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The Impact of DFIG and FSIG Wind Farms on the Small Signal Stability of a Power System

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Outline

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- Models & Methods
- Results & Discussion
- Conclusion
- Suggestions & Comments

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Introduction

Literature Debate – Contradicting Reports.

Objectives:

- Investigate the impact of DFIG and FSIG wind farms on the stability of a multi-machine power system.
- Investigation Routines:
    - Eigenvalue analysis, and
    - Time domain simulation.
- Develop a general understanding of wind farms impact on the stability of the system.

Preliminaries – System Stability

Small signal stability: Stability of a system under conditions of gradual or small perturbations in the system.

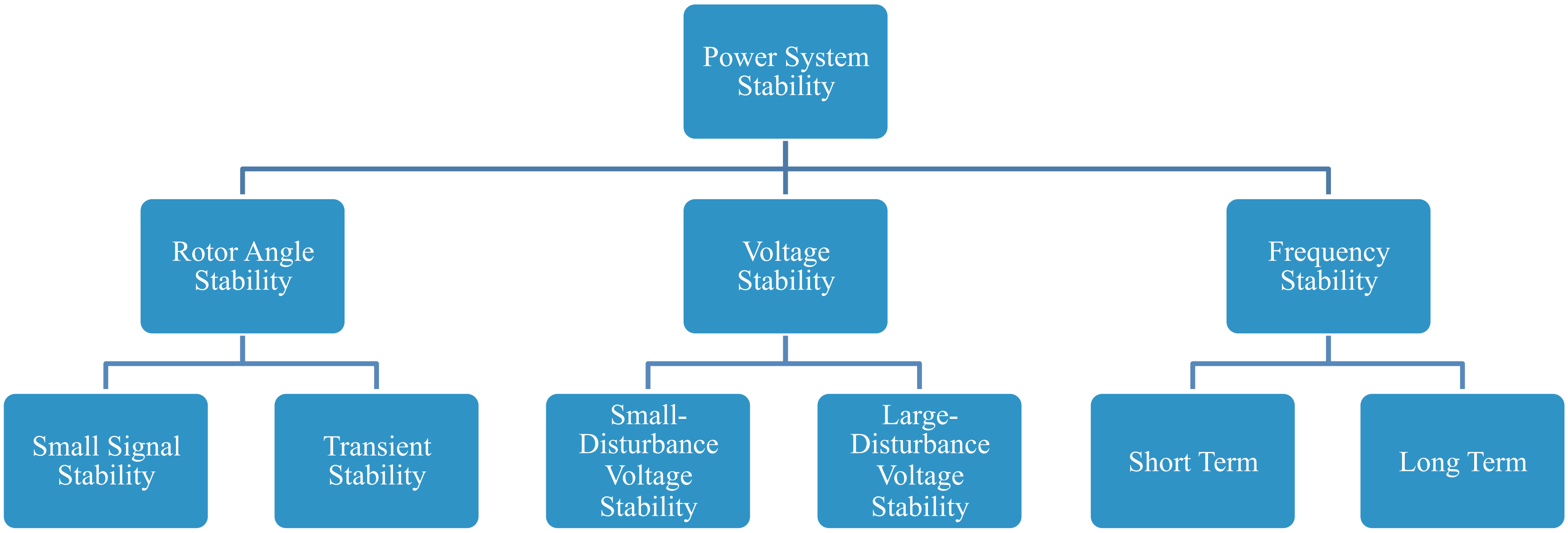

Fig. 1. Classification of Power System Stability

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Preliminaries – System Stability

Electro-mechanical oscillations of small magnitude and low frequency may hinder system stability [0.1 Hz to 3 Hz].

Classified into 4 Categories:

- Local oscillations (0.8 Hz to 4.0 Hz),
- Inter-plant oscillations (1 Hz to 2 Hz),
- Inter-area oscillations (0.2 Hz to 0.8 Hz), and
- Global oscillation (Less than 0.2 Hz).

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Preliminaries – DFIG

Wind Turbine Doubly-Fed Induction Generator (DFIG)

A DFIG comprises:

- Mechanical parts e.g. shaft and aerodynamics,
- Wound-rotor induction generator model with grid side and rotor side power converters,
- Electrical and Pitch Control, and
- Voltage limits and over-current crowbar.

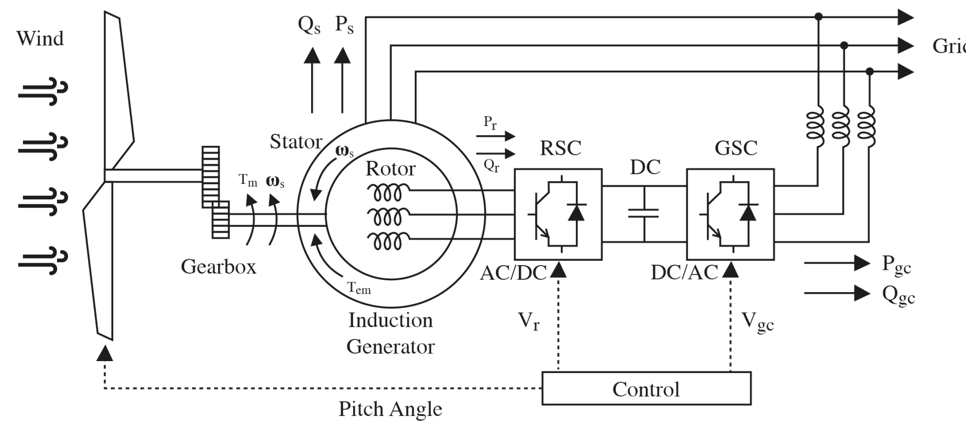

Fig. 2. DFIG

Power converters decouple the network's electrical frequency from the rotor's mechanical frequency enabling the variable-speed operation

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Preliminaries – FSIG

Wind Turbine Fixed-Speed Induction Generator (FSIG)

An FSIG has a simple architecture:

- Aerodynamic blades,
- Gearbox,
- Squirrel-cage rotor induction generator, and
- Capacitors: to counteract the squirrel-cage induction generator's reactive power consumption.

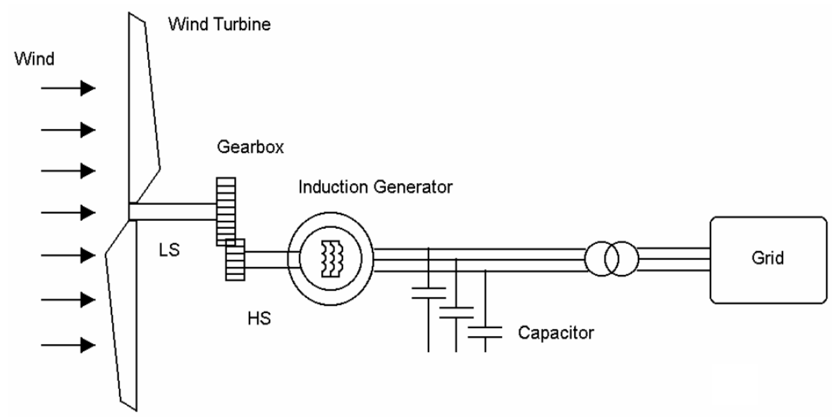

Fig. 3. FSIG

Methods & Models

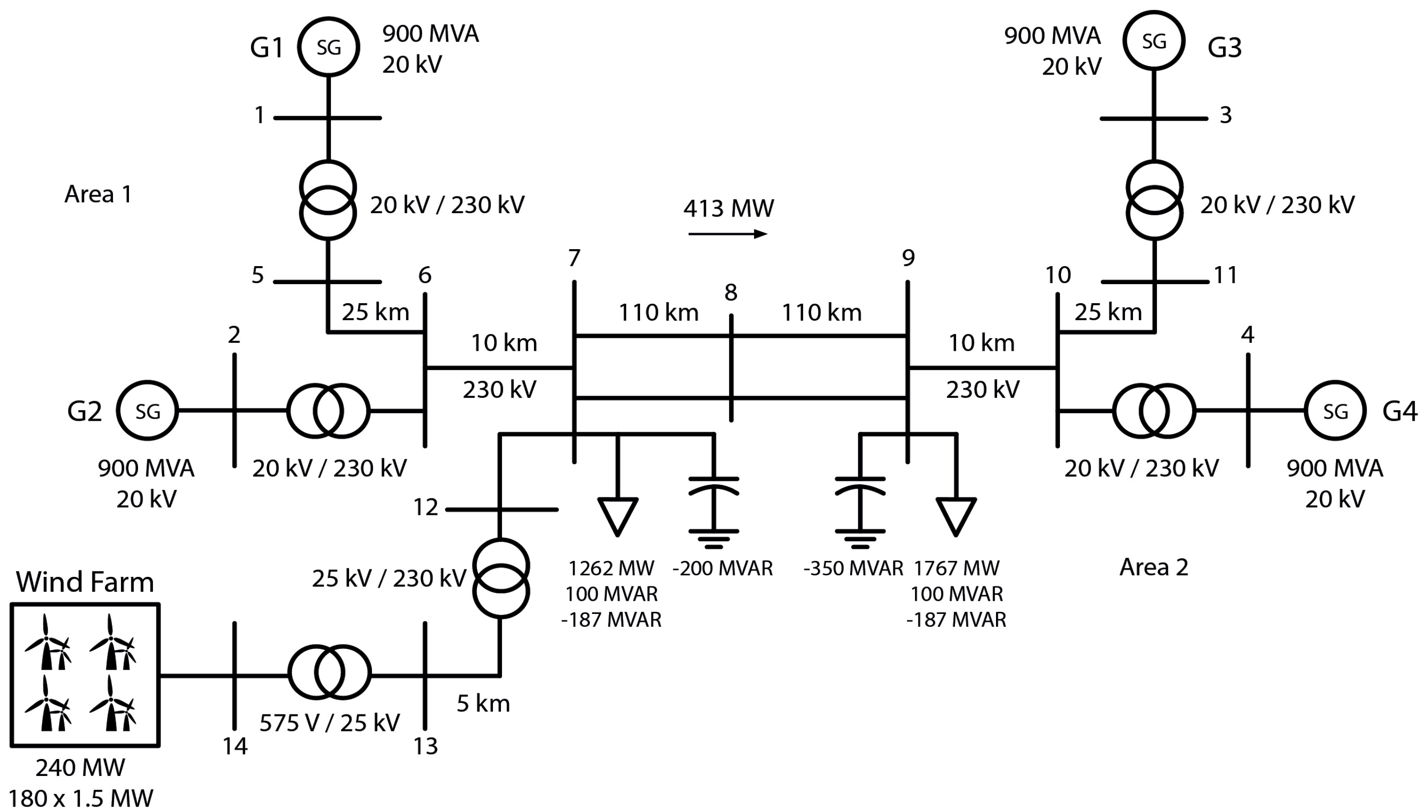

Fig. 4. Single Line Diagram of the Two-Area Test System

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Results & Discussion

Three systems were studied:

- Conventional Kundur two-area four-machine system,
- Two-area four-machine system + 240 MW FSIG wind farm, and
- Two-area four-machine system + 240 MW DFIG wind farm.

Judgments:

- Eigenvalue analysis
  - Three aforementioned systems
  - Varying wind farm tie-lines
- Time domain simulations.
  - Small perturbation with magnitude of 5% applied at time = 1 s for 12 cycles at the voltage reference of Generator 1 in Area 1
  - A three-phase fault at one of the 220 Km transmission lines between Area 1 and Area 2, at time = 1 s cleared after 8 cycles

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Results – Eigenvalue Analysis

Table I. Dominant Eigenvalues of the System without Wind Farm and Systems with DFIG and FSIG Wind Farms

Case	Eigenvalues	Frequency (Hz)	Damping
Without Wind Farm	-13.399 ± 18.706i	2.977	58.23%
	-14.588 ± 15.057i	2.396	69.58%
	-2.996 ± 10.219i	1.626	28.14%
	-2.992 ± 9.734i	1.549	29.38%
	-1.053 ± 3.943i	0.627	25.78%
FSIG Wind Farm	-13.211 ± 18.545i	2.951	58.02%
	-14.445 ± 14.864i	2.365	69.69%
	-2.79 ± 10.049i	1.599	26.75%
	-2.884 ± 9.312i	1.482	29.59%
	-1.008 ± 3.86i	0.615	25.25%
DFIG Wind Farm	-14.522 ± 15.752i	2.507	67.78%
	-3.217 ±9.785i	1.557	31.23%
	-3.419 ± 8.713i	1.387	36.53%
	-7.089 ± 3.267i	0.520	90.82%
	-0.851 ± 3.538i	0.563	23.39%

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Results – Eigenvalue Analysis

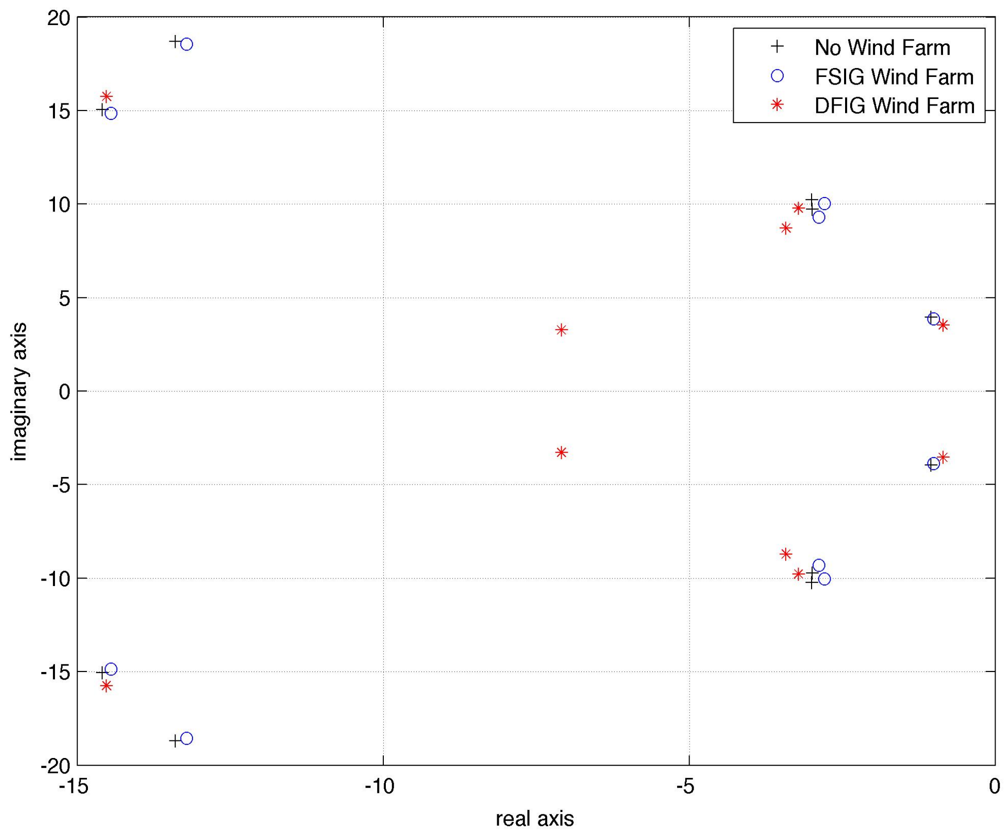

Fig. 5. Dominant Eigenvalues of the System without Wind Farm and Systems with DFIG and FSIG Wind Farms.

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Results – Eigenvalue Analysis

Table II. Dominant Eigenvalues of the System with varying Wind Farm Tie-Line Distances

Case	Eigenvalues	Frequency (Hz)	Damping
DFIG with 5 Km tie-line	-14.522 ± 15.752i	2.507	67.78%
	-3.217 ±9.785i	1.557	31.23%
	-3.419 ± 8.713i	1.387	36.53%
	-7.089 ± 3.267i	0.520	90.82%
	-0.851 ± 3.538i	0.563	23.39%
DFIG with 150 Km tie-line	-12.751 ± 17.755i	2.825	58.33%
	-13.274 ± 11.9i	1.894	74.45%
	-3.21 ± 9.303i	1.48	32.62%
	-2.265 ±8.93i	1.421	24.58%
	-0.934 ± 3.649i	0.58	24.79%
DFIG with 300 Km tie-line	-13.093 ± 18.629i	2.965	57.49%
	-14.341 ± 14.196i	2.259	71.06%
	-3.321 ± 9.379i	1.493	33.38%
	-2.852 ± 8.709i	1.386	31.12%
	-0.953 ± 3.527i	0.561	26.08%

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Results – Eigenvalue Analysis

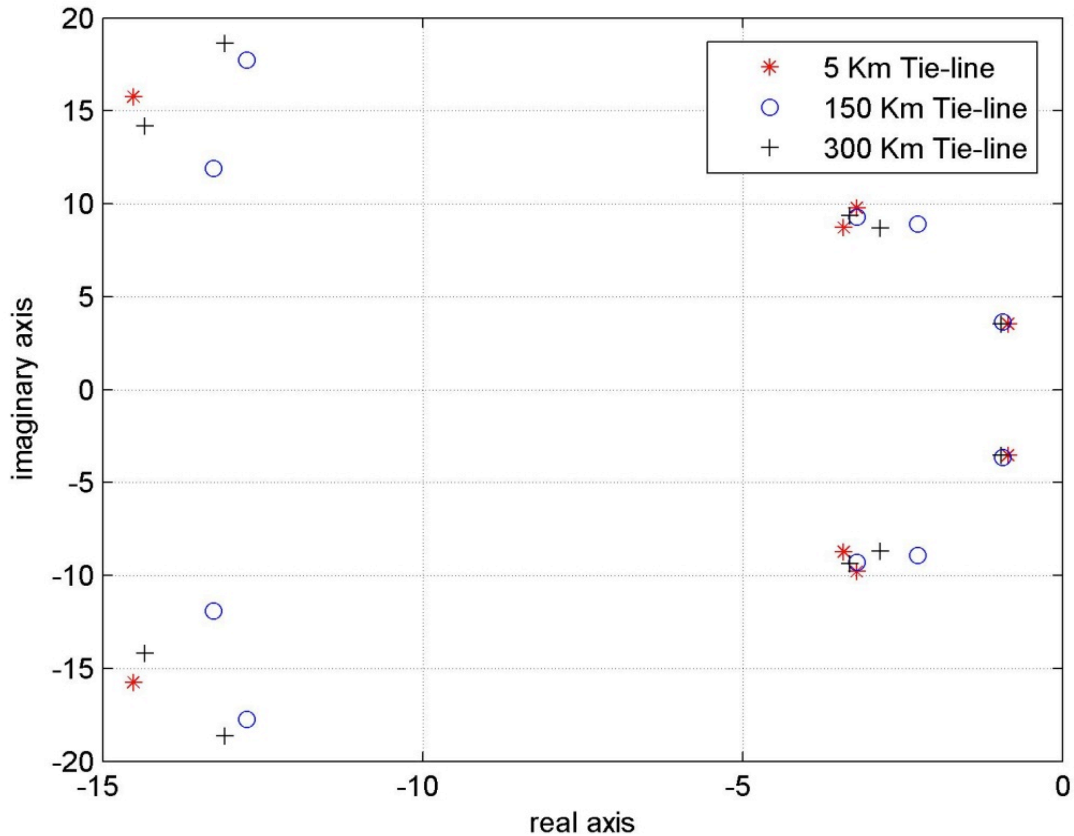

Fig. 6. Dominant Eigenvalues of the System with DFIG Wind Farm with Varying Tie-Line Distances.

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Results – Time Domain Simulations

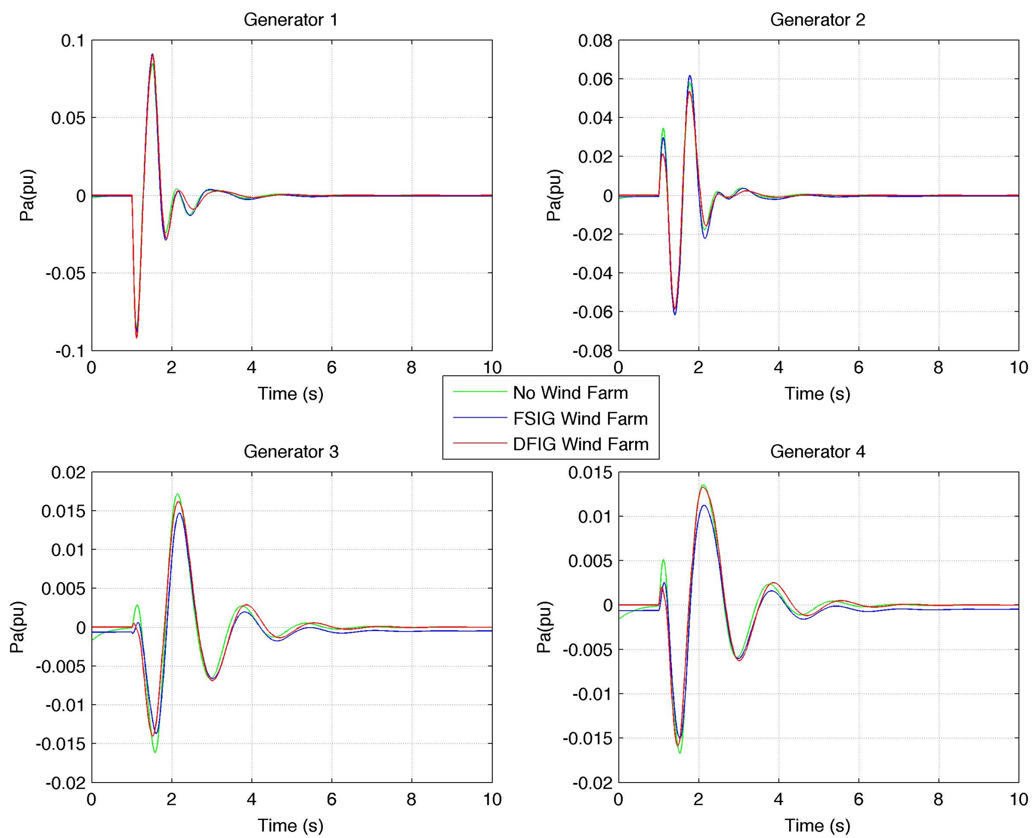

Fig. 7. Accelerating Power (P_a) of all Four Generators in Response to a 5% Magnitude Pulse Applied for 12 Cycles at the Voltage Reference of Gen. 1.

Results – Time Domain Simulations

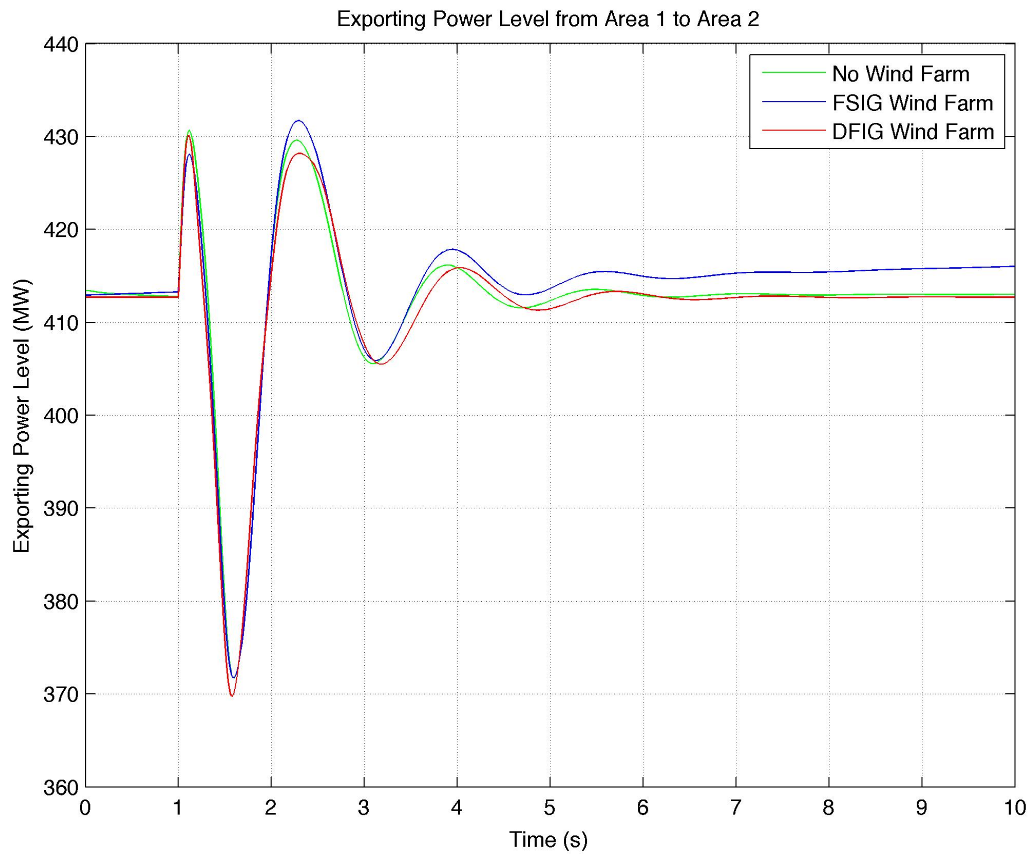

Fig. 8. Exporting Level (MW) from Area 1 to Area 2 in Response to a 5% Magnitude Pulse Applied for 12 Cycles at the Voltage Reference of Gen. 1.

Results – Time Domain Simulations

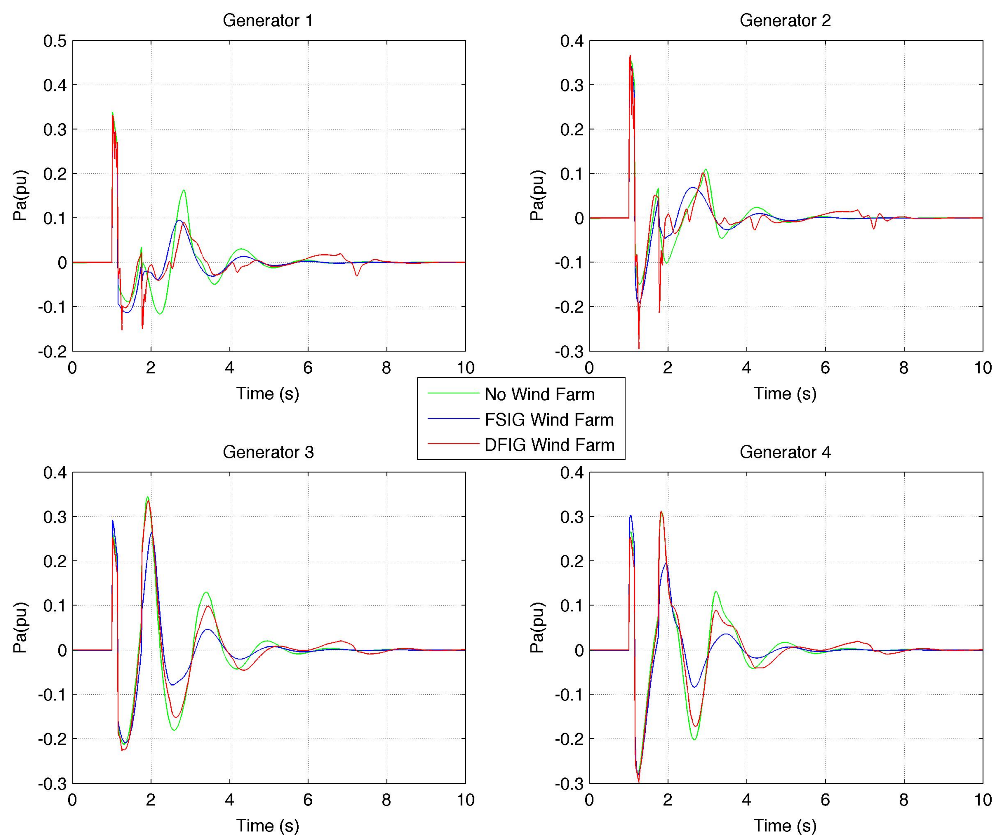

Fig. 9. Accelerating Power (P_a) of all Four Generators in Response to a Three-Phase Fault at One of the Transmission Lines between Area 1 and Area 2.

Results – Time Domain Simulations

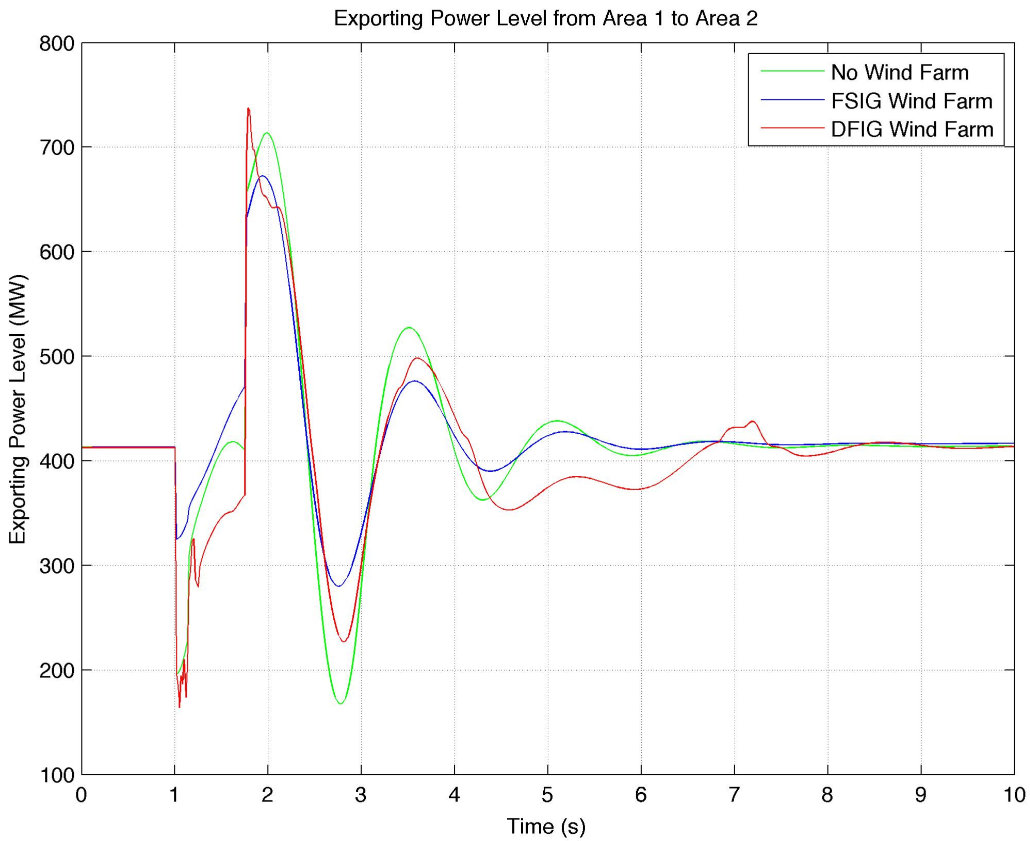

Fig. 10. Exporting Level (MW) from Area 1 to Area 2 in Response to a Three-Phase Fault at One of the Transmission Lines between Area 1 and Area 2.

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Conclusion

- Eigenvalue analysis demonstrated that the FSIG wind farm had a slightly negative impact on the system's stability. While, the DFIG wind farm had a generally positive impact on the damping of the unwanted electro-mechanical oscillations and system stability in most cases.
- Time domain simulations demonstrated that both FSIG and DFIG wind farms improved the system's response to small and large perturbations, with the former exhibiting better improvement.
- The conflicting observations support the claim that there is no general statement on whether wind farms have a positive or negative impact on the stability of a power system.
- Each system should be studied on an individual basis, since wind power penetration alters the original system steady-state conditions and operating points.

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Future Work

- More systems should be studied to develop a more general understating of wind farms impact on the stability of a power system.

- Using the same analogy of adding a Power System Stabilizer (PSS) to the conventional Synchronous Generator, a Wind Turbine Generator Power System Stabilizer (WPSS) may be added to wind turbine generators to improve their contribution to damping of low frequency oscillations and improve overall stability.

Thank you for your Attention

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Discussion

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