UPFC Based Stability Enhancement of PMSG-Based Offshore Wind Farm Fed to An SG-Based Power System

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Abstract—Wind energy system has become increasingly competitive with other renewable-energy power generation options such as solar photovoltaic, geothermal, and marine, tidal, etc. Now a days preferred offshore wind farms became widely used as it is easy to maintain. Due to the wind integration voltage stability become a concern in the existing system. To improve voltage stability various FACTS devices were used. In the present work unified power flow controller is considered to improve the Voltage stability. The performance of UPFC to be compared with SSSC and SVeC.

Keyword: Offshore wind farm, permanent-magnet synchronous generator, series static synchronous compensator, seriesvectorial compensator, stability.

I. INTRODUCTION

In recent years, wind energy has become increasingly competitive with other renewable-energy power generation options such as solar photovoltaic, geothermal, and marine, tidal, etc. Some small-scale offshore wind farms (OWFs) are under evaluation while some large-scale OWFs have been continuously constructing and commercially operating. When delivering large generated electric power of OWFs to power grids, inherent power fluctuations have adverse impacts on the power quality of the power systems to which the OWFs are connected. The second-generation FACTS devices such as a STATCOM, SSSC, and unified power flow controller (UPFC), utilizing voltage source converters (VSCs) based on power semiconductor devices such as gate-turn-off switches and isolated gate bipolar transistors offer greater advantages and are being increasingly installed to improve power system performance. Among the FACTS devices, a STATCOM, has been widely used to provide smooth and rapid steady-state and transient voltage control at the connected buses. In the STATCOM, has been used to achieve both voltage control and damping enhancement of a grid-connected integrated OWF and marine-current farm. On the other hand, series FACTS devices, such as an SSSC, can be effectively used for controlling power flow in transmission line to enhance damping of oscillations occurred in power systems.

UPFC is the most versatile and complex device in the FACTS devices since it combines the good features of a STATCOM and an SSSC.

This new device is SVeC that has a simpler Pulse-width-modulation controller utilized to control active power of a transmission line. Although a SVeC device has not been really produced in the power market yet, it still has many theoretical advantages many specifications of a SVeC such as transformer rating, capacitor, converter, power loss, and estimating power circuit cost are compared with an SSSC to demonstrate the superior specifications of SVeC. However, the SVeC has not been tested on the issue of integrating OWFs to power grid yet. Thus, this paper focuses on the design of the damping controllers for anSVeC and an SSSC to improve the damping of an SG-based power system with a PMSG-based OWF by assigning mechanical mode and exciter mode of the SG-based power system through modal control theory.

This paper is organized as follows. Section II introduces the configuration and models of the proposed SVeC and SSSC applied to the studied SG-based power system with the PMSG-based OWF. Section III demonstrates the design procedure and design results of the damping controllers of the SVeC and the SSSC using modal control theory. Section IV shows the comparative eigenvalue results of the studied system using the proposed SVeC and SSSC with the designed damping controllers. Section V depicts the comparative transient responses of the studied system under a severe disturbance using the proposed SVeC and SSSC with the designed damping controllers. Finally, specific important conclusions of this paper are drawn in Section VI.
II. PROBLEM FORMULATION

The proposed SVeC and SSSC are connected. In series with TL2, respectively, and they are located near the PCC. The OWF is represented by a large equivalent aggregated PMSG with an AC/DC converter, a DC-link, a DC/AC inverter, and a step-up transformer of 0.69/23 kV. The shaft of the equivalent aggregated wind PMSG is directly driven by an equivalent aggregated variable-speed WT. The utilized mathematical models of the studied system are described as follows.

A. Wind Turbine Model and Mass-Spring-Damper Model

The captured mechanical power (in W) by a WT can be depicted by

\[ P_{mw} = \frac{1}{2} \rho w A_{rw} V_w^3 C_{pw} (\lambda_w, \beta_w) \]  

1. \( \rho_w \) is the air density (kg/m³)
2. \( A_{rw} \) is the blade swept area (m²)
3. \( V_w \) is the wind speed (m/s)
4. \( C_{pw} \) is the power coefficient of the WT

\[ \phi = \lambda w + d_6 \beta_w - d_9 \beta_{o} \]  

\[ \frac{1}{\beta_{o}} = \frac{1}{\lambda w} + d_6 \beta_w - d_9 \beta_{o} + 1 \]  

B. Permanent-Magnet Generator and Power Converters

The -axis equivalent circuit model of the studied wind PMSG can be written as

1. Real power balance at each bus
2. Reactive power balance at each bus

(i) Load flow constraints

In power system, the total active power loss of all the lines of system is

\[ P_i - V_i \sum_{j=1}^{N_B} V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) = 0 \]  

In power system, the total reactive power loss of all the lines of system is

\[ Q_i - V_i \sum_{j=1}^{N_B} V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) = 0 \]  

where,

- \( P_i \) is the real power injected into network at bus \( i \)
- \( Q_i \) is the reactive power injected into network at bus \( i \)
- \( G_{ij} \) is the mutual conductance between bus \( i \) and \( j \)

C. SSSC Model

The SSSC consists of a voltage-source inverter (VSI) that converts a DC voltage into a three-phase AC voltage. Hence, the equivalent components of an SSSC consist of a three-phase voltage source with fundamental frequency, a series coupling transformer, a DC capacitor, and a controller. A phase-locked loop (PLL) is used to determine the reference angle, which is phase-locked to phase of the voltage. The magnitude of the line current and its relative angle.

With respect to the PLL angle are then calculated. The phase angle of the line current is calculated by adding the relative angle to the PLL angle. The angle in can be added to the phase angle to acquire the final angle in, where of the required voltage is either in an inductive mode or in a capacitive mode. Fig also shows an auxiliary signal (or damping signal) that comes from a damping controller that will be designed for the SSSC in the next section to achieve to stability improvement. Whenever the damping controller is used, the subtraction of and, instead of only, is multiplying by the current magnitude to obtain required voltage magnitude.

D. SVeC Model

A single line schematic of the power circuit of the studied SVeC. This device includes a series injection transformers connected to a capacitor bank through a PWM ac controller. When the switch is closed, the compensation capacitors are effectively connected in series with the transmission line. On the contrary, when the switch is closed, the transformer Terminal is shorted to isolating the compensation capacitors from the transmission line. The net amount of reactive compensation of SVeC is determined by the total switching period. The duty ratio of the converter is defined as the ratio of the on-period of switch with respect to the total switching period.

The eigenvalues listed in are related to the modes of the WT-PMSG of the OWF system, the eigenvalues
Are referred to the modes of the SG-based SMIB system, the eigenvalue corresponds to the mode of
The SSSC or the SVeC, and the eigenvalue is related to the
designed PID controller. It is worth noting that the two
modes and are the most important dominant modes, i.e.,
mechanical mode and exciter mode, of the studied SG-
based SMIB system. These two modes and are close to the
imaginary axis of the complex plane, and their damping
needs to be improved.

III.PROPOSED SYSTEM

To develop the mathematical model for Reactive
Power problem. To solve the problem by using FACTS
deVICES.

CONCLUSION

In this paper voltage stability have been improved
by damping improvement on PMSG-based owf connected
to an SG-based using facts devices.
SSSC and SVeC helps to improve the damping in the
system. In the proposed system SSSC and SVeC has the
best damping characteristics to improve the performance of
the studied PMSG-based owf fed to an SG-based. Power
system under different operating conditions from the
simulation results. In future existing facts devices can be
replaced by UPFC and multilevel inverter for better
performance.

REFERENCES