dynamic Stability Enhancement of a grid connected Wind Farm Using aN SVeC

NÂNG CAO ỔN ĐỊNH ĐỘNG CỦA HỆ THỐNG ĐIỆN GIÓ NỐI LƯỚI SỬ DỤNG THIẾT BỊ BÙ SVeC

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**Abstract –** In this paper, a grid connected wind farm is studied. For improving the dynamic stability of the studied system a Series Vectorial Compensator (SVeC) is proposed and is connected in series with the common bus of the One Machine connected to Infinite Bus (OMIB) system with the wind farm. An oscillation damping controller (ODC) of the proposed SVeC is properly designed by using Adaptive Neural Fuzzy Inference System (ANFIS) method. The simulation results are performed in Matlab software. It can be concluded from the simulation results that the proposed SVeC can offer better for enhancing the stability of the studied system subjected to a severe disturbance.

**Key words –** Wind Farm, OMIB, Oscillation Damping Controller, Series Vectorial Compensator (SVeC), Stability.

**Tóm tắt –** Trong bài báo này, một hệ thống điện gió nối với lưới điện được nghiên cứu. Để nâng cao độ ổn định động của hệ thống một thiết bị bù vecto nối tiếp (SVeC) được đề xuất và được kết nối vào bus chung (PCC) của hệ thống máy phát điện đồng bộ nối với bus vô hạn (OMIB) và trang trại gió. Để nâng cao độ ổn định của hệ thống điện nghiên cứu, một bộ điều khiển giảm dao động (ODC) được thiết kế cho bộ SVeC dựa trên phương pháp mờ thích nghi (ANFIS). Kết quả mô phỏng được thực hiện bằng phần mềm Matlab. Có thể kết luận từ kết quả mô phỏng rằng thiết bị bù nối tiếp SVeC có thể cải thiện tốt hơn độ ổn định của hệ thống điện nghiên cứu khi có sự cố nghiêm trọng xãy ra trong hệ thống điện.

**Từ khóa –** Trang trị gió, OMIB, Bộ điều khiển giảm dao động, thiết bị bù vecto nối tiếp, ổn định.

# Introduction

Wind energy has become increasingly competitive with other renewable-energy power generation options. Some large-scale wind farms (WFs) have been continuously constructing and commercially operating. When delivering large generated electric power of WFs to power grids, inherent power fluctuations have adverse impacts on the power quality of the power systems with the connected WFs. In order to improve power quality of the these systems, a series power-flow controller, a variable frequency transformer, can be used to reduce power fluctuations of a large-scale grid-connected WF [1]. Although FACTS devices have been mainly used for solving various power system steady-state control problems such as voltage regulation, power flow control, and transfer capability enhancement, damping the inter-area modes ... [2, 3] one of the drawbacks of these devices is using DC capacitors which are quite vulnerable to high temperatures. To overcome this difficulty, a new device using direct AC/AC power conversion principle without large DC-link energy storage components is proposed. This new device is series vectorial compensator (SVeC) that has a simpler pulse width modulation (PWM) controller utilized to control active power of a transmission line [4-6]. Although a SVeC device has not been reality produced on the power market yet, it still has many theoretical advantages.

A comparative dynamic performance of SVeC and thyristor controlled series capacitor (TCSC), SVeC and SSSC were presented in [6] and [7], respectively.

In this paper, a new oscilation damping controller (ODC) for SVeC is designed to damp out the oscilation of the system when a severe fault is happened in system.

The paper is organized as follow. Section 2 introduces the configuration and models of the proposed SVeC applied to the studied One Machine connected to Infinite Bus (OMIB) system with the connected wind farm. Section 3 demonstrates the design procedure and design results of the ODC of the SVeC. Section 4 shows comparative transient and dynamic responses of the studied system under a severe disturbance using the proposed SVeC with the designed damping controller. Finally, specific important conclusions of this paper are drawn in Section 5.

# Configuration Of The Studied System

***Figure 1. One line diagram of the studied system***

Figure 1 shows the configuration of the studied system. In which, the OMIB system using a synchronous generator (SG) and WF of 20 MW is connected to the point of common coupling (PCC) of the OMIB system through a step-up transformer of 0.69/22 kV. The proposed SVeC is connected in series with transmission line near the PCC.

## Wind Turbine Model

The captured mechanical power (in Watt) by a Wind Turbine (WT) can be depicted by

  (1)

where ρ*w* is the air density (kg/m3), *Arw* is the blade swept area (m2), *Vw* is the wind speed (m/s), and *Cpw* is the dimensionless power coefficient of the WT. The *Cpw* can be written by

 (2)

in which

  (3)

  (4)

where ω*bw* is the blade angular speed (rad/s), *Rbw* is the blade radius (m), λ*w* is the tip speed ratio, β*w* is blade pitch angle (degrees), and *d*1-*d*9 are the constant coefficients for *Cpw*.

## WF Model

Figure 2 shows the one-line diagram of an aggregated WF using Doubly Fed Induction Generator (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).



**Figure 2**. One line diagram of the DFIG

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. The detailed operation of the RSC and GSC can be referred to [8].

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].

Figure 3 and Figure 4 show the control block diagram of the RSC and GSC of the studied WF, respectively. The required voltage for the RSC (*vrw*) is derived by controlling the per-unit *q*- and *d*-axis currents of the RSC while the currents of the GSC, *iqgw* and *idgw*, have to track the reference points that are determined by maintaining the DC link voltage *Vdcw* at the setting value and keeping the output of the GSC at unity power factor.

 **Figure 3**. Control block diagram of the RSC

 **Figure 4**. Control block diagram of the GSC

## Model of SVeC

Figure 5 shows 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 *k2* is closed, the compensation capacitors are effectively connected in series with the transmission line. On the contrary, when the switch *k1* is closed, the transformer terminal is shorted to isolating the compensation capacitors from the transmission line.



***Figure 5****. Single-line diagram of SVeC*

The duty ratio (*D*) of the converter is defined as the ratio of the on-period of switch *k2* with respect to the total switching period.

The external of SVeC is represented by the reactance (*XSVeC*)and the voltage source (*Vs*) in series with the transmission line. The main purpose of using SVeC is providing a variable reactance *XSVeC* in series with transmission line. This reactance is adjusted through variations of the duty cycle (*D*) of the controller. By means of varying its equivalent reactance of the transmission line, the power flow of this line is controllable. The equivalent series reactance can be defined as [10]

 (5)

where *n* is the turn ratio of the coupling transformer, *D* is duty cycle, and *XC* is the reactance of the capacitor bank. The value of the voltage source in series with transmission line with line current *ITL* can be described by

  (6)

In [11], power flow between the sending end *V*1 and the receiving end *V*2 can be calculated as follows

**** (7)

where *XTL* is the reactance of the transmission line.

In order to improve oscillations of the system by mean of control active power flows of transmission line, the control block diagram of the controller of this device is proposed in Figure 6. In Figure 6, *Pref* is determined by the percentage of compensation level of SVeC with the active power transmitted in transmission line. In this work, the percentage of compensation is chosen as 50%. The auxiliary signal (*VODC*), is the output signal of Adaptive Neural Fuzzy Inference System (ANFIS) controller which is designed to damp out oscillations of the studied system.



***Figure 6****.Control block diagram of the proposed SVeC*

# Design Oscillation Damping Controller For SVeC

For design the ODC controller by using ANFIS, the rotor speed deviation of SG (Δωr)and the derivative of it(Δωr)/are fed to the ANFIS to generate *VODC* as shown in Figure 6 in order to control *XSVeC*.

The structure of ANFIS is the Sugeno-type as shown in Figure 7. In which the structure rules are given as follows:

If (*x = Ai*) and (*y = Bi*) then (*fi = pix+ qiy + ri*) (8)

where *x* and *y* are the inputs, and *Ai, Bi* are the fuzzy sets, *fi* are the outputs within the fuzzy region specified by the fuzzy rule, and *pi, qi* and *ri* are the designed parameters that are determined during the training process, and *i* is number of membership functions of each input [12].

In this paper, five linguistic variables for each input variable are used. These are NB (Negative Big), NS (Negative Small), ZR (Zero), PS (Positive Small), and PB (Positive Big). There are also five linguistic variables for output variable, namely, IB (Increase Big), IS (Increase Small), KV (Keep Value), DS (Decrease Small), and DB (Decrease Big).

The control rules subject to the input signals and the output signal are listed in Table 1.

***Figure 7.*** *Structure of an ANFIS model*

***Table 1: Control Rules Of The Studied ANFIS***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  **Δ**$ ω$ **(Δ**$ ω$*)’* | **NB** | **NS** | **ZR** | **PS** | **PB** |
| **PB** | IB | IB | KV | DB | DB |
| **PS** | IB | IS | KV | DS | DB |
| **ZR** | IB | IS | KV | DS | DB |
| **NS** | DS | DS | KV | IS | IS |
| **NB** | DS | DS | KV | IS | IS |

 By using the ANFIS toolbox in MATLAB with the type of membership function, the number of epochs, and the learning algorithm are chosen as Gauss, 30, and Hybrid, respectively.

The comparative transient responses of the studied system in time-domain simulation subject to disturbance conditions will be performed in the next section.

# Time Domain Simulation

 This section uses the nonlinear system model to compare the damping characteristics contributed by the proposed SVeC joined with the designed ODC on stability improvement of the studied system under a severe fault. It is assumed that the WF operates under a base wind speed of 12 m/s.



*(a) Voltage at PCC*



*(b) Rotor speed of SG*



*(c) Active power of SG*

***Figure 8****. Comparative responses of the studied system.*

Simulation results of the proposed system have been presented in Figure 8. This figure plots the comparative transient responses of the studied system with the proposed SVeC in cases of without controller (black lines) and with the designed ODC controller (blue lines) subject to a mechanical torque suddenly change 0.2 p.u at SG. The fault is suddenly applied to the grid at *t* = 2 s and is cleared after 0.1 s. It is clearly observed from the comparative transient simulation results shown in Figure 8 that the proposed SVeC with the designed ODC controller can offer better damping to the studied system.

For more clearly, Figure 9 shows the result of the active power of the WF which is performed in the same fault in case of difference wind speed condition.



***Figure 9****. Active power of WF with difference wind speed conditions.*

# Conclusions

This paper has presented the stability improvement of an integrated WF into OMIB system. The proposed SVeC is connected in series with the transmission line. An ODC controller is designed by using ANFIS method. Time-domain simulations of the studied system subjected to a severe fault at the connected bus has been systematically performed to demonstrate the effectiveness of the studied system. It can be concluded from the simulation results that the proposed SVeC joined with the designed controller has better damping characteristics to improve the performance of the system.

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