APPLYING ANFIS TO CONTROL WIND GENERATOR FOR REDUCING POWER OSCILLATION

ỨNG DỤNG THUẬT TOÁN MỜ THÍCH NGHI TRONG ĐIỀU KHIỂN MÁY PHÁT ĐIỆN GIÓ NHẰM GIẢM DAO ĐỘNG CÔNG SUẤT

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ABSTRACT

The content of this research paper presents the method to control Grid Side Converter (GSC) of a Doubly Fed Induction Generator (DFIG)-based wind turbine (WT) for improving the stability of the generator. To present the power systems, a well-known power system with three Synchronous Generators (SGs) and nine buses that is widely used in many types of research is applied. The Adaptive Neural Fuzzy Inference System (ANFIS) algorithm which combines between fuzzy logic and neuro-network that has advantages of both above controllers is proposed to replace the traditional Proportional Integral (PI) controller. The simulation results are performed by using commercial Matlab software when happening severe faults in the studied system such as three-phase short-circuit fault and wind speed suddenly change. It can be clearly concluded from the simulation results that the proposed ANFIS controller is suitable to enhance the stability of the DFIG-based wind turbine generator and power systems as well.

Keywords: *Doubly Fed Induction Generator (DFIG); Adaptive Neural Fuzzy Inference System (ANFIS); Grid Side Converter (GSC); PI controller; Stability Improvement.*

TÓM TẮT

Nội dung nghiên cứu của bài báo trình bày về phương pháp điều khiển bộ biến đổi công suất nối lưới (GSC) của máy phát điện gió nguồn kép (DFIG) trong việc nâng cao ổn định của máy phát. Hệ thống điện được sử dụng là hệ 3 máy phát đồng bộ kết nối với 9 bus. Thuật toán điều khiển mờ thích nghi (ANFIS) là sự kết hợp nhiều ưu điểm giữa logic mờ và mạng nơ-ron được đề xuất để thay thế cho bộ điều khiển truyền thống PI. Các kết quả mô phỏng được thực hiện trên môi trường Matlab khi hệ thống xảy ra các sự cố nghiêm trọng như ngắn mạch 3 pha và khi tốc độ gió thay đổi đột ngột. Từ các kết quả mô phỏng ta có thể kết luận rằng bộ điều khiển mờ thích nghi đề xuất là phù hợp cho việc điều khiển nâng cao ổn định của máy phát điện gió nguồn kép dẫn đến giúp ổn định dao động của hệ thống điện có kết nối với máy phát này.

Từ khóa: *Máy phát điện gió nguồn kép (DFIG); Bộ điều khiển mờ thích nghi (ANFIS); Bộ biến đổi phía lưới (GSC); bộ điều khiển PI; Nâng cao ổn định.*

1. INTRODUCTION

Doubly fed induction generator (DFIG) is used widely for wind power plants since it has much more advantages compared to the permanent magnet synchronous generator (PMSG) such as the ability to independently reactive power and an active power controller, more efficiency due to generating power from the rotor… However, as stator windings are connected directly to the power network so that this generator type is extremely sensitive with noises from the power system so that enhancing the abilities of the control unit to increase the stability of DFIG generator needs to be carried out and renovated in these years. In [1], the rotor current of the DFIG generator is considered and analyzed in many different circumstances in relevance to the increase, decrease the output voltage. Responding ability DFIG generator when it has a high voltage can be gained by controlling the transformer at the grid side converter (GSC) as mentioned in [2]. Or in [3], a feed-forward control method is also presented to improve the stability of DFIG in both unbalanced and balanced situation of the power network. Beside traditional control methods, genetic algorithm (GA) is also applied in controlling DFIG to enhance the stability of wind power plants connecting to power network when incurring low voltage faults [4].

Nowadays, with the development of the power electronics technology, flexible alternating current transmission system devices (FACTS) can be used to help stabilize the system instantly when a serious incident occurs. In which, Static Var Compensator (SVC) can be used in wind power plants using DFIG generator [5], Static Synchronous Compensator (STATCOM) [6] is also applied to improve the dynamic stability in the power system…

This paper concentrates on enhancement stability of wind power plants using DFIG generator which is connected with the power network by applying adaptive neural fuzzy inference system (ANFIS) replacing for the traditional PI controller of the GSC.

2. STUDIED SYSTEM

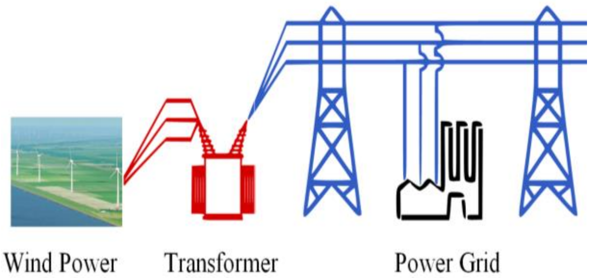


***Figure 1**. Principle diagram of studied system.*

In this research, the principle diagram of the studied system is presented in figure 1 including a wind power plant with the power of 100-MW and it is connected to the power network. In that, wind power plant is replaced as a DFIG, the power system is replaced by 9-bus power system including 3 synchronous generators and 3 loads. Details of each block are described as below.

2.1 Doubly fed induction generator model

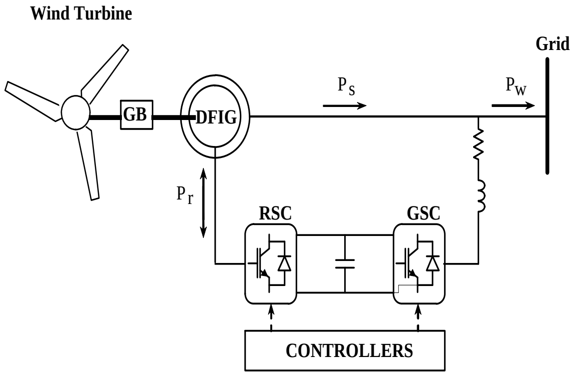


***Figure 2**. Equivalent model of DFIG*

Figure 2 presents principle diagram of a DFIG with stator circuit is connected with the network, whereas the rotor circuit is connected at the rotor side converter (RSC) and a grid side converter (GSC). In this profile, the power of converters is designed approximately 30% of the rated power of the generator.

A DFIG-based wind generator is an electrical machine that both stator and rotor can generate power. Generating power of rotor is in ratio with slip factor *s* of the generator and calculated as

$$P_r = -s.P_s \qquad (1)$$

with P_r is generating power of rotor.

P_s is generating power of the stator. (2.2)

Slip factor is calculated by equivalence:

$$s = \frac{\omega_s - \omega_r}{\omega_s} \qquad (2)$$

with ω_r is rotor speed và ω_s is synchronous speed.

If generators are operated lower than the synchronous speed that $s > 0$ so $P_r < 0$ and rotor consume power. In contrast, if generators are operated lower than the synchronous speed that $s < 0$ and $P_r > 0$ so the rotor generates power to the network.

The descriptive equivalences of DFIG generator model are given as follow.

Voltage equivalence at stator:

$$v_{ds} = R_s i_{ds} - \omega_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad (3)$$

$$v_{qs} = R_s i_{qs} + \omega_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \quad (4)$$

Voltage equivalence at rotor:

$$v_{dr} = R_r i_{dr} - (\omega_s - \omega_r)\psi_{qr} + \frac{d\psi_{dr}}{dt} \quad (5)$$

$$v_{qr} = R_s i_{qr} + (\omega_s - \omega_r)\psi_{dr} + \frac{d\psi_{qr}}{dt} \quad (6)$$

Power P and Q on stator terminal:

$$P_s = \frac{3}{2}.(v_{ds}.i_{ds} + v_{qs}.i_{qs}) \quad (7)$$

$$Q_s = \frac{3}{2}.(v_{qs}.i_{ds} - v_{ds}.i_{qs}) \quad (8)$$

Power P and Q on rotor terminal:

$$P_r = \frac{3}{2}.(v_{dr}.i_r + v_{qr}.i_{qr}) \quad (9)$$

$$Q_r = \frac{3}{2}.(v_{qr}.i_{dr} - v_{dr}.i_{qr}) \quad (10)$$

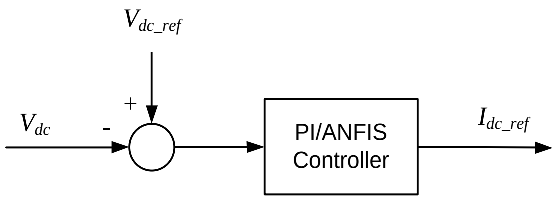
In that:

ψ is the flux of the generator.

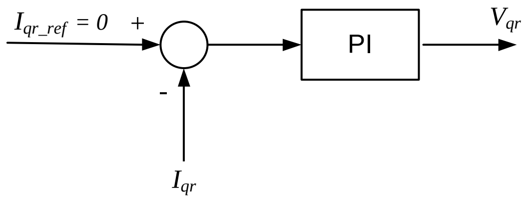
r, *s* are parameters of rotor and stator.

d and *q* are parameters projected on axis *d* and *q* of the *0dq* coordinate system.

Out of that, for the system can operate, it requires controllers for both RSC and GSC. In this paper, authors concentrate on GSC controller to control common DC voltage stability of both converter and reactive power controller from two specific parameters I_{dc_ref} and V_{qr} as control flowchart in figure 3 with control requirement is *Pmax*, it means $Q = 0$ [5].



a) V_{DC} control block



b) Reactive power control block

***Figure 3**. Control flow chart for GSC*

From theories base on a simulation model for DFIG wind generator system as figure 4. In that:

Block 1 (Aerodynamics): Simulating functions of the wind turbine to convert the kinetic energy of wind into mechanical power at the turbine. Input signals are wind speed, rotation of the pitch angle and angular velocity of the turbine. The output signal is torque at the turbine.

Block 2 (Driver train): Simulating the function of transmitting gear between the wind turbine and the rotor shaft of DFIG.

Block 3 (Stator): Simulating the stator of DFIG with input signals are the current and electromotive value of stator windings, the output signal is the voltage value. The values are converted to the *dq* coordinate system.

Block 4 (Rotor Dynamic): Simulating the rotor of DFIG with input signals are stator current, voltages on rotor windings and angular velocity of the rotor. Output signals are the electromotive value of stator, current in rotor winding and electromotive torque (T_e).

Block 5 (Controllers): Simulating controller blocks used for DFIG including RSC and GSC. At here, we ignore the controlling of pitch angle.

Block 6 (DC link): The role of this block is supplying power and connection for two power converter. Input signals of DC link block are an active power of the stator and rotor of DFIG, from that, it will generate a DC voltage signal by controlling GSC block.

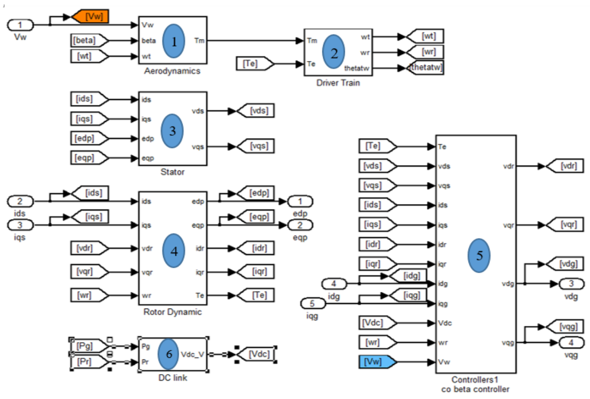


***Figure 4**. DFIG generator model is built in MATLAB software*

2.2 Power system model

Power system used in this paper is a well-known power system with 3 generators and 9 buses that is widely used in many types of research about the power system. Detailed parameters are presented in [7]. In that, a synchronous generator (SG) model is selected as a simple model type 4 as in [5].

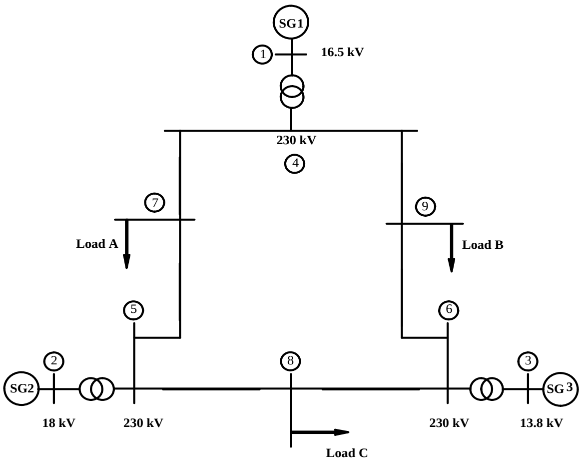


***Figure 5**. Three generators nine buses system*

3. DESIGN CONTROLLER UNIT

With fuzzy inference, we can easily design the desired system by the If-Then rules which is the nearest to human processing. With most applications, this allows creating a simpler solution with a shorter time. Moreover, we can easily use our knowledge about an object to optimize the system directly. However, with many advantages, the fuzzy inference controller system still has some disadvantages such as the design and optimization of fuzzy inference needs experience about the object, it is not completely easy with the beginners.

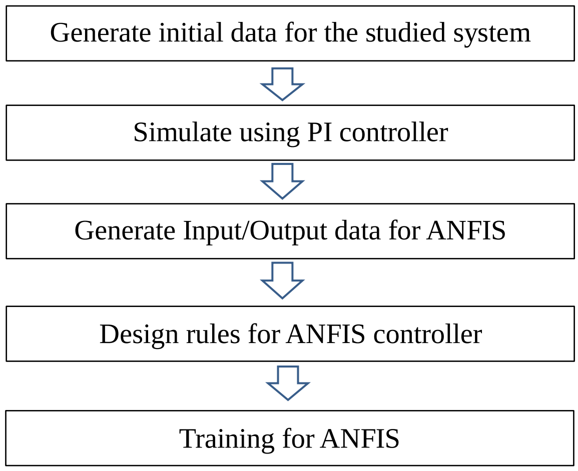


***Figure 6**. Steps for training ANFIS.*

In contrast, the neural network has the ability to learn so we can train a neural network to be approximate any nonlinear function, especially when we knew input and output data. But the basic disadvantage of the neural network is difficult to explain obviously about the operations of the neural network. So that, modification of the parameters in a neural network is hard to find.

For these above reasons, the combination between fuzzy logic and neuro-network that has adaptive neuro-fuzzy inference system (ANFIS) will promote the advantages of both above controllers. The flow chart of this algorithm is shown in figure 6.

In this paper, the ANFIS is proposed as a replacement for the PI controller as showed in figure 3a. In that, two inputs of the ANFIS controller is error and integral of input error as shown in figure 7. In the specific circumstance, the selected signal is the voltage values of the DC converter.

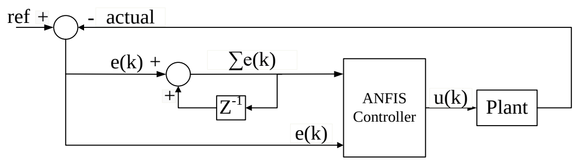


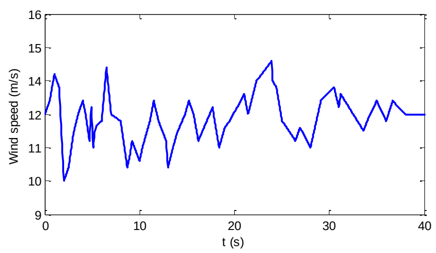
***Figure 7**. Block diagram of ANFIS*

4. RESULTS

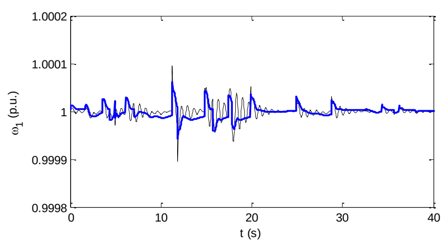
To evaluate the affections of ANFIS controller to the studied system compared to the PI controller, this paper executes simulation when wind speed increases and decreases as depicted in figure 8(a).

Figure 8(b) to figure 8(d) show the rotor speed of three generators as can see rotor speeds of three generators are affected when having changes in wind speed. However, these alternations are very low. When applying the ANFIS controller as a replacement for the PI controller, this oscillation is reduced significantly which presented by the bold blue lines.

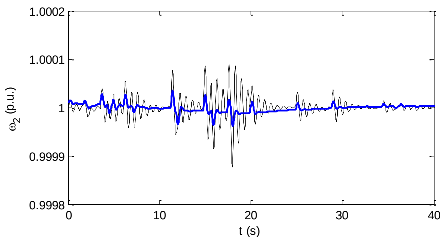
Moreover, figure 9 has presented responses of rotor speed of three generators when it had a failure that the load is disconnected dramatically at wind generator bus (bus 7) occurred at the time 2s lasted in five periods. It can be recognized from simulation results in this circumstance that the oscillation of all three generators are reduced significantly when the ANFIS controller is installed.



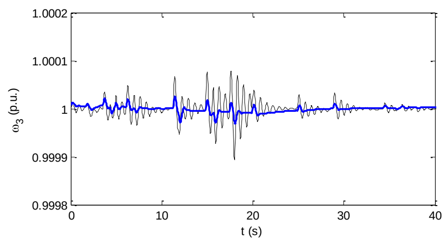
a) Wind speed



b) Rotor speed of generator 1

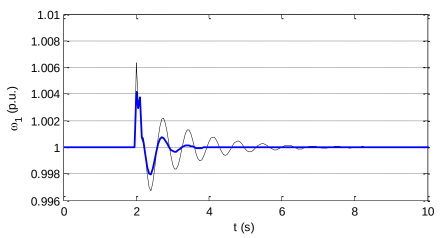


c) Rotor speed of generator 2

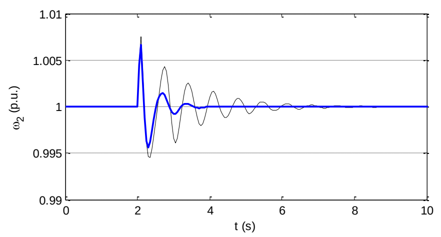


d) Rotor speed of generator 3

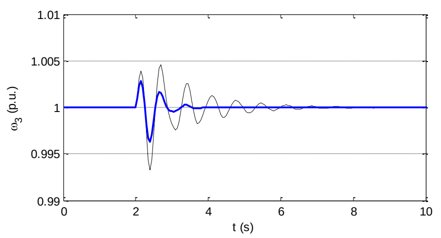
***Figure 8**. Responses of the system when wind speed changes dramatically.*



a) Rotor speed of generator 1



b) Rotor speed of generator 2



c) Rotor speed of generator 3

***Figure 9**. The response of the system when occurring 3-phase short circuit fault.*

5. CONCLUSION

This paper has presented the application of adaptive neuro-fuzzy inference system (ANFIS) to control the grid side converter (GSC) of Doubly Fed Induction Generator (DFIG) to enhance the stability of the studied system. Simulation results are presented and executed on a variety of dangerous conditions of the studied power system as a three-phase short circuit fault or the rapid changes of wind speed. It can be concluded from the simulation results that the designed ANFIS controller can be used to replace PI controller for controlling wind power of wind generator to enhance the stability of the power system which has a connection to wind power plants.

REFERENCES

[1] Y. Ling and X. Cai, *Rotor current dynamics of doubly fed induction generators during grid voltage dip and rise*, International Journal of Electrical Power & Energy Systems, vol. 44, no. 1, pp. 17–24, 2013.

[2] R. Li, H. Geng, and G. Yang, *Asymmetrical high voltage ride through control strategy of grid-side converter for grid-connected renewable energy equipment*, in Proceedings of the International Electronics and Application Conference and Exposition (PEAC '14), pp. 496–501, Shanghai, China, November 2014

[3] J. Liang, D. F. Howard, J. A. Restrepo, and R. G. Harley, *Feedforward transient compensation control for DFIG wind turbines during both balanced and unbalanced grid disturbances*, IEEE Transactions on Industry Applications, vol. 49, no. 3, pp. 1452–1463, 2013

[4] T. D. Vrionis, X. I. Koutiva, and N. A. Vovos, *A genetic algorithm-based low voltage ride-through control strategy for grid-connected doubly fed induction wind generators*, IEEE Transactions on Power Systems, vol. 29, no. 3, pp. 1325–1334, 2014.

[5] L. Wang and D. N. Truong, *Stability improvement of a DFIG-based offshore wind farm fed to a multi-machine power system using a static VAR compensator*, 2012 IEEE Industry Applications Society Annual Meeting, Las Vegas, NV, 2012, pp. 1-7.

[6] D. V. N. Ananth and G. V. Nagesh Kumar, *Fault ride-through enhancement using an enhanced field oriented control technique for converters of grid-connected DFIG and STATCOM for different types of faults*, ISA Transactions, 2015

[7] P. M. Anderson and A. A. Fouad, *Power System Control and Stability*, IEEE Press, 2d ed., 2003.

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