Effects of Facts Devices in the Wind Farm Protection: Comparison of STATCOM and SSSC (Using POD Controller)

Abhishek Jain[1],
Assistant Professor,
[1]Department of Electrical Engineering,
Ganga Institute of Technology and Management,
Jhajjar

Ishika Garg[2], *Student*
[2]Department of Electrical Engineering,
Ganga Institute of Technology and Management,
Jhajjar

When integrating to the power system, large wind farms pose stability and control issues. A thorough study is required to identify the potential problems and to develop measures to mitigate them. Although integration of high levels of wind power into an existing transmission system does not require a major redesign, it necessitates additional control and compensating equipment to enable recovery from severe system disturbances.This Paper investigates the use of a Static Synchronous Compensator (STATCOM) and SSSC along with wind farms for the purpose of stabilizing the grid voltage after grid-side disturbances such as a three phase short circuit fault, temporary trip of a wind turbine and sudden load changes. The DC voltage at individual wind turbine (WT) inverters is also stabilized to facilitate continuous operation of wind turbines during disturbances.

Index Terms—About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

The concern about environmental pollution and energy shortage has led to increase interest in technologies for the generation of renewable electrical energy. Among various renewable energy sources, wind power is the most rapidly growing in Europe and the United States. The concept of a variable-speed wind turbine (VSWT) equipped with a doubly fed induction generator (DFIG) is receiving increasing attention because of its advantages over other wind turbine generator concepts. In DFIG concept, the induction generator is grid-connected at the stator terminals; the rotor is connected to the utility grid via a partially rated variable frequency ac/dc converter (VFC), which only needs to handle a fraction (25%–30%) of the total DFIG power to achieve full control of the generator. The Variable frequency converter consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back by a dc-link capacitor. During a grid fault, the RSC of the DFIG may be blocked to protect it from over current in the rotor circuit. The wind turbine trips shortly after the converter has blocked and automatically reconnects to the power network after the fault has cleared and the normal operation has been restored.

The problem of voltage instability can be solved by using dynamic reactive compensation. Shunt flexible ac transmission system (FACTS) devices, such as the SVC, TCPAR, TCSC, SSSC, UPFC, IFPC, GUPFC, HPFC, and the STATCOM, have been widely used to provide high-performance steady state and transient voltage control at the point of common coupling (PCC). The application of an SVC or a STATCOM to a wind farm equipped with fixed-speed wind turbines (FSWTs) and squirrel-cage induction generators (SCIGs) has been reported in open literatures for steady-state voltage regulation for short-term transient voltage stability.

II. FACTS OVERVIEW

FACTS stand for flexible AC transmission system. FACTS controller are defined as power electronics based system provided the control of one or more AC transmission parameters.

FACTS parameters are used for many following purposes:

a) Power Flow control
b) Flicker mitigation
c) Power quality improvement
d) Stability improvement
e) Voltage control
f) Reactive Power compensation

In general, FACTS controllers can be divided into four categories.

a) Series controllers.
b) Shunt controllers
c) Combined series Controllers
d) Combined series shunt Controllers.

A. *Statcom Model*

Figure 1 shows the basic model of a STATCOM which is connected to an ac system bus through a coupling transformer. In STATCOM, the maximum compensating current is independent of system voltage, so it operates at full capacity even at the low voltages. The STATCOM's advantages include flexible voltage control for power quality improvement, fast response, and applicability for use with high fluctuating loads.

The output of the controller Qc is controllable which is proportional to the voltage magnitude difference (Vc - V) and is given by

$$Q_c = \frac{V(V_c - V)}{X}$$

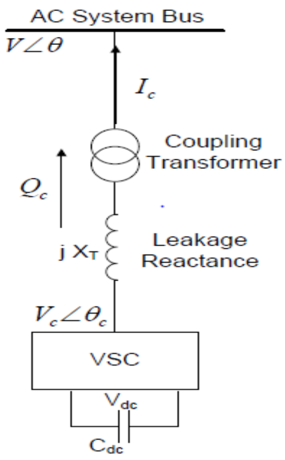

Figure 1: Schematic Diagram For STATCOM

B. SSSC Model

Neglecting harmonics, we can express the system equations (including SSSC) in D{Q variables (referred to a synchronously rotating axis). The advantage of using these variables is that in steady state, the D{Q components are constants and can be expressed as rectangular coordinates of phasors . For stability studies involving phenomena of frequency below 5 Hz, it is adequate to express the network equations using phasors by neglecting network transients. However, for phenomena involving higher frequencies, one cannot ignore network transients (even for studies involving sub synchronous frequency oscillations). We can illustrate the derivation of the network equations by considering the single line containing a SSSC shown in Fig. 7.2. Neglecting, zero sequence components, we can express the network equations (using two phase variables, α and β) in the complex form given below.

$$L\frac{di}{dt} + R\hat{i} = \hat{v}_S - \hat{v}_C - \hat{v}_R$$

where

$$\begin{aligned} \hat{i} &= (i_\beta + j i_\alpha), \quad \hat{v}_S = v_{S\beta} + j v_{S\alpha}, \\ \hat{v}_C &= v_{C\beta} + j v_{C\alpha}, \quad \hat{v}_R = v_{R\beta} + j v_{R\alpha}, \end{aligned}$$

Transforming from α, β to $D - Q$ components which are related as,

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_D \\ i_Q \end{bmatrix}$$

Where μ =! 0t+μ0. There is no loss of generality in assuming μ0 = 0. Similar transformation as given above applies to the variables VSα; VSβ and VSD; VSQ and so on.

We can also express as a complex equation given below.

$$(i_\beta + j i_\alpha) = (i_Q + j i_D) e^{j\omega_0 t} = \hat{I} e^{j\omega_0 t}$$

Latter can be expressed as

$$L\frac{d(\hat{I}e^{j\omega_0 t})}{dt} + R(\hat{I}e^{j\omega_0 t}) = (\hat{V}_S - \hat{V}_C - \hat{V}_R)e^{j\omega_0 t}$$

Simplifying, we get,

$$L\frac{d\hat{I}}{dt} + j\omega_0 L\hat{I} + R\hat{I} = \hat{V}_S - \hat{V}_C - \hat{V}_R$$

where

$$\begin{aligned} \hat{I} &= I_Q + jI_D, \quad \hat{V}_S = V_{SQ} + jV_{SD}, \quad \hat{V}_C = V_{CQ} + jV_{CD}, \\ \hat{V}_R &= V_{RQ} + jV_{RD} \end{aligned}$$

In steady state, $\hat{I}$ is a constant and $\frac{d\hat{I}}{dt} = 0$. Hence, we get (in steady state),

$$(R + j\omega_0 L)\hat{I} = \hat{V}_S - \hat{V}_C - \hat{V}_R$$

III. WIND ENERGY

Wind is a continuously varying source of energy and so is the active power generated by the wind turbine. Wind generators are generally of two types: fixed and variable speed. Fixed speed generators are induction generators with capacitor bank for self-excitation or two-pole pairs or those which use rotor resistance control. Variable speed generators are either DFIG (which is a round rotor machine) or full power converters such as squirrel cage 6 induction generators, permanent magnet synchronous generators, or externally magnetized synchronous generators. Variable speed wind turbines are connected to the grid using power electronic technology and maximize effective turbine speed control.

Variable speed wind turbines such as DFIGs are the most popular wind turbines being installed today because they perform better than the fixed speed wind turbines during system disturbances. DFIGs are the only class of wind generators capable of producing reactive power to maintain unity power factor at the collector bus.

Wind Turbine	*Rated Speed*	*Cut out speed*	*Generator*	*Power Control*
GE 1.5 MW	13 m/s	25 m/s	DFIG	Active blade pitch
GE 2.5 MW	12.5 m/s	25 m/s	PM generator	Active blade pitch
GE 3.6 MW	14 m/s	27 m/s	DFIG	Active blade pitch
VESTAS 1.65 MW	13 m/s	20 m/s	Asynchronous	Active Stall
VESTAS 1.8 MW	15 m/s	25 m/s	Asynchronous with Optislip	OptiSlip / Pitch
VESTAS 3 MW	15 m/s	25 m/s	Asynchronous with Optispeed	OptiSpeed and OptiTip Pitch regulation
NORDEX 2.5 MW	15 m/s	25 m/s	DFIG	Pitch
NORDEX 3 MW	13 m/s	25 m/s	DFIG	Pitch
SUZLON 0.95 MW	11 m/s	25 m/s	Asynchronous	Pitch

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Table1.1 Types of wind turbines produced by various wind generator manufacturers

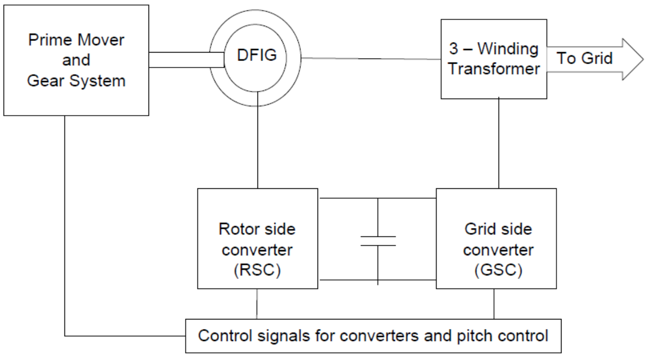

Figure 2: Block diagram of a Doubly-fed induction generator

IV. TEST SYSTEM AND SIMULATION RESULT

V. IMPACT OF STATCOM ON RELAY PROTECTION SYSTEM

In this paper, we simulated a scenario of an Induction Generator (IG) wind farm integrated with the grid system under three phase short circuit fault by using MATLAB/Simulink. Fig. 3 shows simulation case and network modeling of the integration of wind farm with grid system based on STATCOM. The faults is initialed at t =15s. In order to study the impacts of STATCOM on protection system, we first disable the STATCOM manually. Fig. 4 shows the simulation results of voltage measurements from the grid and power generation from wind farm when STATCOM is disabled. From Fig. 4 we can observe that due to the lack of reactive power support, the grid voltage dropped below 0.9 p. u. which results in the overload of the wind turbine and the relay trips at t=13.43s by the AC over current protection from the turbine. For the comparison, Fig. 5 shows the simulations results with STATCOM enabled. From Fig. 5, we can conclude that with the help of STATCOM for reactive power compensation during voltage sag, the system voltage is close to 1.0 p. u., which maintains the voltage stability in the system during the faults. The relay is tripped at t=15.11s by the under voltage protection from the wind turbine unit. From the comparison result of two cases above, we can see that with the using of STATCOM, steady voltage could be obtained, and the relay can function well with designed tripping time.

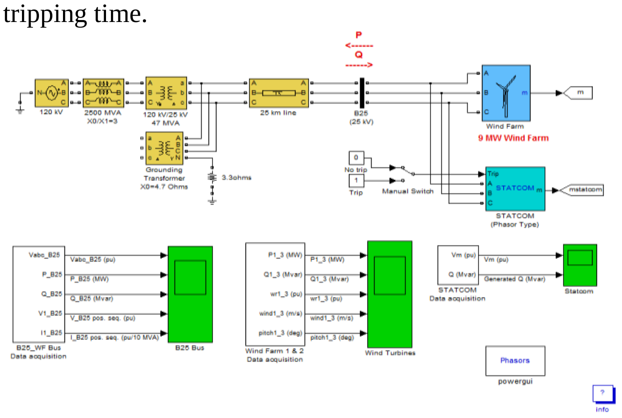

Figure 3: Network modeling of case study for STATCOM with wind farm

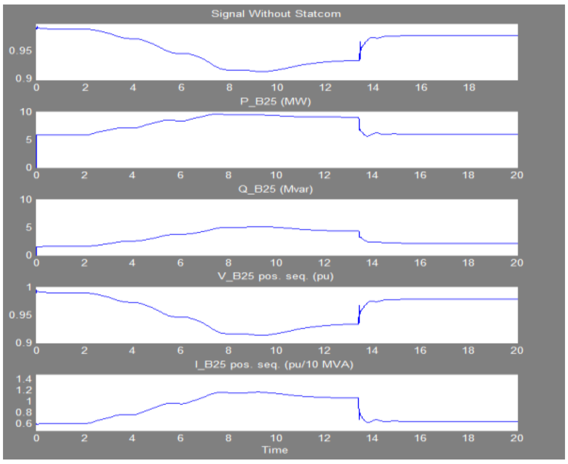

Figure 4: Case study result for system without STATCOM

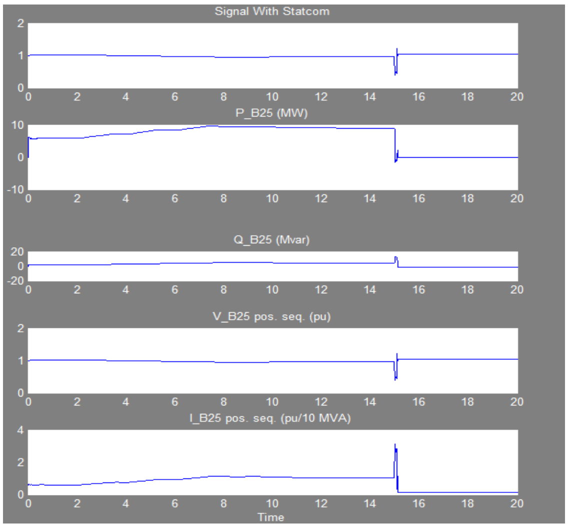

Figure 5: Case study result for system with STATCOM

A. *Impact of SSSC on Wind Farm using POD controller:*

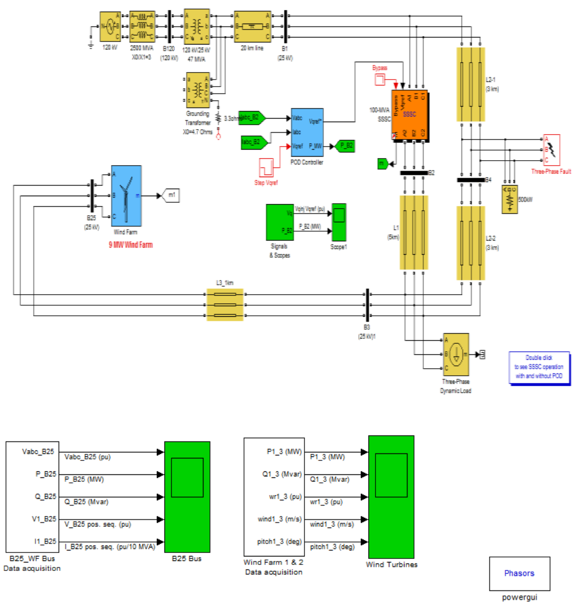

Figure 6: Network modeling of case study for SSSC with wind farm and POD controller

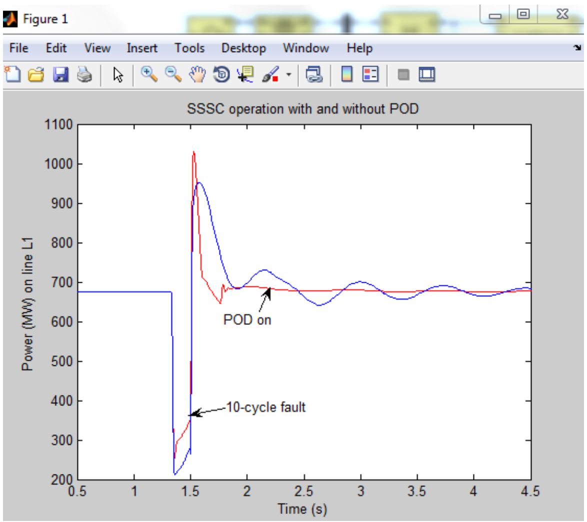

Figure 7: SSSC operation with or without POD

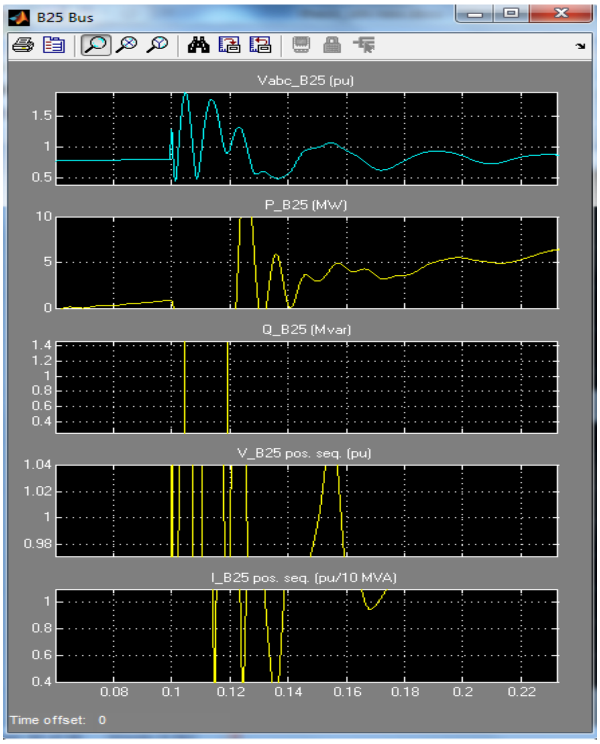

Figure 8: Case study result for system with SSSC (using POD controller)

VI. CONCLUSION AND FUTURE SCOPE

Power system with wind farms performance can be improved using FACTS devices such as STATCOM and SSSC. The dynamic model of the studied power system is simulated using Simulink Matlab package software. To validate the effect of the STATCOM and SSSC controller of power system operation, the system is subjected to different disturbances such as faults and power operating conditions. The digital results prove the powerful of the proposed STATCOM and SSSC controller in terms of Stability improvement, power swings damping, voltage regulation, and an increase of power transmission and chiefly as a supplier of controllable reactive power to accelerate voltage recovery after fault occurrence.

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