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Dynamic Stability Improvement of a Grid Connected Wind Generators: A Case Studied

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Abstract - ***In this paper, dynamic stability improvement of a grid connected wind power system in Ninh Thuan power system has been presented. The installed capacity of wind power system is 20 MW including of 10 x 2-MW wind turbine-based doubly fed induction generators (DFIG) interconnected to the 22-kV power grid. When a large amount of wind power being integrated into power system, it will make system stability deterioration thus a static VAR compensator (SVC) is proposed to improve the stability of the studied system. Simulation results are performed to test the stability of the system with a severe fault. It can be concluded that when the employed SVC joining with studied system the dynamic stability is improved under a severe operating condition.***

Key Words: *DFIG, SVC, dynamic stability.*

1. INTRODUCTION

In recent years, the extraction of power from the wind has become a recognized industry due to its simple economics and clean energy. But the ability of a power system to absorb available wind energy and maintain the system reliability and stability is reduced as the wind penetration in the system is increased [1]. Relating to wind power generators in wind power generation systems, doubly-fed induction generators (DFIGs) are the most widely used [2]. It has been recognized that the controllers have a critical impact on the stability performance of grid connected DFIG. Therefore, the controllers should be designed appropriately [3]. In [4], rotor angles of synchronous generators are directly influenced by the type of reactive power control employed by the wind generation. The implementation of appropriate control strategies in wind farms, particularly the terminal voltage control, can lessen the reactive power requirements of conventional synchronous units and help to mitigate large rotor angle swings. Meanwhile, it is suggested that a good control strategy for the static synchronous compensator (STATCOM) will significantly improve the system dynamics [5]. At present these methods for improving stability are not very economical. For solving this problem a power system stabilizer (PSS) are installed for synchronous generator (SG), through properly regulating PSS and AVR parameters to observe the stability of various situations. The simulation results shown that wind power integrated system with auto voltage regulator (AVR) and PSS has damping effect, can reduce the oscillation of rotor angle difference, improve voltage stability [6].

The growing utilisation of wind power brings new challenges for voltage control and reactive power compensation. The amount of integrated wind power in one area can be increased by using extra reactive power support, i.e. static var compensator (SVC), thus increasing the voltage stability limit with respect to the produced active power at the wind farm. It is recognised that voltage control and reactive power compensation have influence on the damping of the system's oscillation modes, but in an interconnected system it is not always obvious if this has a positive or negative impact. Furthermore, it is relevant to ask if changes in power system damping, e.g. caused by changes in power flow or stabilizer tuning, affect the voltage stability limits [7].

This paper focuses on increasing dynamice stability of the 20-MW grid connected wind power generators system in Ninh Thuan Province, Vietnam.

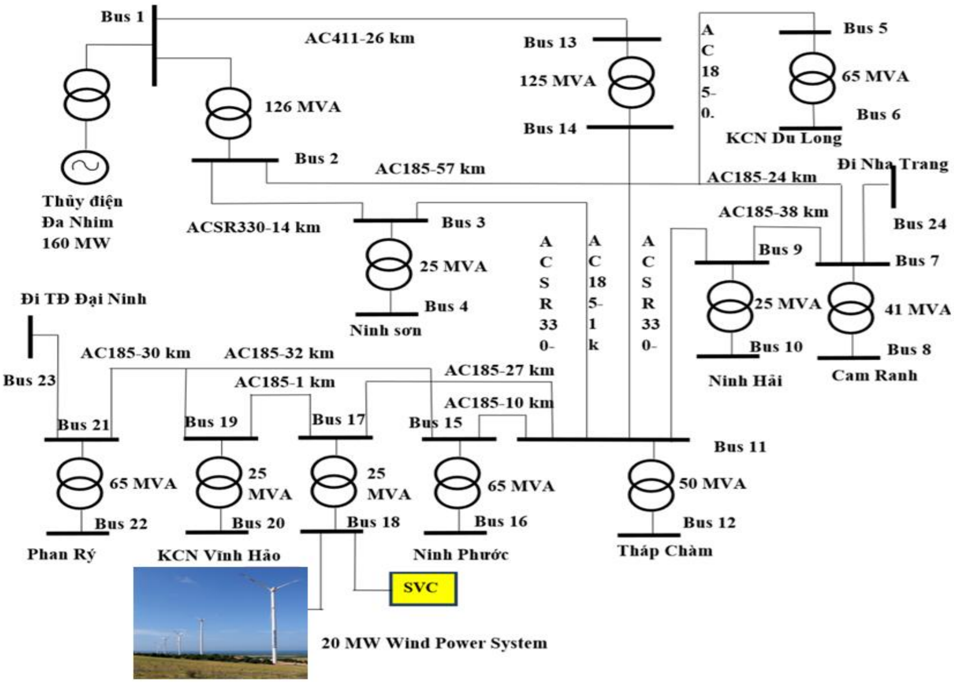


Fig -1: Studied Ninh Thuan power grid system configuration

2. SYSTEM CONFIGURATION

The 22-kV system with 20-MW wind farm including 10 x 2-MW wind turbine doubly fed induction generator (DFIG) in Ninh Thuan Province connected to a 110-kV national grid. The overall of Ninh Thuan is shown in Fig. 1. For modelling this complex system, the 20-MW wind farm is represented by a large equivalent aggregated DFIG driven by an equivalent aggregated wind turbine (WT) through an equivalent gearbox connected to Bus 18 [8]. The proposed SVC is connected to the same bus of wind system for supplying adequate reactive power to maintain voltage profile and to damp oscillations of the system. The employed mathematical models of the studied system are described as follows.

2.1. Wind Turbine Model

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

$$P_{mw}=\frac{1}{2}\rho_w\cdot A_{rw}\cdot V_W^3\cdot C_{pw}(\lambda_w,\beta_w) \tag{1}$$

where ρ_w is the air density (kg/m^3), A_{rw} is the blade impact area (m^2), V_W is the wind speed (m/s), and C_{pw} is the dimensionless power coefficient of the WT. The power coefficient of the WT C_{pw} is given by

$$C_{pw}(\psi_{kw},\beta_w)=c_1\left(\frac{c_2}{\psi_{kw}}-c_3\cdot\beta_w-c_4\cdot\beta_w^{c_5}-c_6\right)\exp\left(-\frac{c_7}{\psi_{kw}}\right) \tag{2}$$

in which

$$\frac{1}{\psi_{kw}}=\frac{1}{\lambda+c_8\cdot\beta_w}-\frac{c_9}{\beta_w{}^3+1} \tag{3}$$

$$\lambda_w=\frac{R_{bw}\cdot\omega_{bw}}{V_W} \tag{4}$$

where ω_{bw} is the blade angular speed (rad/s), R_{bw} is the blade radius (m), λ_w is the tip speed ratio, β_w is blade pitch angle (degrees), and c_1 ... c_9 are the constant coefficients for power coefficient C_{pw} of the studied WT. The power coefficients of the WT can be referred to [9]. The cut-in, rated, and cut-out wind speeds of the studied WT are 2.5, 13, and 21 m/s, respectively. When wind speed VW is lower than the rated wind speed of the WT (V_{Wrated}), β_w = 0°. When $V_W > V_{Wrated}$, the pitch-angle control system of the WT activates and the pitch angle of the WT (β_w increases. The output power curve of VESTAS 2-MW DFIG-based WT is shown in Fig. 2 [10].

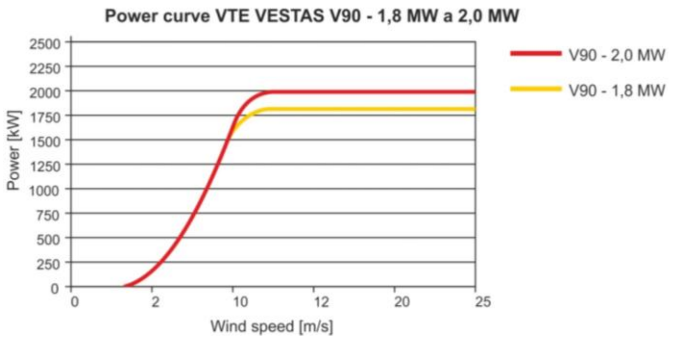


Fig -2: Power curve of wind turbine

2.2. DFIG Model and Control of Power Converters

Fig. 3 shows the one-line diagram of a wind DFIG driven by a WT. The stator windings of the DFIG are directly connected to the low-voltage side of the 0.69/22-kV step-up transformer while the rotor windings of the DFIG are connected to the same 0.69-kV side through a rotor-side converter (RSC), a DC link, a grid-side converter (GSC), and a connection line. For normal operation of a DFIG, the input AC-side voltages of the RSC and the GSC can be effectively controlled to achieve the aims of simultaneous output active-power and reactive-power control [8].

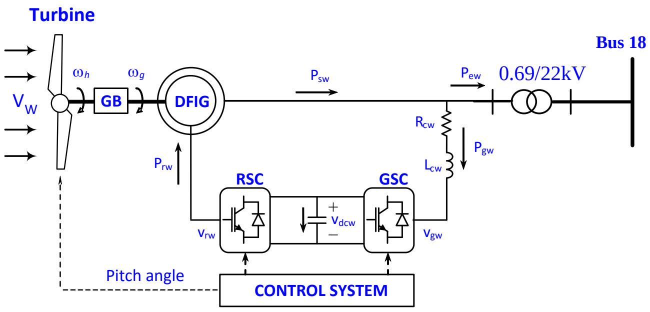


Fig -3: One-line diagram of wind DFIG-based WT

For normal operation of a wind DFIG, the input AC-side voltages of the RSC and the GSC can be effectively controlled to achieve the aims of simultaneous output active-power and reactive power control [9]. Fig. 4 shows the control block diagram of the RSC of the studied DFIG, and the operation of the RSC requires i_{qrw} and i_{drw} to follow the varying reference points that are determined by maintaining the output active power and the stator-winding voltage at the setting values, respectively. The required voltage for the RSC (v_{rw}) is derived by controlling the per-unit q- and d-axis currents of the RSC. The control block diagram of the GSC of the studied wind DFIG is shown in Fig. 5. The per-unit q- and d-axis currents of the GSC, i_{qgw} and i_{dgw}, have to track the reference points that are determined by maintaining the DC link voltage V_{dc} at the setting value and keeping the output of the GSC at unity power factor, respectively. The required per-unit voltage of the GSC (v_{gw}) is derived by controlling the per-unit q- and d-axis currents of the GSC.

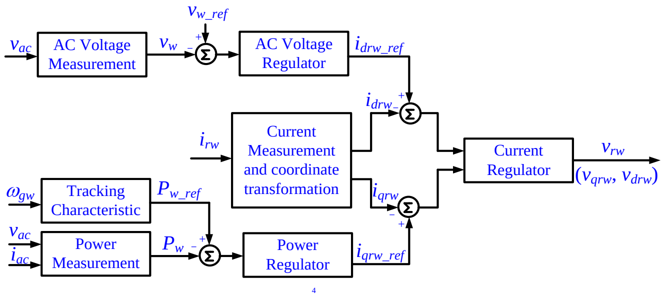


Fig -4: Control block diagram for the RSC of the studied wind DFIG

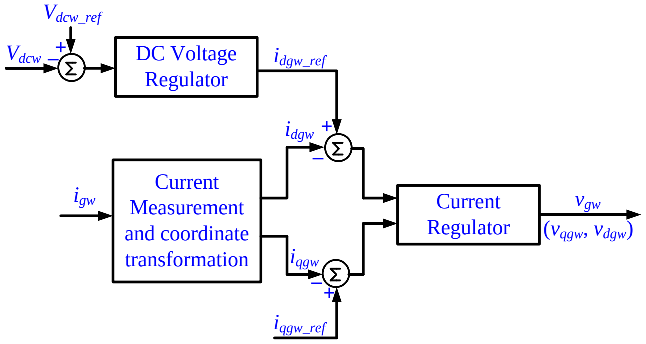


Fig -5: Control block diagram for the GSC of the studied wind DFIG

2.3. SVC Model

The proposed SVC in this paper is for regulating the voltage at its terminals by compensating the proper amount of reactive power delivered to or absorbed from the connected power system. The single-phase equivalent circuit of the SVC with thyristor-controlled reactor-fixed capacitor (TCR-FC) type was shown in Fig. 6 [7, 10].

Assuming a balanced and fundamental-frequency operation, the equivalent B_{SVC} of the SVC is a function of the firing angle α as shown below.

$$B_{SVC}(\alpha) = \frac{2\alpha - \sin 2\alpha - \pi\left(2 - \frac{X_L}{X_C}\right)}{2\pi X_L} \qquad (5)$$

where X_L and X_C are reactance of reactor and capacitor of SVC, respectively.

Fig. 7 shows the control block diagram for the equivalent susceptance B_{SVC} of the studied SVC. When the system voltage is lower than the reference value, the value of B_{SVC} of the SVC is positive to inject reactive power to the system; when the system voltage is higher than the reference value, the B_{SVC} of the SVC is negative to absorb reactive power from the power system.

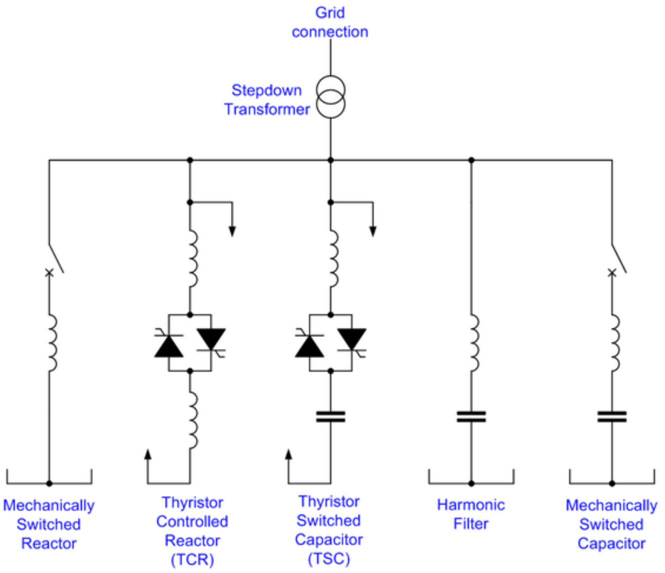


Fig -6: Control block diagram of the employed SVC

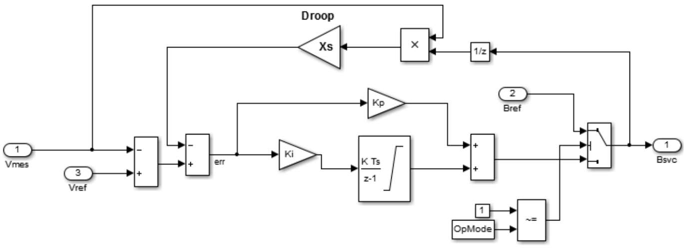
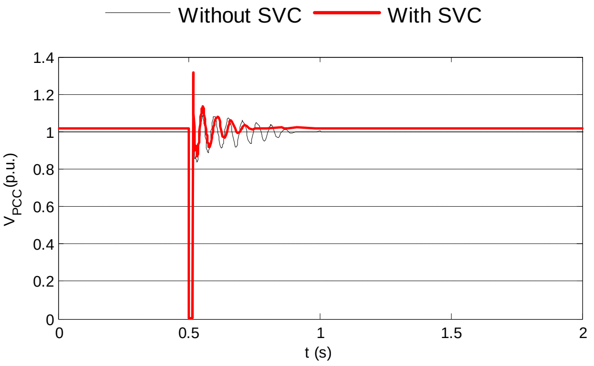


Fig -7: Control block diagram of the employed SVC

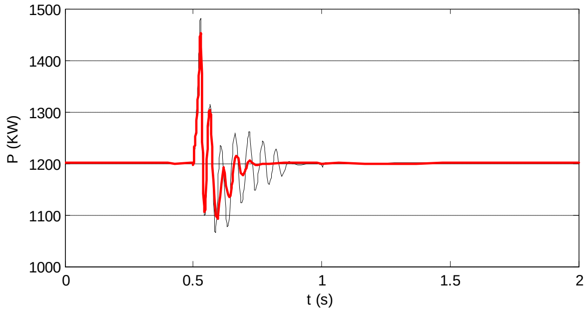
3. TIME DOMAIN SIMULATION

This section utilizes the nonlinear system model to compare the damping characteristics contributed by the proposed SVC. It is clearly seen that, the included SVC does improve the voltage profile. In order to ascertain the improvement on transient voltage stability, the system response to a three phase fault is studied. The short-circuit fault is located at Bus 11 and starts at t = 0.5 s and the fault is cleared after 5 cycles. In this case, the considered wind speed is selected as 10 m/s.

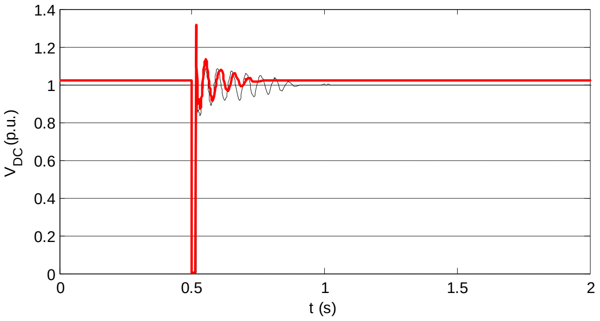
Fig. 8 shows the comparative transient responses of the system with SVC (red lines) and without SVC (black lines). It is clearly seen from Fig. 8(a) that when the SVC is in service the voltage at bus 18 is slightly increased and the damping of the system is better. Other parameters of wind power generator such as the active power, the DC-link voltage and the rotor speed are respectively shown in Figs. 8(b) to (d) also indicating the better transient response when the system with the proposed SVC.



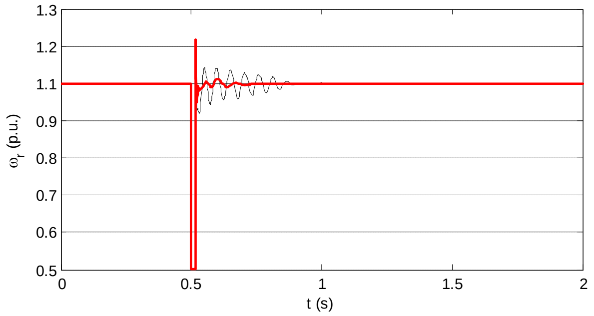
a) Voltage at Bus 8



b) Active power of a DFIG-based wind power system



c) DC voltage at DC-link of DFIG



d) Rotor speed of DFIG

Fig -8: Comparative transient responses of the studied system

4. CONCLUSIONS

This paper has presented the comparative stability improvement of a grid connected wind generators system to the 22-kV power grid of Ninh Thuan Province. To supply the adequate reactive power to the system, PI damping controllers for the proposed SVC have been apply by using try and error method. Comparative time-domain simulation of the studied system subject to a three-phase short-circuit fault at the Bus 11 has been systematically performed to demonstrate the effectiveness of the proposed SVC on suppressing inherent oscillations of the studied system. It can be concluded from the simulation results that the proposed SVC has better damping characteristics to improve the performance of the wind energy system fed to the national power grid under a severe operating condition.

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