Voltage Stability Enhancement of Bac Lieu Wind Power by ANFIS Controlled Static Var Compensator

V.-T. Bui, D.-N. Truong

Abstract - ***In this paper, a 99.2-MW grid-connected Bac Lieu wind farm using Doubly Fed Induction Generator (DFIG) is studied. For improving the voltage stability of the wind connected bus, a Static VAR Compensator (SVC) is proposed and an Adaptive Neuro Fuzzy Inference System (ANFIS) controller for SVC is also designed. Simulation results of the voltage response in time-domain are performed using MATLAB software to evaluate the effectiveness of the designed controller for SVC. From these results, it can be concluded that the proposed ANFIS controller can be applied to enhance the voltage stability of Bac Lieu power system.***

Keywords: ***Doubly Fed Induction Generator (DFIG); Adaptive Neuro Fuzzy Inference System (ANFIS); Static Var Compensator (SVC); Voltage Stability.***

I. INTRODUCTION

In a transmission line, there are many elements such as generators, step-up and/or step-down transformers, transmission lines, etc. Nowadays, renewable energy is so important because of the exhaust of coals or source of water, so that wind generators or solar panels are used enlarger in many countries and wind generators are applied more widely than the other one. An offshore wind farm can include of many wind turbines driven wind generators and the output power of the wind generators can be connected together to be a wind farm and they can feed to a power grid using a step-up transformer. In relevance to a wind generator, a Doubly Fed Induction Generator (DFIG) is the most prevalent generator because of its high effectiveness compared to other types of wind generators such as permanent magnet synchronous generator and induction generator [1]. Moreover, DFIG has capability of controlling both active and reactive power for better grid integration to the transmission line [2]. However, by connecting stator windings directly to the power grid, it is very sensitive to power grid faults. Besides, the randomness of wind energy will affect to the power quality of the connected power systems. Some power quality problems such as voltage fluctuations, flicker, harmonic and voltage deviation of the Baolian wind farm has been studied in [3]. Furthermore, the measurements of a wind farm located in the south-east part of Poland were analyzed and compared with acceptable values [4].

In order to reduce affecting of the power grid to wind farm, many papers have been published. In [5], a power quality study of a large-scale wind farm with and without storage was studied. The paper shown that with the proposed storage system voltage drops and harmonic voltage and current distortion at the wind farm output can be improved when a short circuit occurs in the connection with the power grid.

Besides, Flexible AC Transmission Systems (FACTS) devices have been proposed and applied in power transmission systems and in this situation, Static Var Compensator (SVC) is used to enhance the voltage stability [6, 7].

In large systems, the transmission distance, the SVC is located in the middle of the transmission line to reduce the oscillation of the system to improve grid stability [8,9].

In today's control devices, the controller plays an important role in improving the operability and flexibility of the device. PID (Propotional-Integral-Derivatice) is a linear controller and is used in many control systems.

The main disadvantage of this controller is that it does not respond well when the input is large. Today, many algorithms have been applied to improve the efficiency of the device, such as the fuzzy logic controller used in vibration reduction control when linking generator systems in two large areas [10].

In addition, the fuzzy controller is used to replace the PID controller using the voltage deviation as the feedback signal in the voltage control at the link bus [11]. However, the main disadvantage of fuzzy logic controllers is that they depend on the programmer's experience. To improve the accuracy of the algorithms, combining algorithms together to exploit the advantages of each algorithm is a good solution that is being widely researched.

The study [12] proposed an algorithm combining fuzzy logic and artificial neural network called ANFIS (Adaptive-Network-based Fuzzy Inference System). ANFIS is also a good structure for designing a controller of a FACTS devices [13] because of its simplification and also its ease of designing. ANFIS is used replacing for controllers that are not obvious or cannot be calculated by definite equivalence.

II. CONFIGURATION OF THE STUDIED SYSTEM

The structure of the full paper will be arranged as follows:

A. Introduction to Bac Lieu power system

In this paper, a real wind power connected to power grid in Bac Lieu Province is studied. In which, voltage stability is focused and an SVC is also proposed to improve the stability of the system.

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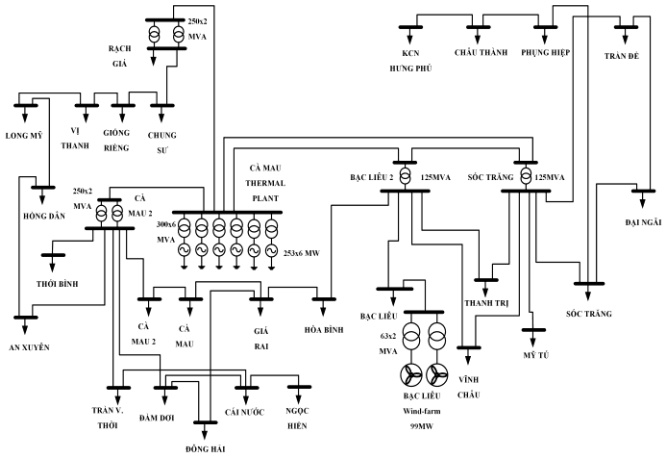


Figure 1. *Location of wind turbine in Bac Lieu province*

The wind farm in this paper is the practical 99.2 MW wind farm in Bac Lieu province, Vietnam including 10 x 1.6MW wind turbines in phase 1 and 52 x 1.6MW wind turbine in phase 2 as shown in Fig. 1. In which, wind turbine model is GE 1.6 XLE – 1.620 MW supplied by General Electric. This project panning a project area of 1,000 ha to transmit the power to the national grid through two parallel 63 MVA transformers and two 110 kV transmission lines. The wind farm has an estimated electricity output of 300 GWh per annum.

B. DFIG Model and Control of Power Converters

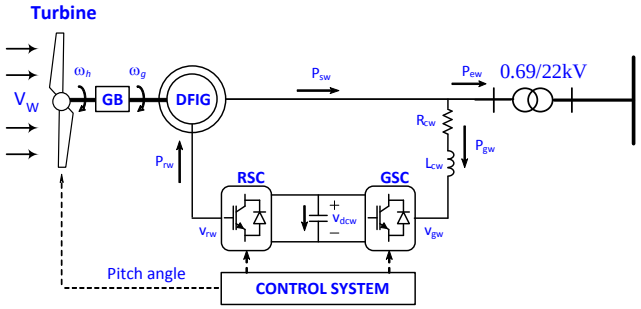


Fig. 2. *One-line diagram of wind DFIG-based WT*

Fig. 2 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 [15].

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 [14]. Fig. 3 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. 4. 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.

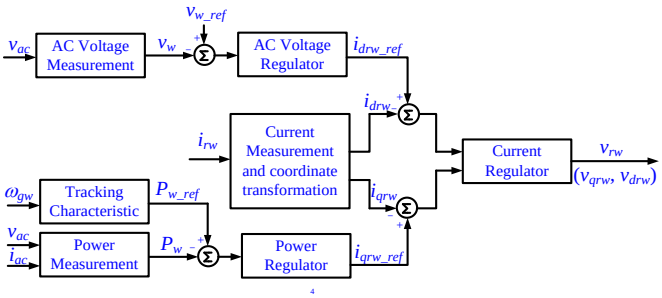


Fig. 3. Control block diagram for the RSC of the studied wind DFIG

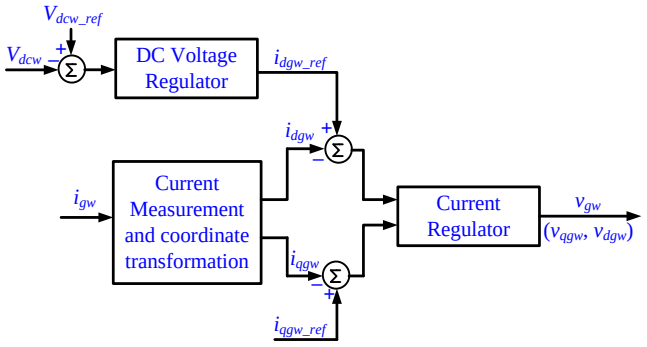


Fig. 4. *Control block diagram for the GSC of the studied wind DFIG*

C. Static Var Compensator Model

The proposed 40 MVAr SVC in this paper is used for adjusting the voltage at connected bus by compensating the reactive power to the power grid. The equivalent model of SVC is shown in Fig. 5. It consists of Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactors (TCR). The control scheme of the studied SVC is presented in Fig. 6 [15].

In the SVC model, if the bus voltage is lower than the reference value, the value of the equivalent susceptance (Bsvc) of the SVC is positive and on the contrary, if the bus voltage is higher than the reference value, the Bsvc is negative.

The relationship between firing angle (α) and the steady state value of B_{TCR} is given as:

$$B_L(\alpha) = \frac{2(\pi-\alpha)+\sin(2\alpha)}{\pi X_L} \text{ with } \frac{\pi}{2} \le \alpha \le \pi \qquad (1)$$

The equivalent susceptance of SVC (B_{SVC}) is as follow:

$$B_{SVC}(\alpha) = \frac{1}{X_C} - B_L(\alpha) \qquad (2)$$

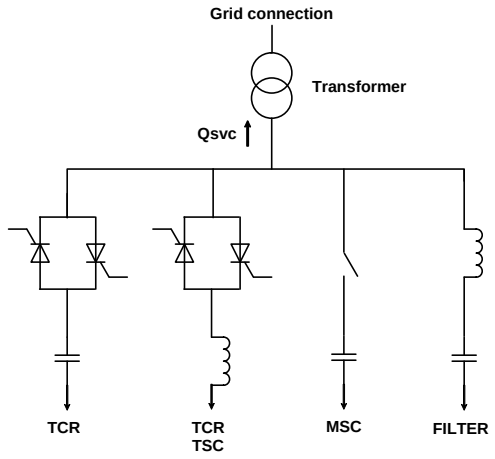


Figure 5. *Single-line diagram of SVC*

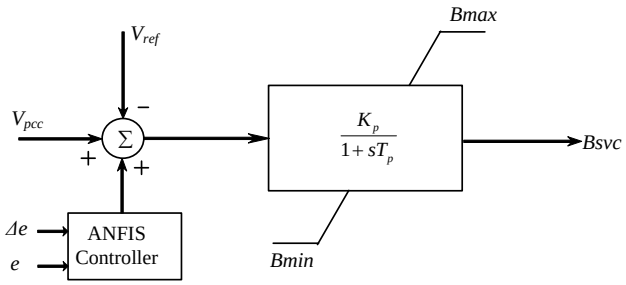


Figure 6. *Single-line diagram of wind DFIG*

III. ANFIS ALGORITHM

ANFIS (Adaptive Neuro - Fuzzy Inference System) uses the available input - output data set, the ANFIS built - in fuzzy inference system (FIS). Its associated function parameters are adjusted using neural network training algorithms such as backpropagation algorithm or propagation combination with minimum squared method. That allows the fuzzy system to "learn" from the data set they are modeling.

ANFIS is structured similarly to a neural network, which maps inputs through dependent functions to corresponding parameters, and then through output functions with corresponding parameters that produce outputs that can be used to explain I / O mapping as shown in Fig. 7.

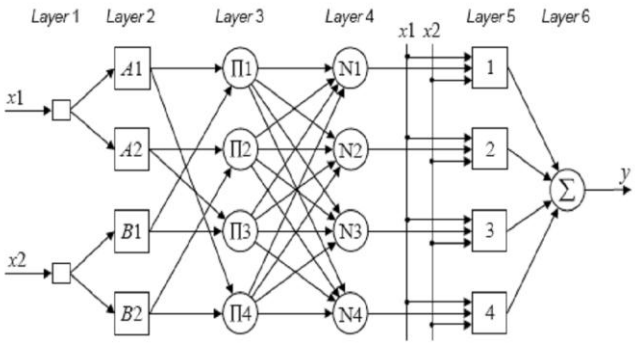
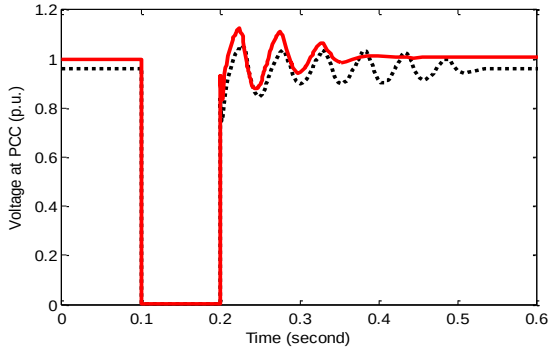


Figure 7. *Structure of the ANFIS*

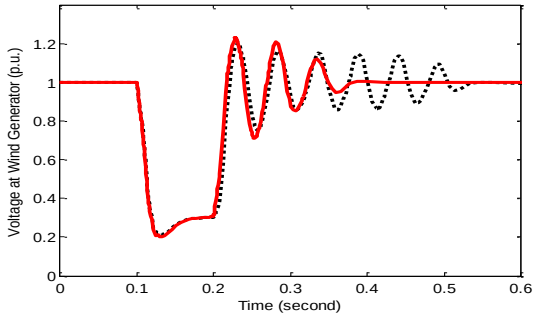
The parameters corresponding to the dependent function will change through the learning process. Calculating these parameters (or adjusting them) is easy with the gradient vector that sets the limit in a good way for the fuzzy inference system modeled data into / out according to a set of parameters.

IV. APPLY ANFIS CONTROLLER FOR SVC

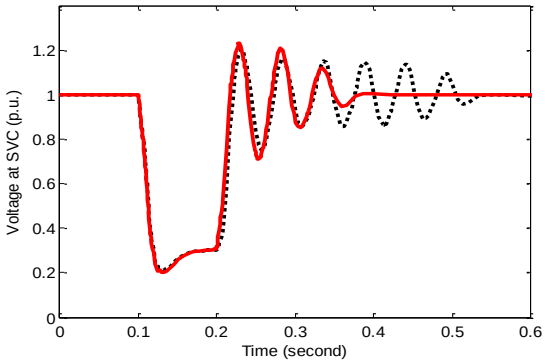
The simulation results based on a simulated Bac Lieu power system and a proposed SVC with ANFIS controller are shown in Fig. 8. In which, the black dotted lines are the responses of the system with SVC and PI controller and the red solid lines are the ones with SVC and the designed ANFIS controller. After applying ANFIS in SVC device, the output value of ANFIS is more stable and more effective, so that the voltage of each node is improved and number of oscillations after three-phase short circuit is also reduced.



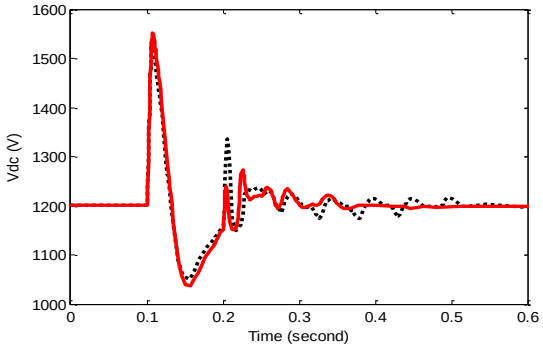
a. Voltage at PCC bus



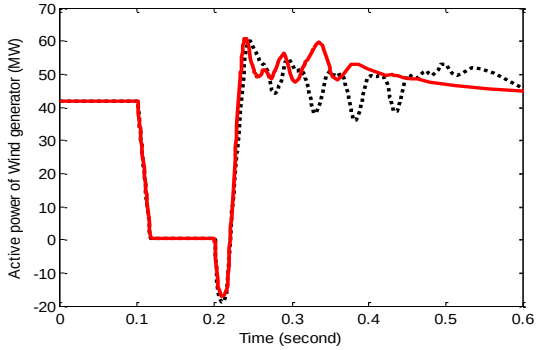
b. Voltage at wind generator



c. Voltage at SVC bus



d. Voltage at DC bus



e. Active power of wind farm

Figure 8. *Response of the system when a three-phase short circuit fault happened in the connected wind power bus*

V. CONCLUSION

As shown in this paper, with a power transmission line is connected to wind farm and an SVC, it has presented that the proposed ANFIS controller for SVC can improve the voltage quality and reduce the number and amplitude of oscillation after hardly condition as a three-phase short circuit. It can be concluded from time-domain simulation results on MATLAB that ANFIS controller has more advantages compared to the PI controller and can enhance power quality of the studied system under many different operating conditions.

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