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Presentation a New Method Based on Using Emotional Intelligent Controllers for Wind Turbine Active and Reactive Power Equipped With DFIG

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***Abstract*— Regarding to the serious challenges facing widespread use of wind turbines (Part of which should rest in the design phase and the other in control phase and by developing effective controlling strategies) and also lack of proper efficiency of various strategies of classic control, the appeal of the intelligent tools and ideas especially with regard to benefits seem invaluable. In this paper, in order to control the active and reactive power of wind turbine equipped with DFIG, an appropriate control strategy (in the form of vector control) has been provided and to implement this control strategy, the new intelligent controllers designed based on the mechanism of human brain emotional learning have been used. According to simulation results, the proposed control system has had a good performance in terms of response rate, response ripple and persistent error and also enjoys significant consistency against any changes in wind speed and parameters of the system.**

***Keywords*—** Active and Reactive Power, Double Fed Induction Generator (DFIG), Emotional Learning, Wind Turbine, Intelligent Controller

I. INTRODUCTION

IN recent years the use of renewable energy including wind energy has risen dramatically. In figure 1 the growing trend of producing electricity using wind power from late 2009 until the second half of 2011 in the world has been shown. Because of the increasing development of wind power production, improvement of the control of wind turbines using classical or intelligent methods is necessary. One of the common controllers in industrial systems is the classical PI controller that despite its simple construction enjoys an acceptable performance (especially in the areas of linear systems) [2].

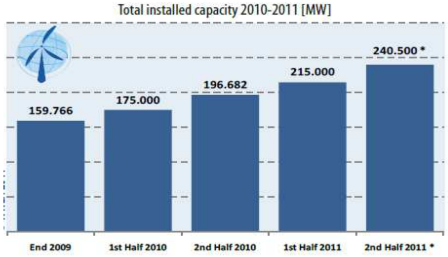

Fig. 1. Trend of producing electricity using wind power in the world [1]

In [3], [4] two samples of the application of this controller is given for controlling wind turbines. However, in systems such as wind turbine, which enjoys non-linear and undefined factors, in principle using a simple PI controller will not follow a desired response. This is due to the fact that the control system parameters with wind speed change (and therefore changing the system work point) and system parameters change need to be adjusted again.

This defect may be overcome in two ways: the use of classical linear control methods (adaptive/resistant) or the use of neural - fuzzy intelligent control methods (having adaptive-extension power and the possibility of on – line implementation). In [5]-[7] the classical control method of sliding mode (which is the oldest and still most popular method of resistant nonlinear control) is used to control the wind turbine system. Also in [8]-[10] the neural - fuzzy intelligent methods are used to achieve better solutions in the design of wind turbine control system. Wind turbines equipped with double fed induction generator of coiling rotor due to their advantages (including: production capacity in a range of wind speed, good performance, No need for capacitor banks for producing required reactive power of generator and lower-cost of power electronic converters) have widely been used. Therefore, analysis of wind turbines equipped with double fed induction generators and methods for controlling it, is one of the main analyses in producing wind power.

According to Fig. 2, the way of connecting DFIG to the grid is so that coiling stator (coil power) directly and the rotor coiling (controls) have been connected through adapter $AC/DC/AC$ to the network. The duty of the rotor side

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converter is controlling active and reactive power of the machine and the grid side converter by maintaining constant (control) the capacitor voltage between two voltage converter controls the voltage at the connection point to the grid [11], [12].

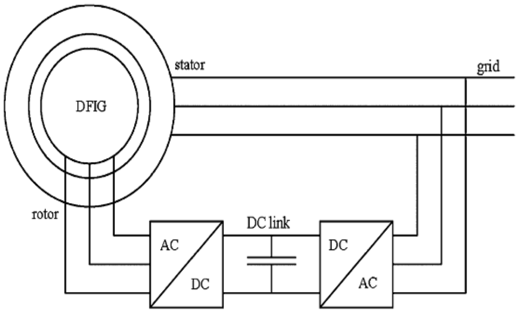

Fig. 2. Connecting DFIG to the grid

Given the high importance of effective control of wind turbine equipped with DFIG many studies have been performed in this field. Reference [13] PhD thesis on the analysis, modeling and controlling wind turbine is equipped with DFIG. In [14], [15] for the implementation of the proposed control strategies for controlling wind turbines equipped with DFIG, PI controllers have been used. Also in [16]-[19] a variety of control strategies for controlling wind turbines equipped with DFIG have been reported. Optimizing the performance of control system (in terms of transient and persistent behavioral indicators and adaptation to new conditions) of wind turbine equipped with DFIG is very important that proposing a new control strategy and its implementation using intelligent tools to accomplish this can be instrumental.

In this paper, the proposed control strategy for controlling active and reactive power of wind turbine equipped with DFIG has been implemented with the help of emotional intelligence controllers.

II. WIND SPEED MODEL

In [20], the wind speed is considered as the sum of the following four components:

1) The average wind speed (v_{av})
2) The velocity gradient (v_r)
3) Gust speed (v_g)
4) Disturbance (v_t)

Therefore, the wind speed can be written as follows:

$$v = v_{av} + v_g + v_r + v_t \tag{1}$$

The average wind speed component represents the average wind speed at specified intervals. The slope speed component in fact represents the constant increase in wind speed in terms of stability which is determined by following several functions:

$$v_r = \begin{cases} 0 & t < T_{sr} \\ A_r \frac{(t-T_{sr})}{(T_{er}-T_{sr})} & T_{sr} < t < T_{er} \\ A_r & t > T_{er} \end{cases} \tag{2}$$

Where A_r is the range of slope velocity, and T_{sr} and T_{er} are considered as the starting and finishing times of wind of slope, respectively. In [20], the jet wind speed component is has been modeled as follows:

$$v_g = \begin{cases} 0 & t < T_{sg} \\ A_g \left\{ 1 - \cos\left[2\pi \frac{(t-T_{sg})}{(T_{eg}-T_{sg})} \right] \right\} & T_{sg} < t < T_{eg} \\ 0 & t > T_{eg} \end{cases} \tag{3}$$

The disturbance component which is responsible for describing the randomness of wind speed would be as:

$$v_t = 2\sum_{i=1}^{N} \left[S_v(\omega_i)\Delta\omega \right]^{1/2} \cos(\omega_i t + \phi_i) \tag{4}$$

In which $\omega_i = \left(i - \frac{1}{2}\right)\Delta\omega$ and ϕ_i is a random variable with uniform probability in range zero to 2π .Also, $S_v(\omega_i)$, the spectral density function which was introduced by Wickets, has been presented in [21] as follows :

$$S_v(\omega_i) = \frac{2K_N F^2 |\omega_i|}{\pi^2 \left[1 + (F\omega_i / \mu\pi)^2 \right]^{4/3}} \tag{5}$$

In which $K_N = 0.004$, $F = 2000$ and μ is the average speed at high altitude. In [22] it was concluded that the parameter values of $N = 50$ and $\Delta\omega = 0.5\text{-}20$ would be suitable for the simulation.

III. DESIGNING INTELLIGENT CONTROLLER BASED ON HUMAN BRAIN MECHANISMS OF EMOTIONAL LEARNING

In this paper, according to the model presented in [23] from human brain mechanisms of emotional learning, an intelligent control strategy has been presented for controlling blocks which has the same performance with a self- regulatory PID controller. From this perspective, the minimum value of the proposed intelligent structure in addition to the general and valuable characteristics of intelligent structures (including the system- being abandoned, adaptation and expansion power and ...), its small volume of preparing process compared to the massive and time consuming process of off-line preparing, a PID controller is self – regulatory one since its self- regulatory characteristic is achieved based on a function of a mechanism for emotional learning and as on – line. Regardless of the details, schematic of brain emotional learning system has been shown in Figure 3 that following in order to illustrate the proposed computational model of emotional learning, the amygdala- orbitofrontal is used.

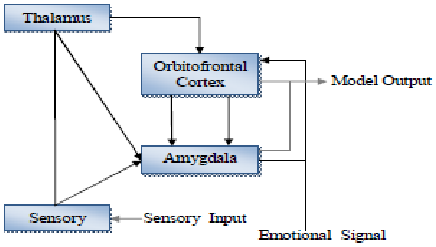

Fig. 3. Block View of computational models of brain mechanisms of emotional learning [23]

MO Computational model output (the emotional learning amygdala- orbitofrontal system's response to input stimuli and the emotional rewards / Composition EC signal) is equal to:

$$MO = AO - OCO \tag{6}$$

In which AO and OCO are respectively output units of amygdala and orbitofrontal and are equal to:

$$\begin{aligned} AO &= G_a \cdot SI \\ OCO &= G_{oc} \cdot SI \end{aligned} \tag{7}$$

In which G_a and G_{oc} are respectively equivalent gain of amygdala and orbitofrontal units. Learning low in the amygdala and orbitofrontal units, respectively, is:

$$\begin{aligned} \Delta G_a &= k_1 \cdot \max(0, EC - AO) \ \geq 0 \\ \Delta G_{oc} &= k_2 \cdot (MO - EC) \end{aligned} \tag{8}$$

In which k_1 and k_2 are respectively learning rate inamygdala and orbitofrontal units.

Because of using max operator, unit gain of amygdala is subject to increased univocal changes. In other words, the desired working conditions (which will be reflected in the large amounts of emotional signals EC) gradually increase the gain of the amygdala unit to its physical limits. However, for unknown reasons, if conditions are unfavorable in the future (with a small amount of emotional signals EC) the amygdala unit will not be able to diagnose this problem and correct its answer and practically will respond the same as desired conditions. However, the orbitofrontal unit gain is allowed to positive/negative change so that the amygdala unit can properly carry out the reform against the unfavorable responses.

By combining (6) and (7) we have:

$$MO = (G_a - G_{oc}) \cdot SI \equiv G(SI, EC, \ldots) \cdot SI \tag{9}$$

In other words, the output of amygdala-orbitofrontal system in emotional learning is the product of a variable G gain (dependent on several factors, including EC emotional signals, SI stimulation input, etc.) in the SI stimulus input. Citing the proven values of PID controller, most direct proposal for formulating SI stimulation signal, is a PID-like frame:

$$SI = k_P \cdot e + K_I \cdot \int_0^t e\,dt + K_D \cdot \dot{e} \tag{10}$$

In which e is the tracking error of closed-loop system. It should be explained that for various reasons including the noise of measurement devices, actually worse the operating system so at best, PID controller will not have better performance than PI controller. Therefore, the only two options P and PI will remain for SI stimulation signal. EC Emotional signals in general, should indicate the desirability of the performance of the controller and closed loop system. Therefore, without losing the whole, EC can be written based on a weighted combination of the primary / secondary areas of application (including tracking the desired output, trying to control the minimum or equivalent maximum efficiency, etc.):

$$EC = a_{ec1} \cdot e + a_{ec2} \cdot MO + other\,terms \tag{11}$$

From the above, the easiness of embedding the secondary goals in intelligent structures (including the obvious advantages of intelligent structures in comparison with the classical structures) is clearly implied. In figure 4 block display of the proposed intelligent controller based on human brain a mechanism of emotional learning has been shown.

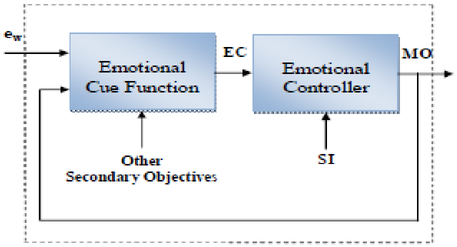

Fig. 4. The block display of proposed intelligent controller based on the brain emotional learning

IV. IMPLEMENTING OF CONTROL STRATEGY FOR WIND TURBINE EQUIPPED WITH DFIG

In Fig. 5 diagram block of vector control (proposed) of wind turbine equipped with DFIG has been shown. Also, in Fig. 6 details related to the control subsystem related to Fig. 5 has been shown. Control strategy must be in the way that dual fed induction generator can track be in the maximum absorbable power of the wind turbine at any wind speed.

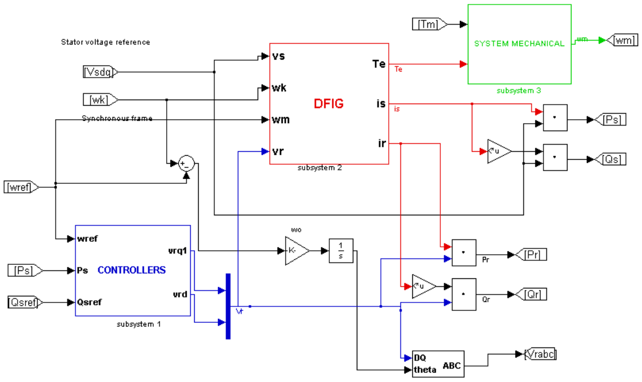

Fig. 5. Diagram block of vector control (proposed) of wind turbine equipped with DFIG

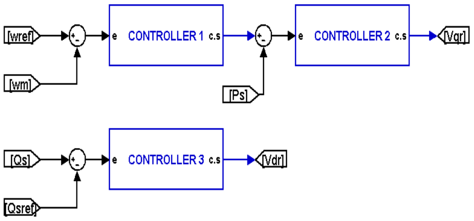

Fig. 6. Details related to the control subsystem related to Fig. 5

Accordingly, the controller number 2 has been designed so that the active power produced by two fed induction generator can track the desired active power at any time through by injecting the desired voltage to the rotor Q component. The duty of controller No.1 is also production of desired active power (for controller No. 2) by tracking the reference speed of the rotor. Meanwhile, and amount of exchanges of reactive power between the DFIG and network is controlled by controlling the voltage of d component of rotor and this has been performed using the controller No. 3.

All simulations were done using MATLAB software for 18 seconds. In Fig. 7, wind speed profile (based on the model presented in Part 2) has been shown as a default. The simulation results of diagram block in Fig. 5, for wind speed profile of Fig. 7, are also given in Fig. 8 to Fig. 11, respectively. It should be noted that all used controllers have been designed as intelligent and based on brain emotional learning. Fig. 10 and Fig. 11 show active and reactive power produced by the DFIG, respectively. Fig. 8 and Fig. 9, respectively, show the rotor speed and mechanical torque of turbine rotor and electrical torque of DFIG. The simulation results indicate that training of intelligent emotional controllers are done in less than 2 seconds and then the control system would fulfill the expected goals as well.

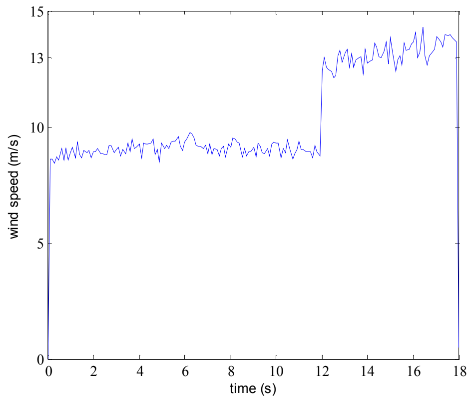

Fig. 7. Wind speed profile

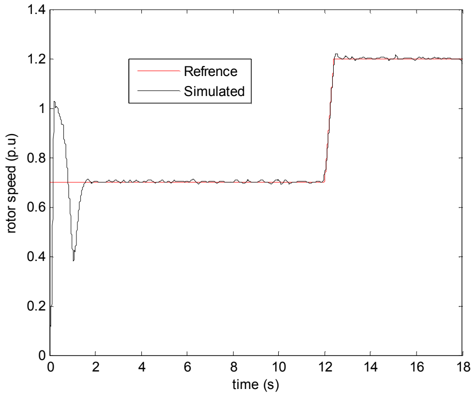

Fig. 8. Rotor speed

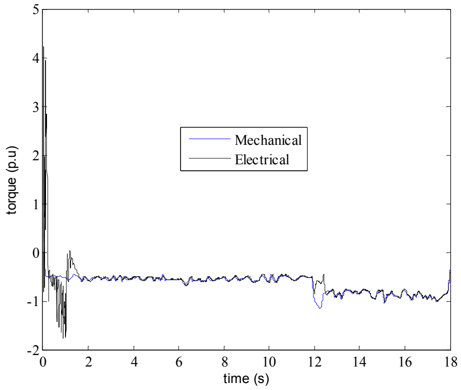

Fig. 9. Mechanical torque and electrical torque of DFIG

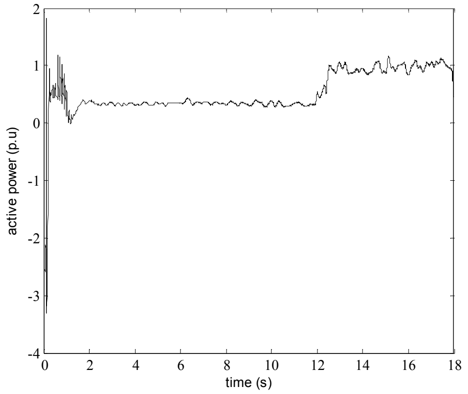

Fig. 10. Active power produced by the DFIG

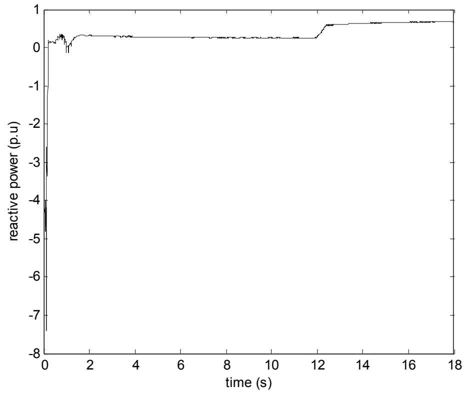

Fig. 11. Reactive power produced by the DFIG

Then, to show the significant structural consistency of proposed intelligent controllers toward changes in the work point (change in wind speed) and system parameters, The performance of emotional controllers are shown in Fig. 13 to Fig. 16, respectively, against the speed profile of Fig. 12 (which is largely different from the speed profile of Fig. 7) and for changes in the parameters of the generator (as the 30% change in stator resistance, stator inductance, rotor resistance, magnification inductance, the rotor inductance). Comparing current and previous results indicates that the noticeable performance difference is only in the transient behavior of the extended period of about 2 to 2.5 seconds. Technical specifications of DFIG have been shown in Table 1.

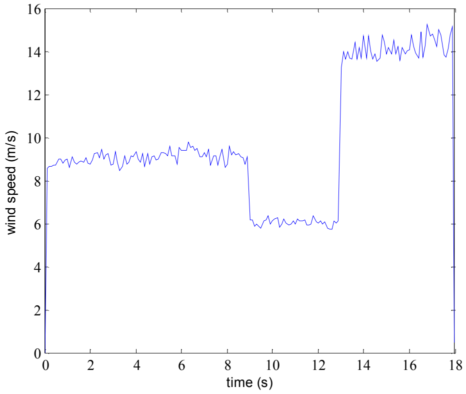

Fig. 12. Wind speed profile

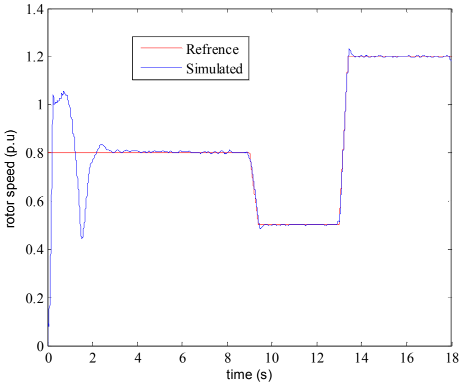

Fig. 13. Rotor speed

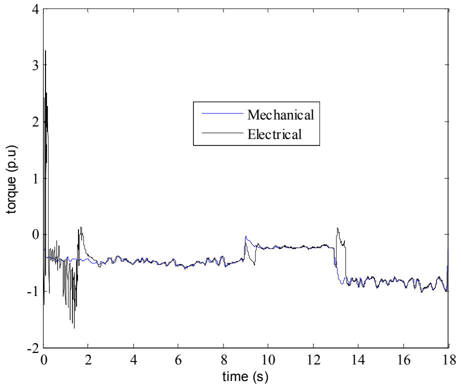

Fig. 14. mechanical torque and electrical torque of DFIG

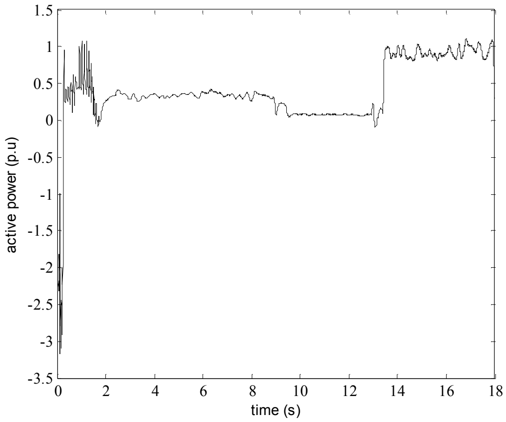

Fig. 15. Active power produced by the DFIG

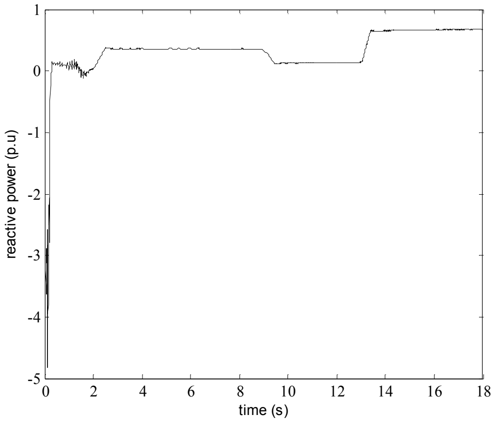

Fig. 16. reactive power produced by the DFIG

Table 1: Technical specifications of DFIG

Stator voltage	400V
Stator frequency	60 Hz
Generator's Nominal Power	660 Kw
Rotor resistance	0.02 p.u
Stator resistance	0.05 p.u
Rotor leakage inductance	0.1 p.u
Stator leakage inductance	0.03 p.u
Mutual inductance	5 p.u
Number of pole pairs	4

V. CONCLUSIONS

Analysis of wind turbines equipped with double-feed induction generators and their control methods is one of the main analyses in wind power generation. Regarding the improved capabilities of the intelligent controllers (include: high adaption and generalization ability, model-free capability, and also the ability of online implementation), these controllers can be used as wind turbine control systems to achieve more desirable responses and also to facilitate designing process. In this paper, an appropriate control strategy for active and reactive power control of wind turbines equipped with DFIG has been presented and implementing this control strategy has been done with the help of the new emotional intelligent controllers. According to simulation results, this control system meets the following objectives:

1- The desired quality from the perspective of transient and persistent behavioral indicators in the same simple structure (desired quality in terms of response rate, ripple response and lasting tracking error),

2- The remarkable consistency against work point changes (change in wind speed) and system parameters (by changing the work point and system parameters, they do not need to be redesigned but against these changes they are modified automatically and maintain their optimal performance).

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