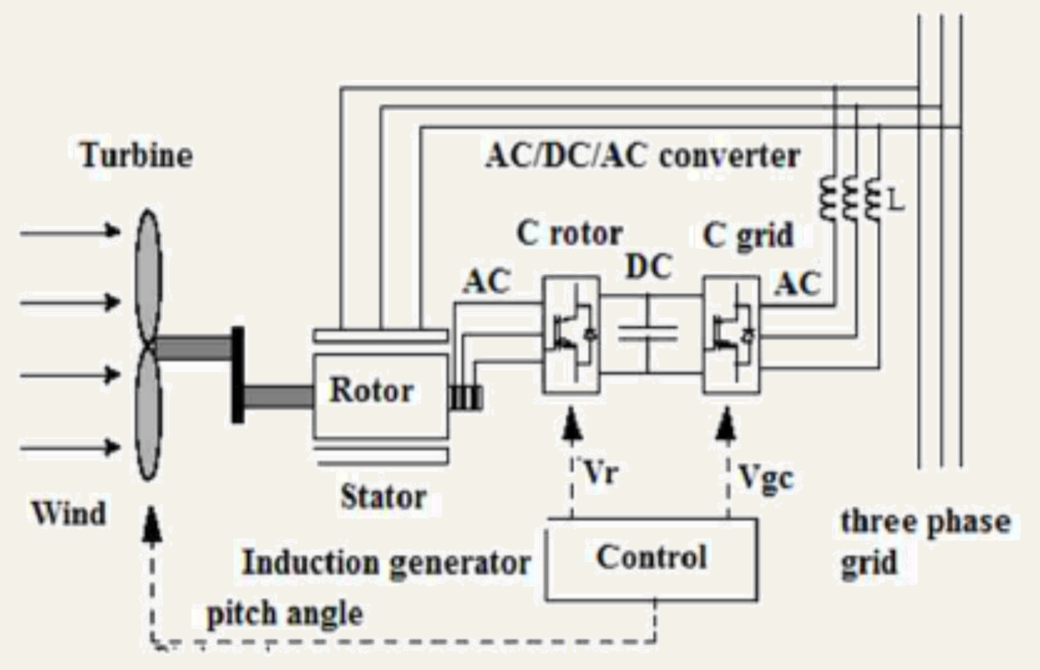

Figure 2: DFIG structure.

The active and reactive power generated in the stator can be computed using the following equations:

$$P_s = \frac{3}{2}(V_{ds} I_{ds} + V_{qs} I_{qs}) \quad (8)$$

$$Q_s = \frac{3}{2}(V_{qs} I_{ds} - V_{ds} I_{qs}) \quad (9)$$

B. Modeling of SOFCs Stack

$$E = N_0\left(E_0 + \frac{RT}{2F}\left[\ln \frac{p_{H2} p_{O2}^{0.5}}{p_{H2O}}\right]\right) \quad (10)$$

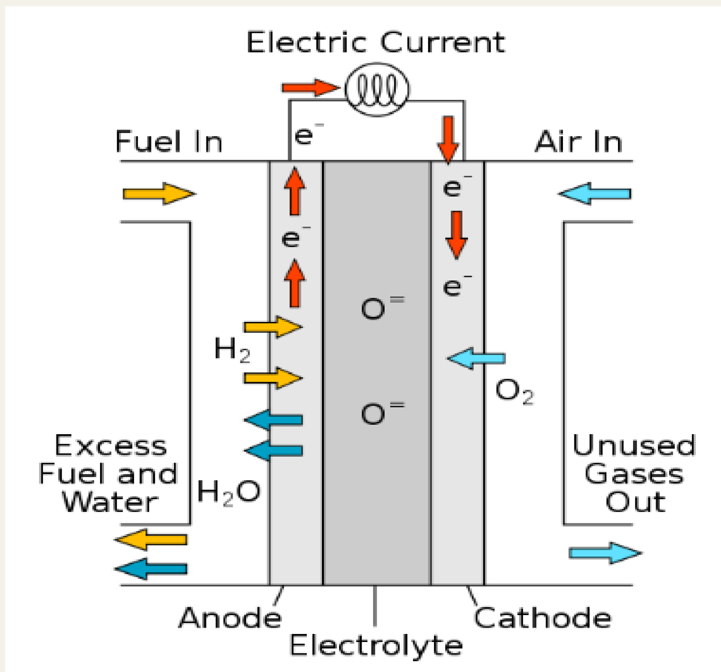

Figure 3: Diagram of a single SOFC.

C. Modeling of STATCOM

$$P_{inj} = V_i(I_d \cos\theta_i + I_q \sin\theta_i) = V_d I_d + V_q I_q \quad (11)$$

$$Q_{inj} = V_i(I_d \sin\theta_i - I_q \cos\theta_i) = -V_d I_q + V_q I_q \quad (12)$$

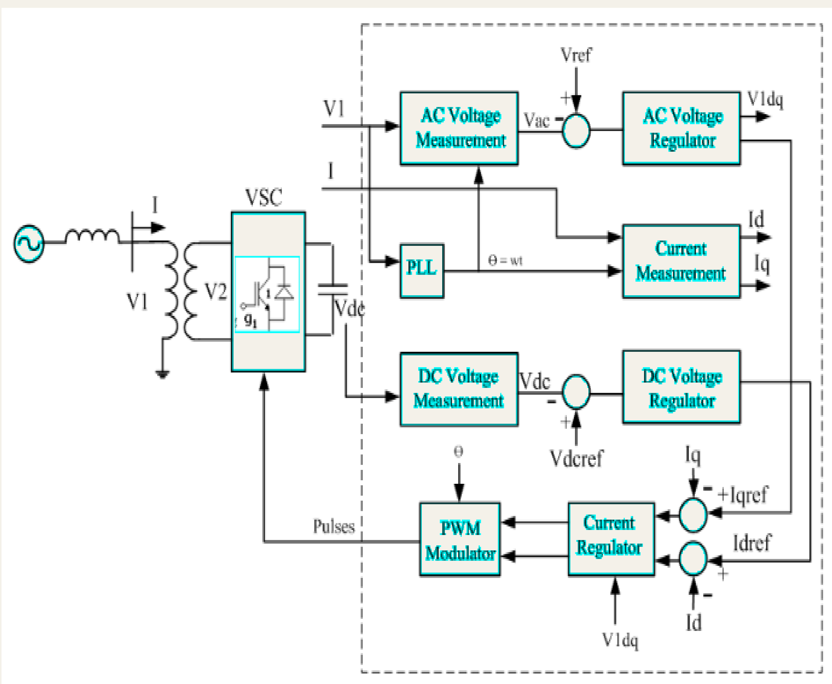

Figure 4: Schematic Diagram of STATCOM control system.

SIMULATION RESULTS AND DISCUSSIONS

- Simulations conducted in MATLAB SIMULINK to evaluate STATCOM impact on weak grid voltage profile.
- Aim to assess grid performance under transient scenarios: three-phase fault, sudden load shift, voltage sag on high voltage bus.
- System features six Doubly Fed Induction Generators (DFIGs) operating under similar conditions.
- External grid utility has limited short circuit capacity of 50 MVA, indicating weakness in responding to disturbances.
- Integration of 5 MW load into entire system via load bus; voltage stepped down to 600V.
- DFIG Wind Turbines operate at nearly unity power factor, resulting in negligible reactive power generation.
- Active power required by load divided between DFIG and Solid Oxide Fuel Cell (SOFC).
- Previous analysis indicates connection of 1.25 kV/30 kV transformer to STATCOM for voltage support.

Simulation Results and Discussion

A. Case one: Three-Phase to Ground Fault

The impact of a three-phase short circuit fault with high impedance (Xf=3) subjected to the terminals of the load is analyzed. The fault begins at t=2.0 seconds and lasts until t=2.2 seconds. Two scenarios are considered in this case: (i) without any compensation, and (ii) with a 20 MVA rated STATCOM.

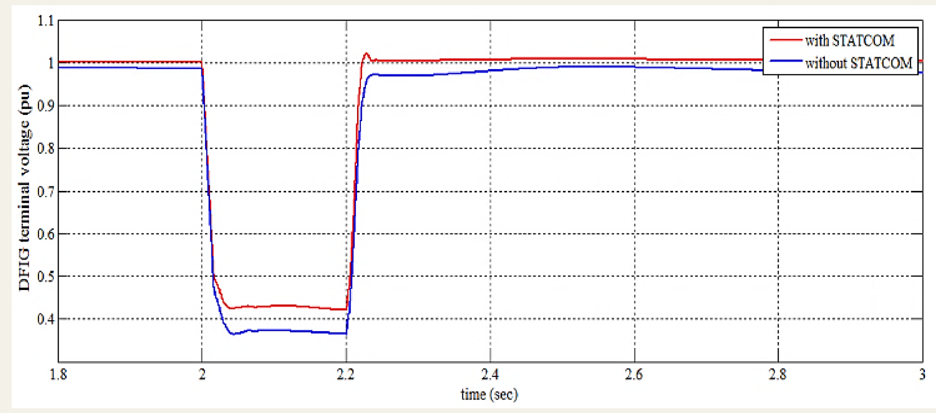

Figure 6: DFIG bus voltage under three phase faults.

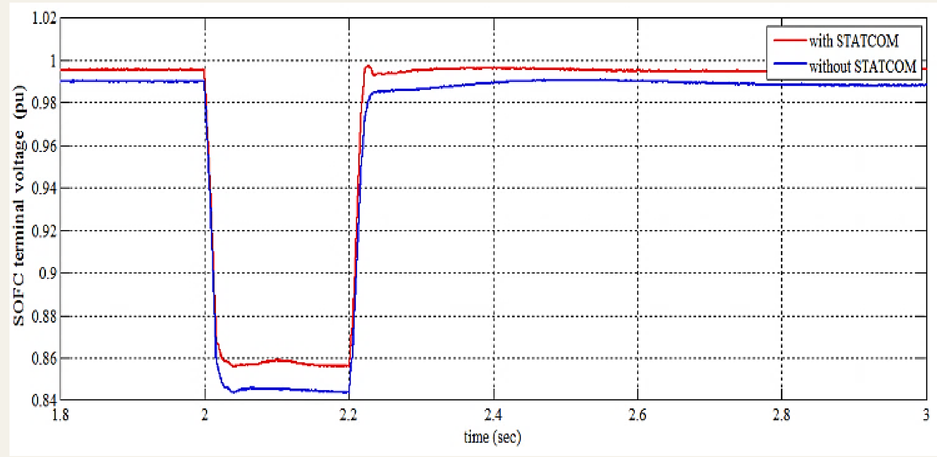

Figure 7: SOFC bus voltage under three phases faults.

B. Case two: 25% Voltage Sag at the Infinite Bus

At t=2.0 seconds, there was a voltage sag of 25% of the rated voltage at the 25kV bus, and the problem was resolved at t=2.2 seconds.

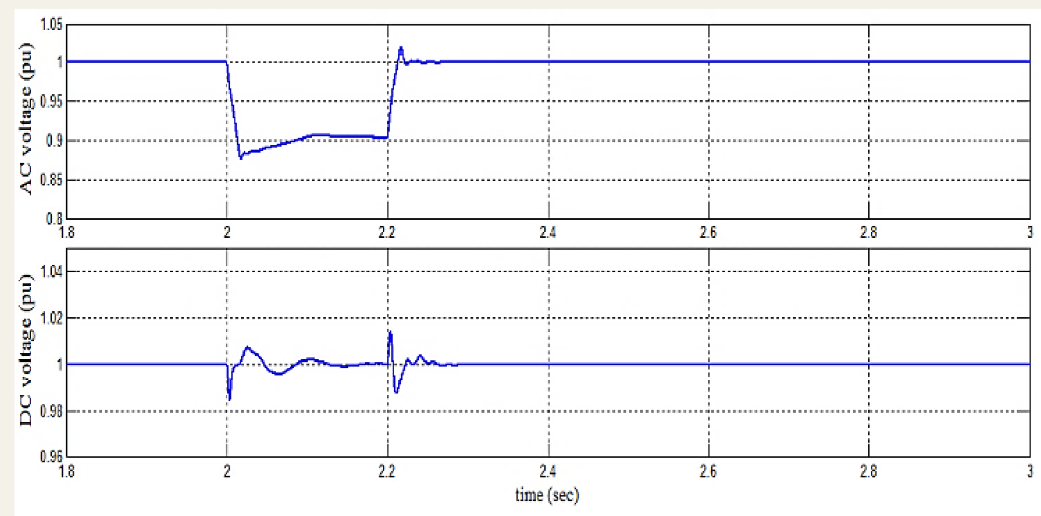

Figure 11: AC and DC bus voltages of the STATCOM for 25% voltage sag.

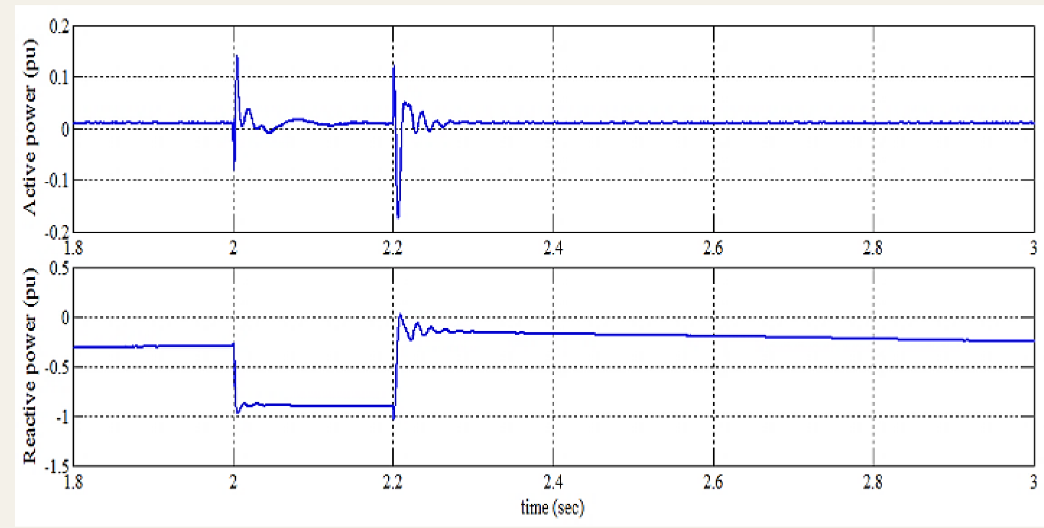

Figure 12: Active and Reactive power of the STATCOM for 25% voltage sag.

Conclusion

- Research focuses on integrating wind farm with utility grid, incorporating Solid Oxide Fuel Cell (SOFC).
- Dynamic model developed to analyze integration process.
- Novel technique proposed to prevent excessive charging of auxiliary storage devices and ensure rapid response from fuel cell by making simultaneous step and ramp changes in fuel cell reference power.
- Fuel cell exhibits response rate exceeding expectations.
- Implementation of three-phase Voltage Source Inverter (VSI) model with PQ control approach, demonstrating fast and accurate response.
- Integrated DFIG Wind Park + SOFC system capable of generating reactive power due to control approach.
- Focus on modeling DFIG within system, requiring reactive power adjustments during grid disturbances.
- Properly sized STATCOM can be employed to correct reactive power when connected to unstable grid.
- Simulation tests show STATCOM's additional voltage and reactive power support considerably improves turbine ability to recover from faults by hastening restoration of voltage characteristics.

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