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 increasinglycompetitive with other renewable-energy power generationoptions such as solar photovoltaic, geothermal, and marine, tidal, etc. Some small-scale offshore wind farms (OWFs) areunder evaluation while some large-scale OWFs have beencontinuously constructing and commercially operating. Whendelivering large generated electric power of OWFs to powergrids, inherent power fluctuations have adverse impacts on thepower quality of the power systems to which the OWFs are

Connected.The second-generation FACTS devices such as static synchronous compensator 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 family, the shunt FACTS devices, such as 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 agrid-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. A 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 advantagesmany 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.

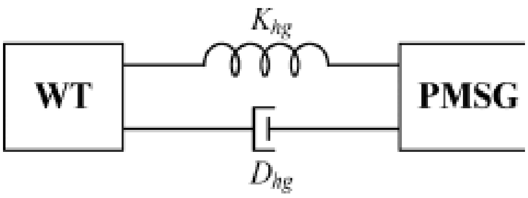

Fig.1 Model of a WT coupled to the rotor shaft of a wind PMSG

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 PMSGbased OWF.Section III demonstrates the design procedure anddesign 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

$$P_{mw} = \frac{1}{2} p_w A_{rw} V_w{}^3 C_{pw}(\lambda_w, \beta_w) \text{.............} \quad (1)$$

- Pwm is the air density (kg/m)
- Arw is the blade swept area (m)
- Vw is the wind speed (m/s)
- Cpw is the power coefficient of the WT

$$C\rho\omega(\emptyset\omega,\beta\omega) = d_{1}{}_{((\frac{d_2}{\varphi_\omega})-d_3}.\beta_\omega - d_4.\beta_\omega^{d_5} - d_6)exp\left(-\frac{d_7}{\varphi_\omega}\right) \dots\dots\dots\dots\dots (2)$$

$$\frac{1}{\varphi_\omega} = \frac{1}{\lambda_\omega + d_8.\beta_\omega} - \frac{d_9}{\beta_\omega^3 + 1} \dots\dots\dots\dots.\dots\dots\dots\dots (3)$$

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

$$P_i - V_i \sum_{j=1}^{N_B} V_i\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) = 0 \ \dots\dots.. (4)$$

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

$$Q_i - V_i \sum_{j=1}^{N_B} V_i\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = 0 \dots\dots\dots\dots\dots (5)$$

where,

P_i is the real power injected into network at bus i

Q_i is the reactive power injected into network t bus i

G_{ij} is the mutual conductance between bus i and j

The inequality constraints are

1. generator voltage
2. Shunt capacitor
3. Transformer tap setting

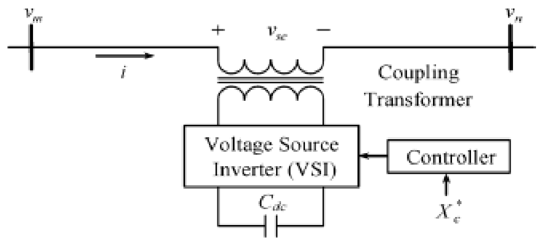

Fig. 2 Fundamental configuration of an SSSC.

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 alsoshows 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.

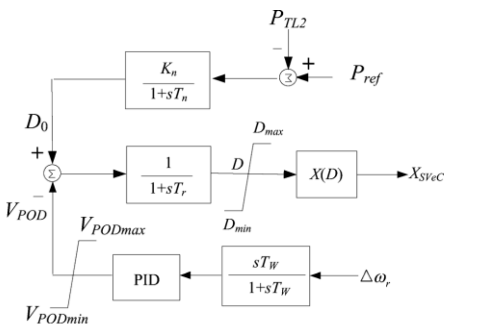

Fig 3 SVeC including the designed PID damping controller

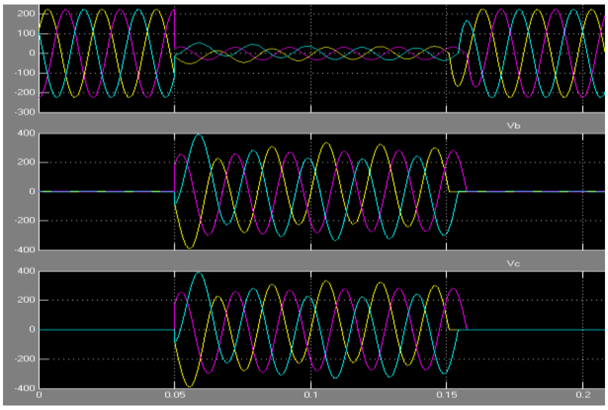

Fig 4Without facts devices

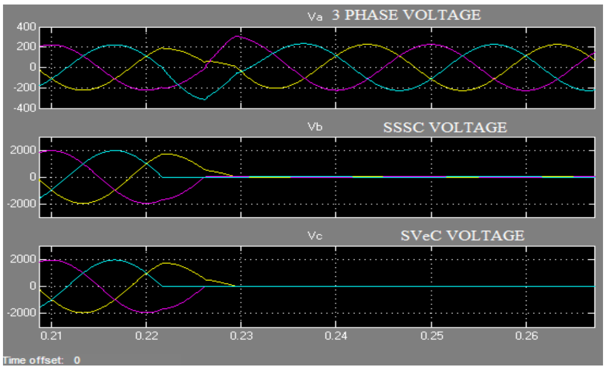

Fig 5 Withfacts devices

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.

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