

# Improving the Stability of DFIG-Based Offshore Wind Farm Using a STATCOM

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**ABSTRACT:** The damping of offshore wind farm fed to a multi-machine system is improved using a Static Synchronous Compensator. The STATCOM along with PID damping controller and a hybrid PID and fuzzy logic controller are designed to improve the damping characteristics under various operating conditions. The offshore wind farm is designed by a Doubly-Fed Induction Generator driven by a wind turbine through an equivalent gearbox. Root-loci plots under various wind speed operating conditions have been carried to show the effectiveness of the PID damping controllers. This is done by a computer simulation and the simulation results are compared with various controllers.

**KEY WORDS:** Doubly-fed induction generator, fuzzy logic controller, multi-machine system, offshore wind farm, stability, static synchronous compensator

## I. INTRODUCTION

Now a day's power transmission and distribution systems face higher demands for power, quality and reliability at low cost, and low environmental effect. Transmission networks needs to operate at high transmission levels, and thus power engineers have faced some major operating problems such as transient stability, oscillation damping and voltage regulation etc. While generator excitation controllers are helpful in achieving rotor angle stability or voltage regulation enhancement, with only excitation control, the system stability may not be maintained when large fault occurs close to the generator terminal, or simultaneous transient stability and voltage regulation enhancement may be difficult to achieve. The recent technologies and use of FACTS controllers like static synchronous compensator (STATCOM) in power transmission systems can improve the smooth and rapid reactive power compensation to power systems, and can be used to provide voltage support, increase the transient stability and improve power system damping. Several FACTS equipment is readily available or still under development, based on the solid state switch with conventional thyristors and on the voltage source inverter with GTO switches. All these equipment provide controllability to the AC transmission system by adjusting the reactive power in shunt and series impedance of transmission line. The STATCOM was proposed by several researchers to compensate the reactive current from or to the power system. This function is similar to the synchronous condenser with rotating mass, but its time response is extremely faster than that of the synchronous condenser. This condition is very effective to increase transient stability, to enhance voltage and to damp the low frequency oscillation for the transmission system.

In DFIG-based OWF connected to a power grid through a line-commutated high-voltage direct-current (HVDC) with a damping controller located at the rectifier current regulator of the HVDC link was proposed to contribute adequate damping to the OWF under various wind speeds and different disturbance conditions. But this control scheme was only suitable for the systems having a long distance from OWFs to onshore grids. In, a variable frequency transformer (VFT) was proposed to smooth the fluctuating active power generated by the OWF sent to the power grid and improve the damping of the OWF. In, a DFIG-based wind power plant (WPP) was connected to a three-machine nine-bus system to compare voltage stability of the system at a point of common coupling when the system was with and without the WPP.

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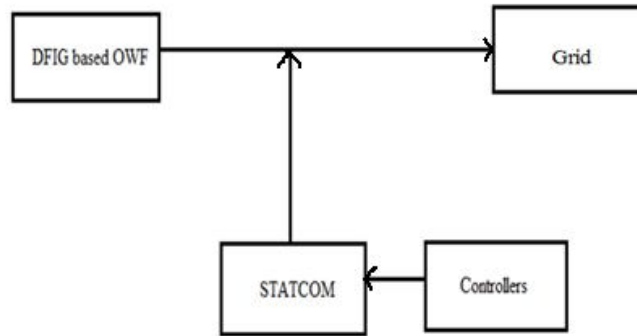


Figure :1 block diagram of DFIG based offshore system

The dynamic performance of DFIG-based wind turbines connected to multi-machine systems under three different configurations was presented. A new control strategy for improving fault ride-through capability of wind farms connected to a multi-machine power system was proposed in, while a small series dynamic braking resistor was located at the stator circuit of the DFIG along with a DC-chopper braking resistor. Especially, increase of wind-power penetration could lead to the problem of sudden disconnection of considerable amount of power generation in case of a transient fault occurred in the system, causing the system to be unstable from an otherwise harmless fault situation. Here, static synchronous compensator (STATCOM) is one of the good controllers for dynamic compensation of reactive power when the voltage is lower than the normal voltage range.

## II. STATCOM

STATCOM or Static Synchronous Compensator is a shunt device, which uses force commutated power electronics (i.e. GTO, IGBT) to control power flow and improve transient stability on electrical power networks. It is also a member of the so-called Flexible AC Transmission System (FACTS) devices. The STATCOM basically performs the same function as the static var compensator but with some advantages. The term Static Synchronous Compensator is derived from its capabilities and operating principle, which are similar to those of rotating synchronous compensators (i.e. generators), but with relatively faster operation.

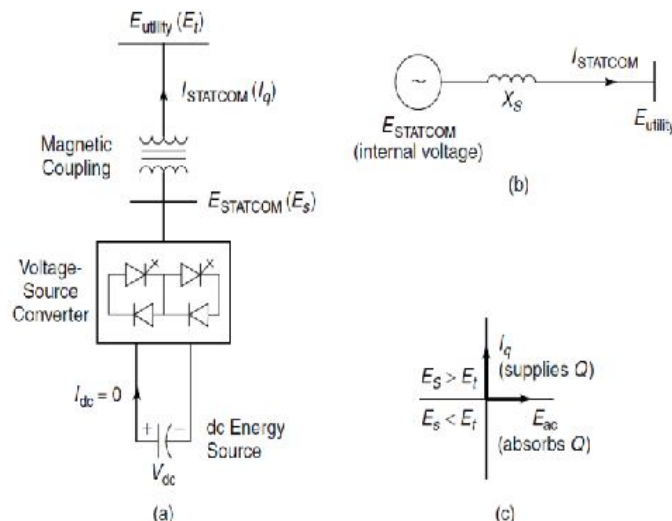


Figure: 2 The STATCOM principle diagram: (a) a power circuit; (b) an equivalent circuit; and (c) a power exchange from the ac system.

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In the case of two AC sources, which have the same frequency and are connected through a series reactance, the power flows will be: Active or Real Power flows from the leading source to the lagging source. Reactive Power flows from the higher to the lower voltage magnitude source. Consequently, the phase angle difference between the sources decides the active power flow, while the voltage magnitude difference between the sources determines the reactive power flow. Based on this principle, a STATCOM can be used to regulate the reactive power flow by changing the output voltage of the voltage-source converter with respect to the system voltage.

STATCOMs are typically applied in long distance transmission systems, power substations and heavy industries where voltage stability is the primary concern. In addition, static synchronous compensators are installed in select points in the power system to perform the following:

- ✓ Voltage support and control
- ✓ Voltage fluctuation and flicker mitigation
- ✓ Unsymmetrical load balancing
- ✓ Power factor correction
- ✓ Active harmonics cancellation
- ✓ Improve transient stability of the power system

### III. PID CONTROLLERS

PID is the combination of proportional (p), the integral (i), and the derivative (d) controls. A proportional controller ( $K_p$ ) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control ( $K_i$ ) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control ( $K_d$ ) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Since many control systems using PID control have proved better, it has a wide range of applications in industrial control.

The PID damping controller for the proposed STATCOM to achieve stability improvement of the studied system using a unified approach based on modal control theory. PID controller is used when dealing with higher order capacitive processes (processes with more than one energy storage) when their dynamic is not similar to the dynamics of an integrator.

### IV. DOUBLE FED INDUCTION GENERATOR

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle mainly used in wind turbines. Doubly fed generators are electric motors or electric generators that have windings on both stationary and rotating parts, where these windings transfer power between shaft and grid. Usually the stator winding is directly connected to the three-phase grid and the three-phase rotating winding is fed from the grid through a converter. Doubly fed machines are used in applications that require varying speed of the machine's shaft in a limited range around the synchronous speed.

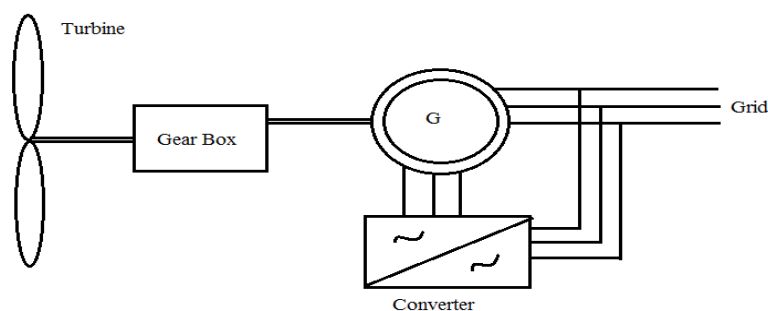


Figure: 3 design of wind turbine

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A DFIG wind turbine can transmit power to the network through both the generator stator and the converters. When the generator operates in super-synchronous mode, power will be delivered from the rotor through the converters to the network, and when the generator operates in sub-synchronous mode, the rotor will absorb power from the network through the converters. It uses a wound-rotor induction generator with slip-rings to transmit current between the converters and the rotor windings and variable-speed operation is obtained by injecting a controllable voltage into the rotor at the desired slip frequency. The rotor winding is fed through a power converter, based on two AC/DC IGBT based voltage source converters (VSCs), and linked through a DC bus.

The variable-frequency rotor supply from the converter enables the rotor mechanical speed to be decoupled from the synchronous frequency of the electrical network, thereby allowing variable-speed operation of the wind turbine. The “crowbar” is used to protect the generator and converters by limiting the voltages and over-current.

## V .SIMULATION RESULTS

The simulink model with STATCOM is shown in the figure:5. The output waveform with fault is shown in the figure :5, figure :6 represents the output waveform with rectification of fault. Figure :7& 8 represents the waveform when the circuit breaker closed and opened.

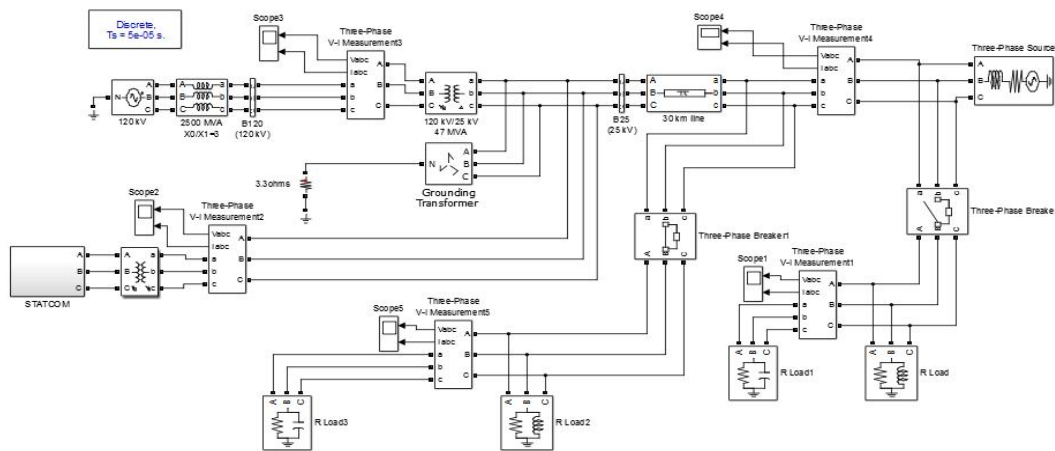


Figure:4 simulink model

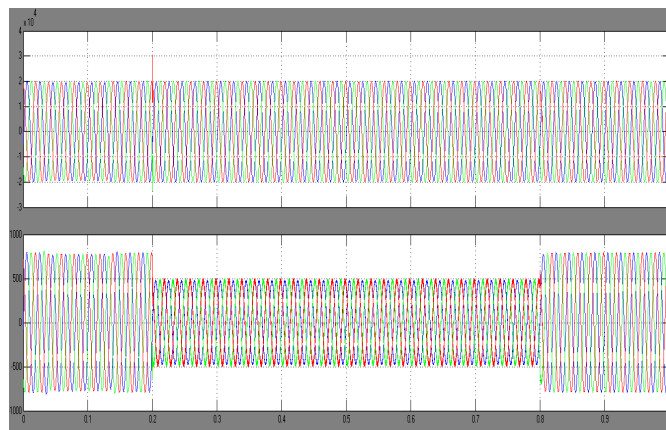


Figure: 5 output waveform with fault

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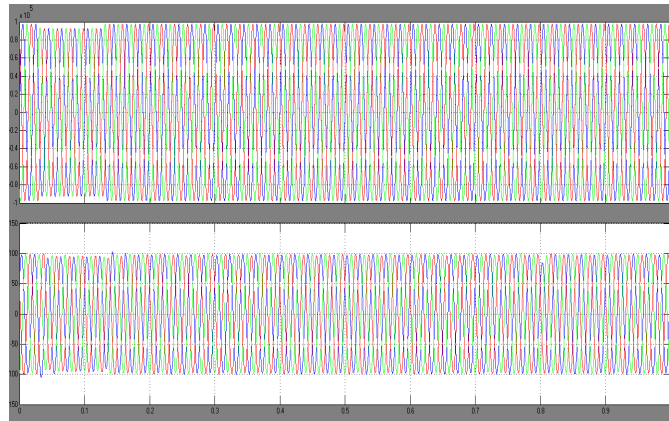


Figure: 6 output waveform

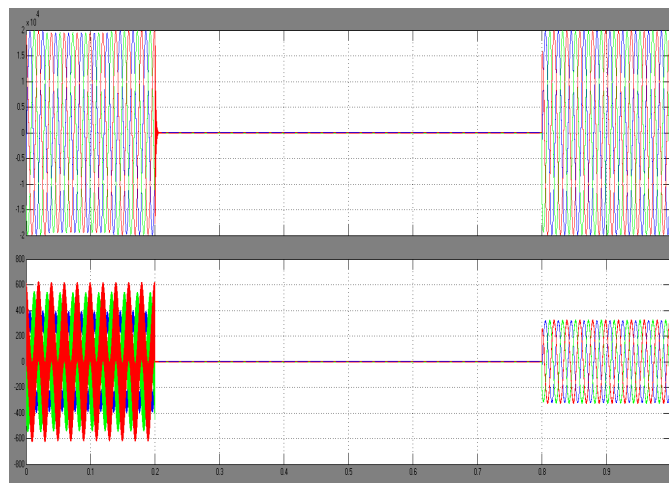


Figure: 7 waveform when circuit breaker closed

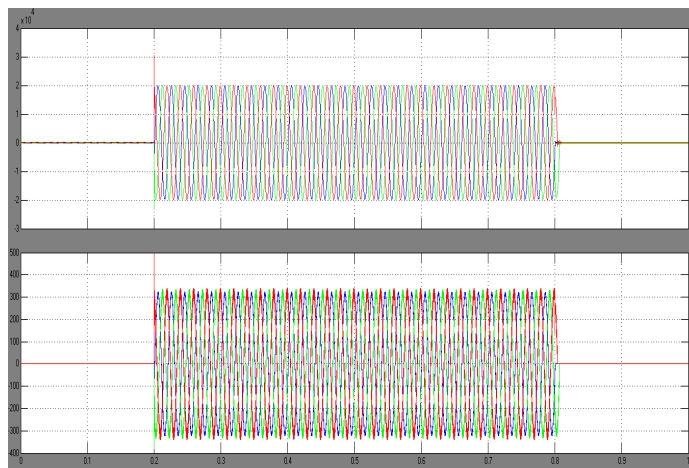


Figure: 8 waveform when circuit breaker opened

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## VI. CONCLUSION

This paper has presented the stability improvement of a DFIG-based OWF fed to a multi-machine system using a STATCOM. The STATCOM is proposed and is connected to the connected bus of the OWF to the multi-machine system. To supply the adequate reactive power to the system, a PID damping controller for the STATCOM has been designed by using a modal control theory to assign two dominant modes of the studied system to the desired locations on the complex plane. Root-loci plots under various wind speed operating conditions have been carried to show the effectiveness of the designed PID damping controller. Moreover, for improving the performance of the studied system with the designed PID, a hybrid PID plus FLC damping controller is also designed. Comparative time-domain simulations of the studied system subject to a three-phase short-circuit fault at the connected bus have been systematically performed to demonstrate the effectiveness of the proposed STATCOM joined with the two designed damping controllers on suppressing inherent oscillations of the studied system. It can be concluded from the simulation results that the proposed STATCOM joined with the designed hybrid PID plus FLC damping controller has the best damping characteristics to improve the performance of the DFIG-based OWF fed to the studied multi-machine system under different operating conditions.

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