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Power Management of a DFIG-Based Wind Farm to Support System Frequency

Olfa Awedni*

Electric Engineering Department,
National Engineering School of Sfax, Control and Energy Management Laboratory (CEMLab) BP 1173, 3038, Sfax, Tunisia.
Tel.: (+216) 74 274 418 / Fax: (+216) 74 275 595.
E-mail: Olfaawedni16@gmail.com.
* Corresponding Author.

Abdelkarim Masmoudi

National School of Electronics and Telecommunications of Sfax, Tunisia.
E-mail: abdelkarim.masmoudi@enetcom.usf.tn.

Lotfi Krichen

Electric Engineering Department,
National Engineering School of Sfax, Control and Energy Management Laboratory (CEMLab) BP 1173, 3038, Sfax, Tunisia.
Tel.: (+216) 74 274 418 / Fax: (+216) 74 275 595.
E-mail: lotfi.krichen@enis.rnu.rn.

***Abstract*— As the capacity of wind energy installation is considerably increasing around the world, the wind energy is actually becoming a major alternative of conventional power generations systems. Accordingly, the wind farm active power control represents one of the most critical concerns to ensure the security and stability of the entire power system. As a result, developping advanced dispatching strategies has become an imperative issue so that the wind farm power satisfies the quality requirements of the power grid. Among the several active power control requirements, this paper particularly focuses on power deviation control for the case of a double fed induction generator (DFIG) - based wind farm. This mode of control is fundamental for wind farm frequency support in order to deal with the case of frequency drop occurrence. Therefore, the study presented in this paper proposes an optimization algorithm for power deviation control taking into consideration the system frequency regulation demand. The aim of this algorithm is to offer improved functioning constraints to the considered power control in order to assure the enhancement of the whole system performance. Finally, the simulation results of the studied power control strategy implementation are carried out in order to evaluate and validate the performance of the proposed control.**

***Keywords*—Wind farm; DFIG; Pitch control; Power management; Power deviation; Frequency support; Optimization algorithm.**

I. Introduction

Taking into consideration the growth of the energy consumption around the word, conventional energy resources infrastructure is actually risking to face a break off within the following few decades, which makes it obvious that the word is predicted to suffer a serious energy shortage. For the purpose of solving this issue, the major growing area of interest converges principally to study the integration of renewable energy resources in the main utility grid. In view of that, renewable energies systems can produce electricity by means of unlimited clean resources, reliable manufacturing costs and better energy quality efficiency in comparison with traditional energy resources. In this context, the significant high growth rate of the wind energy worldwide makes it actually seem to be one of the most promising renewable energies. Recently, the technology of wind energy has revealed a considerable enhancement in wind turbines installations which are responsible of converting wind into electricity with respect to the environmental requirements and with competitive construction costs [1, 2].

With such a growing level of wind energy penetration, many critical concerns regarding wind farms integrations have come out especially those related to frequency regulation control issue [3-5]. Consequently, we need to propose a frequency regulation control scheme based on DFIG based wind farm model. The proposed strategy of control consists essentially on power limiting, namely, the wind turbines are controlled to produce less than they are capable of at a given wind speed in order to offer to the DFIG the ability to release a part of its stored kinetic energy during the occurrence of system frequency drops. As a result, it becomes possible to increase the injected active power and support the frequency decrease by using the available reserve on active power [6-9]. Consequently, it is actually an imperative necessity to supervise of the wind farm active power in order to guaranty the safety, the stability and the reliability of the entire system functioning. Among various active power supervision techniques, considerable amount of recent researches demonstrated that active power allocation shows a competitive performance in enhancing the active power control concerns and thus, avoids possible harmful effects that the power grid could face [10-13]. The aim of the considered technique

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consists on specifying the reference power to each wind turbine according to the desired output power of wind farm.

Based on the above analysis, an optimization strategy of power deviation control is proposed in this paper in order to improve the DFIG based wind farm contribution to power system frequency regulation demand. The goal of this work is decomposed into two parts: a local control according to each wind turbine characteristics « Pitch control » to protect the turbines against mechanical and electrical failures, as well as developing an optimized power deviation control for system frequency support, which can then provide a faster frequency recovery speed and a shorter execution time.

This paper is structured as follows. Based on the typical configuration, section II focuses on wind turbine modeling taking into consideration the maximum power point tracking (MPPT) mode and the pitch angle control. In order to contribute in system frequency support, Section III demonstrates the necessity of developing a power deviation controller among the wind farm control system. In Section IV in order to provide the required power reserve for frequency support, improved functioning conditions are applied to power deviation controller by a proposed optimization algorithm. In Section V, a comprehensive simulation study is carried out in order to evaluate the performance of the proposed control. As a final point, a concluding summary is given in section VI.

II. DFIG Based Wind Farm Model Scheme

The considered wind farm represented in Fig. 1 is connected to the grid. This wind farm is composed of three turbines spatially organized and inter-connected. Each single turbine is based on a doubly fed induction generator at a variable speed.

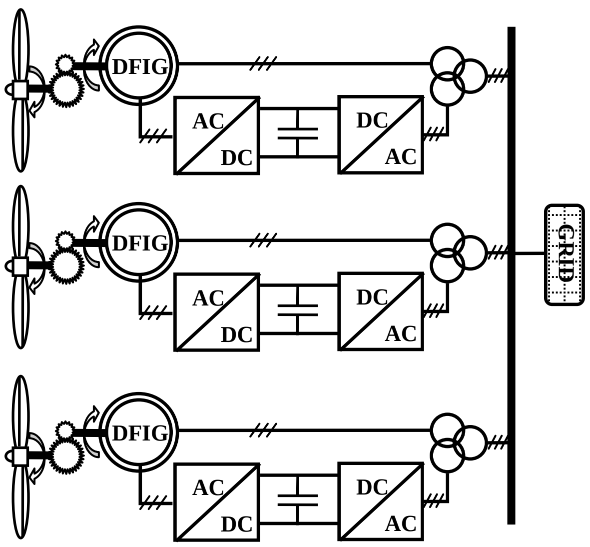

Fig. 1. DFIG wind farm configuration.

A. Wind Turbine Control Level

The wind turbine control stage aims to develop a local control system for every single wind turbine and accomplishes the instructions required by the wind farm control level. Wind turbine generators are generally controlled in the way to extract the maximum mechanical power from the received wind energy [14]. In the aim of simulating the behavior of the wind turbine, it is crucial to determine the torque exerted on its shaft. The output mechanical power can be calculated as follows:

$$P_{aer} = \frac{1}{2}\, C_p\ \rho\, \pi\ R^2\ v^3 \tag{1}$$

Where v is the wind speed, R is the rotor radius, ρ is the air density (1.22 $kg.m^{-3}$), C_p is the wind power coefficient which depends on the pitch angle of rotor blades β, and the tip speed ratio (TSR) λ. The transferred power to each wind turbine is limited by its power coefficient C_p. There are many approximate calculations established for C_p with a specified pitch angle and a given tip speed ratio. In this paper, C_p is given by:

$$C_p(\lambda,\beta) = 0.53\left(\frac{151}{\lambda_i} - 0.58\,\beta - 0.002\,\beta^{2.14} - 10\right) e^{-18.4/\lambda_i} \tag{2}$$

With:

$$\lambda_i = \frac{1}{\dfrac{1}{\lambda - 0.02\,\beta} - \dfrac{0.003}{\beta^3 + 1}} \tag{3}$$

The tip speed ratio is characterized as the ratio between blade tip speed and wind speed; its expression is given as follows:

$$\lambda = \frac{\Omega_{turb}\, R}{v} \tag{4}$$

The turbine mechanical torque is then expressed as the ratio of the turbine mechanical power to the rotational speed:

$$C_{aer} = \frac{P_{aer}}{\Omega_{turb}} = C_p\ \frac{\rho\,\pi\,R^2\,v^3}{2}\ \frac{1}{\Omega_{turb}} \tag{5}$$

The DFIG mechanical speed variation is developed from the fundamental equation of the dynamics modeling as follows:

$$J\ \frac{d\Omega_{mec}}{dt} = C_{aert} - C_{em} - f\ \Omega_{mec} \tag{6}$$

Where J is the rotational inertia, Ω_{mec} is the rotor speed, C_{aert} is the mechanical torque, C_{em} is the electromagnetic torque, and f is a friction coefficient.

In practice, in order to maximize the amount of power extracted from wind energy, it is required to maintain C_p at an optimal value [15]. Fig. 2 represents the power coefficient/tip-speed ratio curves for different pitch angle values.

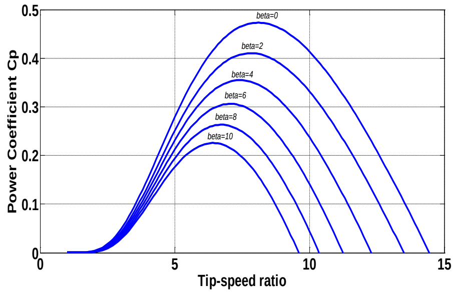

Fig. 2. Wind power coefficient curve

Based on Maximum Power Point Track (MPPT) control strategy, the wind turbine speed is controlled in order to extract the maximum power from the available wind energy. According to the wind turbine rotating speed, the controller applies a check-up curve is called optimum active power curve to indicate the generator output power [16]. The reference value of active power is equal to that given by the MPPT algorithm. The purpose of conventional speed control strategy is to maintain the rotor speed at the optimal operating point, which corresponds to the highest power coefficient value at a specific pitch angle.

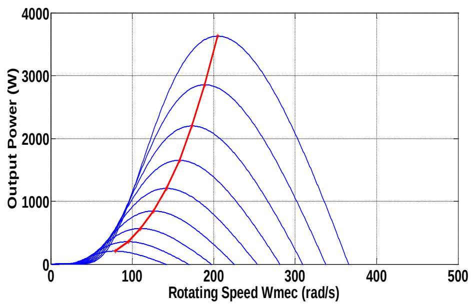

Fig. 3. Power-rotating speed curve and MPPT control strategy

B. *Pitch Control*

Generally, the pitch angle is maintained at zero so as to get the highest coefficient value and provide the optimal operational conditions. But in the case of a very high wind speed, the rotating speed and the wind turbine output power risk exceeding the maximum rated values. Hence, the wind turbine mechanical loads as well as the whole electric machine system might be damaged. The limitation of the concerns mentioned above is achieved by applying the pitch angle control technique. Using this control, the pitch angle will be increased so as to reduce the value of the power coefficient which leads as a result to less extracted power.

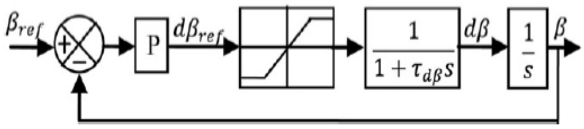

Fig. 4. Pitch control modeling

III. Wind Farm Active Power Control Considering Frequency Regulation Demand

A. *Active Power Management*

In order to satisfy the active power requirements, the wind farm has to be equipped with an active power controller. The wind turbine active power controller computes the pitch angle reference value βref based on the active power regulation information and the operational instructions (wind speed, the maximum power tracking). Therefore, this controller becomes able to adjust the active power output value by supervising the generator pitch angle. Meanwhile, the control level of each individual wind turbine transmits the operational information to the wind farm control level. The details of the wind turbine control level are shown in Fig.5.

According to the power system dispatch units commands, the active power controller should rapidly regulate the power output especially under system faults conditions or emergency situations [17, 18, 19]. The wind farm controller receives the command signals sent by the dispatch units and then controls the wind farm active power in the way the keep it tracking the signals instructions.

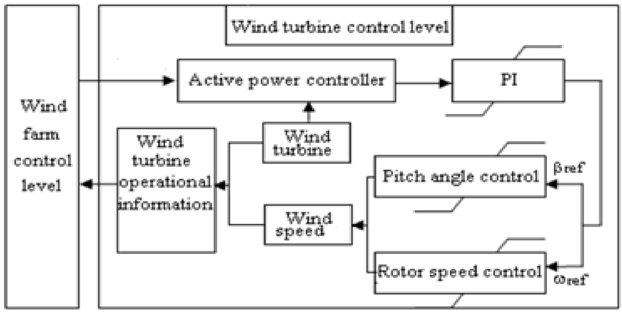

Fig. 5. Active power control

Finally, every single wind turbine will get its specific command and control its active power based on the power reference sent by the wind farm controller. Unless it receives a command signal from the dispatch units, the wind farm is controlled to produce the maximum output power.

B. *Frequency Support*

With the growing of grid-connected wind energy capacities, it becomes imperative to focus on the frequency regulation power ratio to assure the current level of system security [20-24]. The wind farm active power regulation includes power deviation control which limits the wind power real output below the available power output by a given deviation amount. The proposed type of power control lets the wind farm take part in the frequency control and provides an efficient way to support frequency regulation issue. So as to reach this objective, pitch angle control is designed to make the DFIG based wind farm have reserved power capability. For this purpose, for a given wind speed, the DFIG should operate with a pitch angle degree equals to β1 larger than the pitch angle degree β which corresponds to the optimal maximum power operation. By this way, the DFIG becomes able to retain a reserved power capability of ΔP and when the decrease of the frequency exceeds over the setting range, the DFIG based wind farm injects an additional power amount by reducing the pitch angle degree to maintain the system stability.

IV. OPTIMIZATION STRATEGY OF POWER DEVIATION CONTROL

In this section, we are developing an optimization algorithm strategy applied to the wind farm power deviation controller. In order to provide the required power reserve amount, the optimization algorithm commands the wind farm power supervision controller as follows:

- This algorithm starts by classifying the wind farm turbines from those with higher active power ability to those with lower active power ability. Taking into consideration the random variation of wind speed as well as the different dispositions of turbines, this classification becomes very useful.
- In order to provide the needed reserve for power deviation control, the considered strategy instructs the wind farm power controller to limit the active power starting by the wind turbine which is classified with highest power ability.
- For every single wind turbine, the wind farm controller is not allowed to limit more than 50% of the wind turbine active power.
- In case the controller limits 50% of the considered wind turbine power but it is not sufficient to cover the total amount of the required power reserve, then the optimization algorithm controls it to move to the next wind turbine which is classified with second highest power ability.
- The same instructions applied to the first turbine will be applied to the second turbine.
- Until obtaining the required power deviation, the optimization algorithm keeps running the same instructions according to the given turbines power abilities classification.

Applying this optimization strategy offers various benefits to the whole system:

- We can provide the required power deviation without, necessarily, involving all the wind farm turbines but a part of them.
- Only the involved wind turbines are supposed to undergo a power limitation, the rest keep operating in their MPPT mode.
- Consequently, this strategy improves the quality of power control and reduces the system complexity.

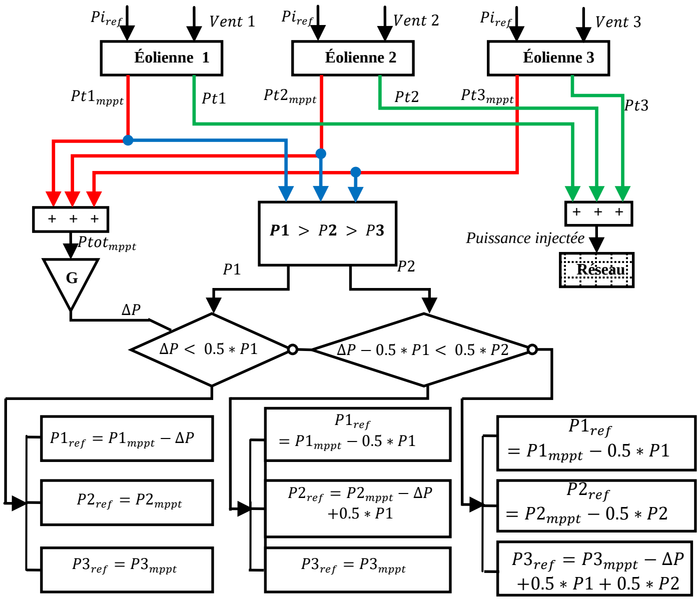

Fig. 6. Optimization algorithm

V. SIMULATION RESULTS

In this section, we apply an active power deviation control guided by the proposed optimization algorithm to a wind-farm model. The considered wind farm is connected to the grid and consisted of 3 wind turbines which are based on double fed induction generators. We applied three different wind speed profiles represented in Fig. 7 during a period of 60 s for the three wind turbines. The implementation of the treated system detailed models is carried out in Matlab/Simulink environment. The simulation results are evaluated as follows:

Every single wind turbine is supervised by its own pitch angle control so that its active power production does not exceed the maximum rated value. In our case the power production of each wind turbine is limited at a maximum value equal to 1500W.

Fig. 8 represents the active power production of each wind turbine according to its MPPT mode, as well as its active power production taking into consideration power deviation control. For both modes we notice the effectiveness of pitch control in limiting the power generation to the rated value. In addition, this result shows that unless it receives a controller command signal the wind farm produces the maximum output power.

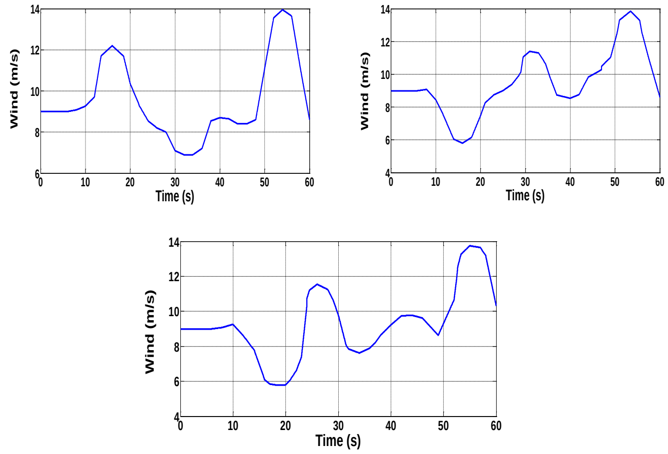

Fig. 7. Applied wind speed profiles

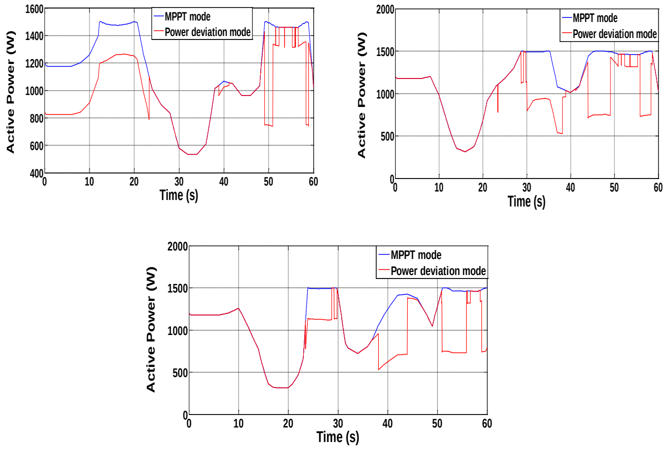

Fig. 8. Turbines power production modes

Fig. 9 illustrates the total wind farm power production with application of power deviation control, compared to the total production resulted from all the wind turbines MPPT modes. This result shows that the proposed control performance in providing the accurate amount of power reserve required by the farm which differs from one period to another as depicted in this simulation result.

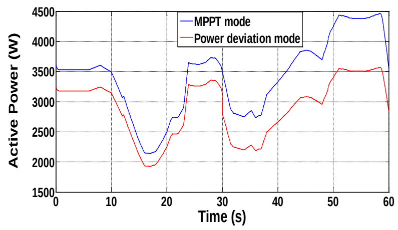

Fig. 9. Wind farm power production modes

As we mentioned previously, thanks to the optimization algorithm the power deviation control does not necessarily involve all the wind farm turbines. Fig. 10 represents the result of an indicator 'D' which indicates whether the wind turbine is involved in providing farm power reserve or not.

If D =1: the turbine is involved.

If D=0: the turbine is not involved.

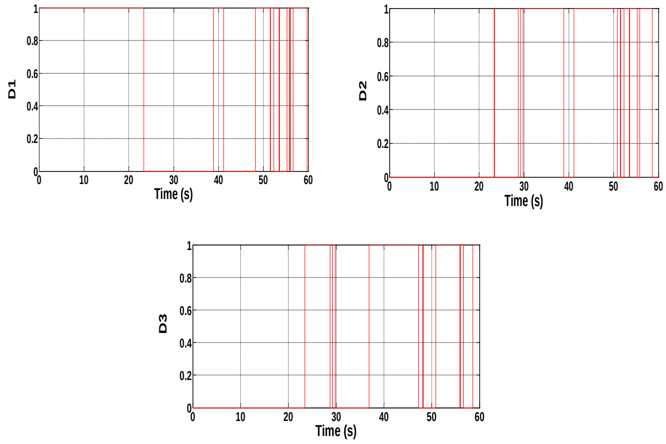

Fig. 10. Turbines modes indicator

Fig. 11 shows the amount of every wind turbine power contribution in providing the required farm power reserve. This simulation result demonstrates that every wind turbine does not contribute with more than 50% of its power as commanded by the optimization algorithm.

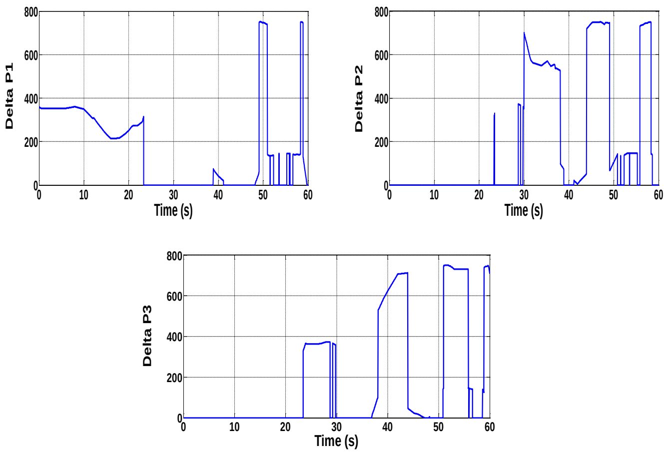

Fig. 11. Turbines power deviations amounts

VI. CONCLUSION

In order to guaranty the stability of the grid when connected to wind power integration, the control strategy of the wind farm active power is a critical concern. The control of a DFIG-based wind farm active power is studied in this paper as well as the power supervision methods. The interest is mainly focused on power management taking into consideration the system frequency regulation demand. Therefore, we are led to principally focus on the type of power deviation control. This mode of power control offers to the system the ability to contribute in frequency support particularly in the case of an unexpected frequency drop. In addition, for an improved functioning performance, an optimization algorithm is illustrated and accorded to the power deviation controller. A comprehensive simulation analysis for the considered control strategy confirms its performance and its effectiveness.

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