Power Stabilization with STATCOM on DFIG Based Wind Farm for Renewable Energy

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ABSTRACT

The demand of electricity is increasing in the world day by day due to increased needs of human being. On the one hand, fossil based energy sources are decreasing and also on the other hand they are creating the CO2 emission to atmosphere. In this case, the use of renewable power will be very economical, clean and beneficial to provide the required energy of consumers. Recent technologic developments and installations of renewable energy sources contribute the generation of renewable energy. In addition, the use of IT technologies combined with renewable energy systems makes the grid more safe and sustainable by providing monitoring and controlling capabilities of the renewable power system. In this study, an application of renewable energy is presented. Furthermore, a simulation of wind energy connected to grid to show the behavior of its components are performed in MATLAB and observed the impact of the Static Synchronous Compensator (STATCOM) in the system..

I. Introduction

To meet carbon reduction targets, it is important that the word begin to use sources of renewable and sustainable energy. The need for environmentally methods of transportation and stationary power are urgent. Therefore, CO2 emission of fossil based energy sources can only be reduce by replacing them with renewable energy sources [1, 2]. So that renewable energies such as wind, solar, hydroelectric, biomass and geothermal can be used as solutions [3, 4]. Algeria is one of the main players in the world energy markets. It is among the payroll producers and exporters of natural gas and oil because of these stocks in classic energy. Algeria needs an energy transfer model that integrates other energy alternatives for meet future needs. Production with renewable energy is a solution to Algeria since it is relatively large potential, which can reduce its dependence on this type of energy and the exploitation of renewable energies [5, 6, 7]. Algeria is the one of top five countries producing natural gas in the world. Therefore, vast majority of the generated energy in Algeria depends on natural gas. Half of the total produced gas is used for 94% electricity generation recently. Electricity consumption in Algeria will increase to 83 TWhr in 2020 and up to 150 TWhr in 2030. In the light of the projection studies, oil and natural gas reserves can cover only some next year’s [6, 8]. The bad news is that Algeria’s natural gas production has fallen about 15% over the past decade, while gas demand has increased 65% as it illustrated in Fig. 1.

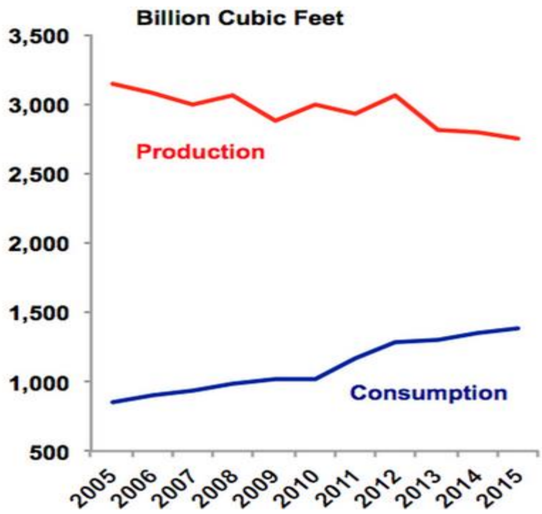

Figure 1. Electricity consumption in Algeria [8].

The good news is that Algeria's proven reserves have stayed very high at 160 trillion cubic feet, and shale gas potential in the country is huge and globally at third. For the renewable energy sources, especially solar and wind energy potentials are at very important level. In the light of this situation, technological advancement in wind electric section is important challenge for evolution in renewable energy. The fluctuation of wind makes changes in the electric energy delivered to the electric network. Consequently, the evolution of electric field to ameliorate the stability of voltage, frequency, and good quality of energy is an important step of research in the wind power field [8, 9]. In the wind energy, the internalization of Doubly Fed Induction Generators (DFIGs) have better stability and frequency of the voltage sustained their separate command of active and reactive power. For that, Flexible AC Transmission Systems (FACTS) are widely used to promote the connection of wind farms to the electrical grid. The FACTS such as STATCOM system is one of them. Many researches have proven that the steady state stability can be demonstrated by controlling the voltage out from the wind system to the grid [7, 8]. The STATCOM system is capable of stimulating the voltage stability by regulating the reactive power. Small voltage changes at the connection points of wind farm can be compensated by sending or receiving the reactive power to or from grid in STATCOM system. STATCOM system is also a good solution for compensating voltage dips. The STATCOM system enhances the voltage stability by controlling reactive power. A lot of strategies have been developed over the past decade to obtain the best power takeout from wind energy conversion system. Several researchers have focused on the importance of the use of STATCOM when it is installed in a wind farm in their studies. Runner et al. [8], Laouera et al. [9], Castaneda et al. [10], Deng et al. [11], Han et al. [12] and Ammar & Joos [13] used the STATCOM system to achieve active and reactive power control from wind farm. Meegahapola & Perera [14] explored the capability constraints to mitigate voltage fluctuations from DFIG wind farms when delivering ancillary services to the network. Wojciechowski & Strzelecki [15], Okedu [16], Gonzalez et al. [17] proposed a new strategy for Reactive Power Control in Wind Farms with STATCOM. Qiao et al. [18] have real time implementation of a STATCOM on a wind farm equipped with DFIG Generators. Liu et al. [19] present the effect of low-voltageride-through technologies on the first Taiwan offshore wind farm planning. In this study, a simulation model of wind turbine with DFIGs and STATCOM developed in MATLAB/Simulink after comparative study and the analysis of all the system to stabilize an electric power are presented. The objective of this paper is to show that STATCOM can help the wind energy to stabilize of voltage especially a voltage dip occurs.

II. Modelling of system:

1. Wind Energy in Algeria.

The 21st zone shown in Fig. 2, offering adequate speed for the establishment of wind farms has been identified in anticipation of the future farms, which should take place in 2018. The Fig.2 shows map of the wind speed in Algeria.

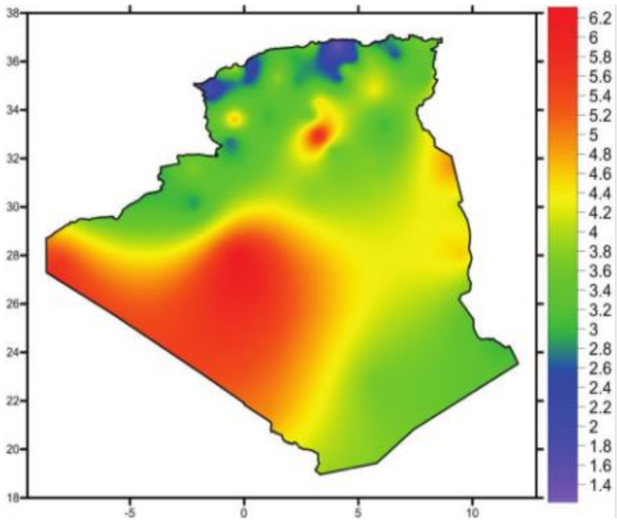

Figure 2. Map of the wind speed in Algeria (CDER 2016).

City of Adrar, which is located at the Sahra region of Algeria, has a better potential for wind energy as shown in Fig.4. The wind speed outstrip is 6.5 m/s [1, 4, 6, 13]. This makes it possible to supply power energy to isolated region like Foggara, where a link to the electric grid impossible or costly [13].

The wind farm located in the region of Adrar has [12] wind turbines with a capacity of 0.85 MW each (Fig.3). It has a total capacity of 10 MW.

Figure 3. Wind power central “10 MW”, Adrar.

In this study, this wind farm is used in the simulation connected to the electric grid with the control by STATCOM system [14-20].
In the past, DFIG type is the most used generator for the wind turbine since it can function at a vast range of speed depending on the wind speed or other specific operational requirements. So, it permits for a good recapture of wind power [4, 21, 22, 23], and dynamic slid command and pitch control may give to remake the voltage at the wind power terminals and maintaining the power system stability after disengagement of an external short-circuit fault [24, 25]. The DFIG has shown better performance for system stability over short-circuit faults in comparison to Induction Generator (IG) due to its capability of decoupling the control of output active and reactive power. The frequency converter is the top dynamic performance of the DFIG results from, which typically function with sampling and switching frequencies up 2 kHz [27, 28, 30, 32].
STATCOM can be used for generating reactive power to stabilize of a wind system also. Flexible power control damping of power system and stabilization of wind generators can be achieved by a voltage source or current source inverter based on FACTS devices [31, 32, 33, 36]. In this paper STATCOM based on a VSC-PWM technique is suggested in order to stabilize the IGs in the wind power in comparison with the use of the DFIGs [37-44].

2. Description of Wind Farm

The wind system considered in this study is depicted in Fig. 9. It has (6 × 1.5) MW wind farm connected to 25 kV distribution line, which transforms electricity into a 120 kV grid. The total power of the 09 MW wind farms with 06 wind turbines of 1.5 MW are simulated. An angle of inclination is controlled to limit the production of energy of the alternator for winds exceeding a rated speed of 9 m/s.

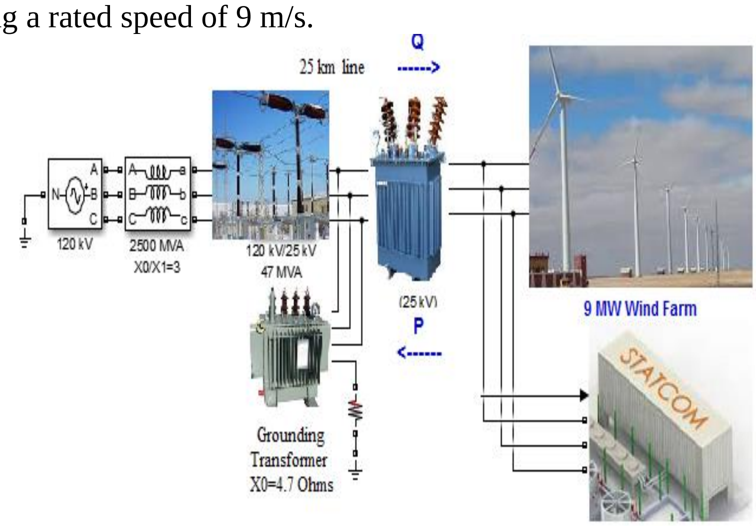

Figure 4. Model of wind energy controlled with STATCOM.

Measured reactive energy produced by the IGs is partly recompensed by the condenser attached to every base bus voltage of a wind turbine (400kVar x 6 x 1.5MW). The remainder of the reactive energy required to preserve the 25 kV voltage is given by a STATCOM.
The mechanical power of wind energy is measured for wind speeds ranging from 4 m/s to 10 m/s for the nominal wind speed of 9 m/s. It gives a nominal mechanical power of 3 MW. The two models of the wind turbine and STATCOM are in phase, which allow us to have stability for 15s, proposed for the simulation.

3. Modelling of Doubly Fed Induction Generators

Mathematical model of an induction generator can be defined by giving its three-phase stator and rotor voltage equations as in Eqs. (1) and (2).

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} I_{sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \phi_{sa} \\ \phi_{sb} \\ \phi_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_{ra} \\ V_{rb} \\ V_{rc} \end{bmatrix} = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} I_{ra} \\ I_{rb} \\ I_{rc} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \phi_{ra} \\ \phi_{rb} \\ \phi_{rc} \end{bmatrix} \quad (2)$$

where subscriptions s and r denote stator and rotor quantities, respectively. The subscripts a, b and c are used for phases a, b and c quantities, respectively. The symbols v and i are for voltages and currents and φ represents flux linkages.

Winding resistances of stator and rotor are Rs and Rr. Three phase stator resistances are assumed equal to each other for power balance. In similar, rotor resistances are also assumed as equal to each other.

Three phase flux linkages can be given in matrix form in terms of stator and rotor currents. As in Eqs. (3) and (4):

$$\begin{bmatrix} \phi_{sa} \\ \phi_{sb} \\ \phi_{sc} \end{bmatrix} [L_s] \begin{bmatrix} I_{sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} + [M_{sr}] \begin{bmatrix} I_{ra} \\ I_{rb} \\ I_{rc} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \phi_{ra} \\ \phi_{rb} \\ \phi_{rc} \end{bmatrix} = [L_r] \begin{bmatrix} I_{ra} \\ I_{rb} \\ I_{rc} \end{bmatrix} + [M_{rs}] \begin{bmatrix} I_{sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} \quad (4)$$

The inductance matrices are defined by Eqs. (5), (6) and (7):

$$[L_s] = \begin{bmatrix} l_s & M_s & M_s \\ M_s & l_s & M_s \\ M_s & M_s & l_s \end{bmatrix} \quad (5)$$

$$[L_r] = \begin{bmatrix} l_r & M_r & M_r \\ M_r & l_r & M_r \\ M_r & M_r & l_r \end{bmatrix} \quad (6)$$

$$[M_{sr}][M_{rs}] = \begin{bmatrix} \cos(\theta_e) & \cos(\theta_e + 2\pi/3) & \cos(\theta_e - 2\pi/3) \\ \cos(\theta_e - 2\pi/3) & \cos(\theta_e) & \cos(\theta_e + 2\pi/3) \\ \cos(\theta_e + 2\pi/3) & \cos(\theta_e - 2\pi/3) & \cos(\theta_e) \end{bmatrix} \quad (7)$$

Dynamic equation of induction generator in terms of inertia, mechanical and electrical torques can be written as in Eq. (8):

$$J \frac{d\Omega}{dt} = T_m - T_e \quad (8)$$

where J is the inertia of the machine, Tm is the mechanical torque and Te is the electromagnetic torque.

III. Simulation Results

The model of the wind turbine and STATCOM used to see turbine's change against a variation in the wind rate. SimPower systems starts observing the sign on the wind farm by looking the following elements: generator speed, wind speed, active power, reactive power, and pitch angle for each turbine. Firstly, the impact of STATCOM on the system is observed and then, the simulation is performed. The model uses the specialized technology of SimPower systems at Simulink to accelerate the simulation speed.

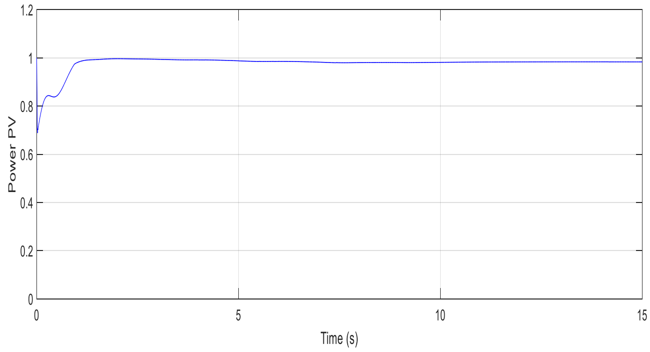

Figure 5. Power PV simulation

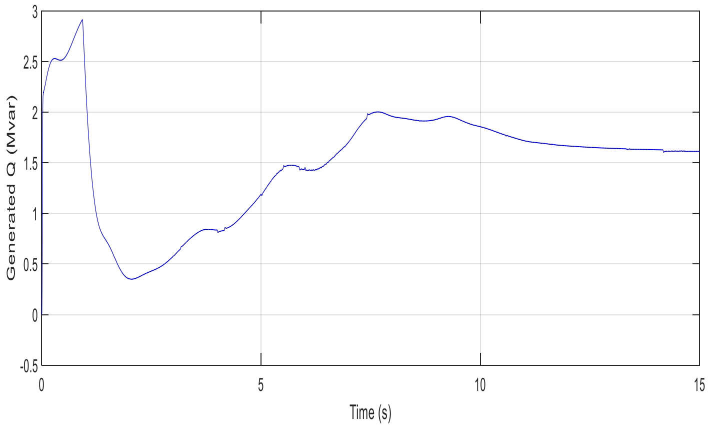

Figure 6. Generated reactive power, Q.

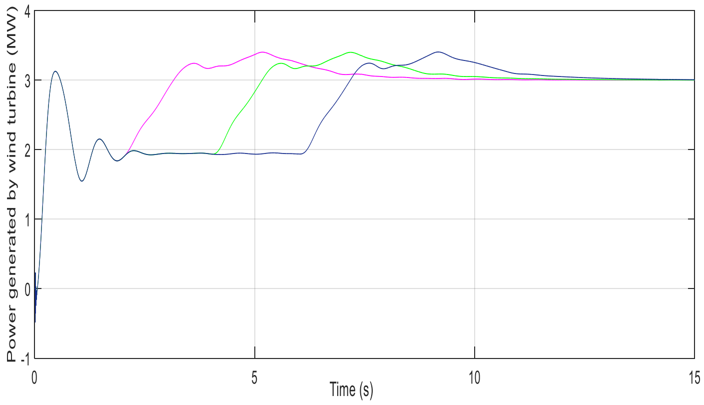

Figure 7. Power generated by wind 1, 2 and 3.

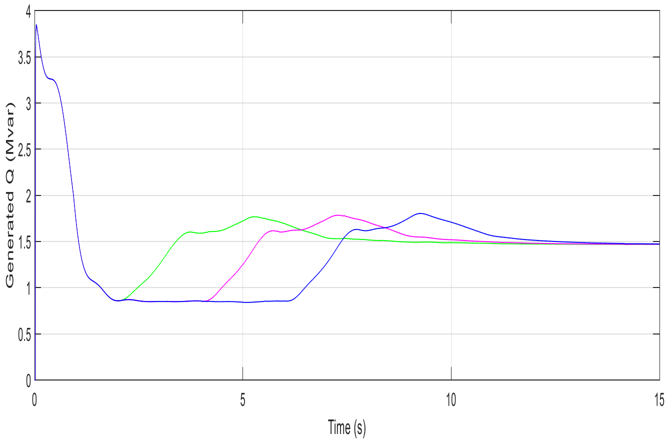

Figure 8. Generated reactive power of wind farm.

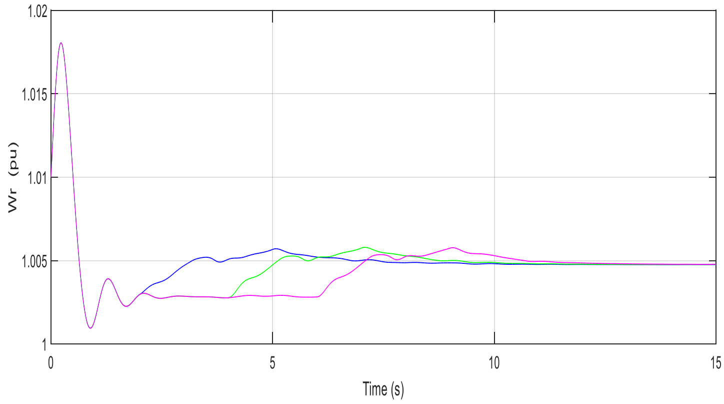

Figure 9. Angular speed of wind energy.

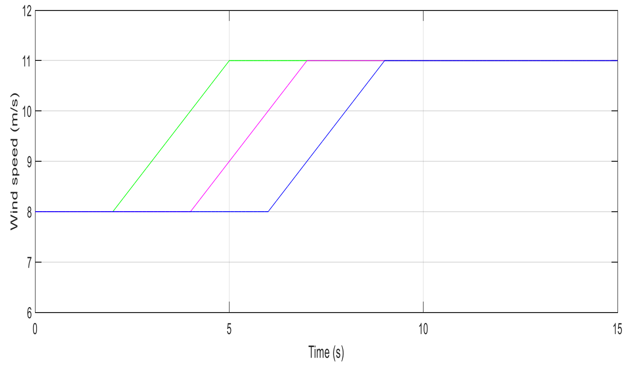

Figure 10. Profile the speed of wind energy.

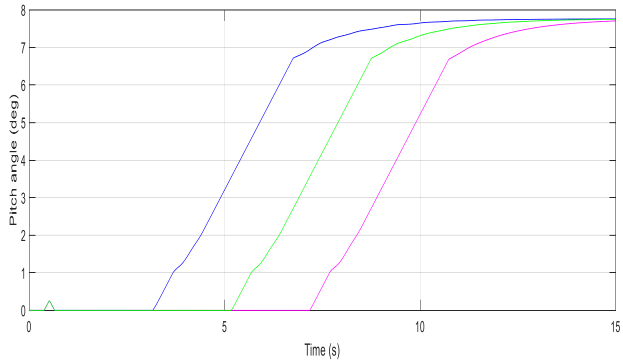

Figure 11. Pitch angle.

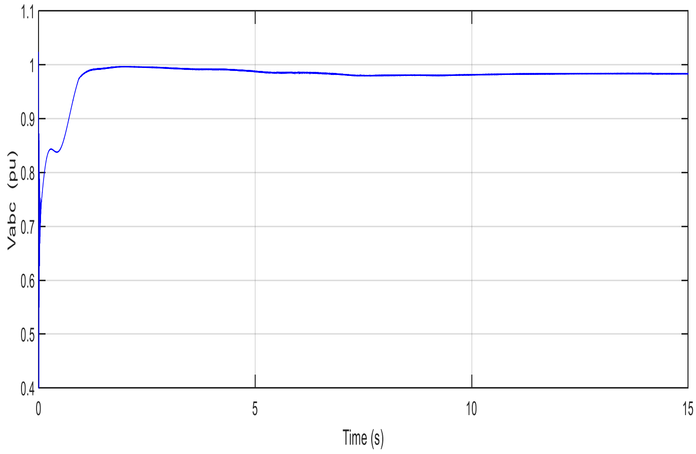

Figure 12. Power of distribution line Vabc.

The Fig. 9 depicts that speed angular varies exactly among [1 and 1.005] pu at full load. Every wind power has a security system overseeing voltage, current and generator speed. For that, wind speed is set at 8 m/s, then starting at t=2s for wind one, wind speed is forced to 11 m/s in 3 seconds. The same gust of winds two and three, respectively with 2s and 4s delays as shown in Fig. 10. After that, a casual error is put in for at the base voltage terminals (575 V) at t=15 s of wind tow, as shown in Fig. 11.

As observed in Fig. 7, for each wind, the produce active energy debut growing slowly to reach its estimated value of 3 MW in about 8s. Above this time frame, the wind speed will have augmented from 1.0028 pu to 1.0047 pu as shown in Fig. 9. At the start, the pitch angle of the turbine blades is 0 degree. When the outing power overtakes 3 MW of Fig. 7, the pitch angle is augmented from 0 deg to 8 deg in order to bring output power back to its nominal value as given in Fig. 11.

For wind speed 11m/s, the global measured power is 9 MW and the STATCOM keep the voltage at 0.984 pu by producing 1.62 MVAR as shown successively in Figs. 5 and 6. We observe in Fig. 8 that the generated active and reactive power increasing in the same times. At nominal power, every pair of wind turbine takes up 1.47 MVAR.

IV. Conclusion

Wind energy sources in Algeria were discussed in this article. After that, the essential foundation of intelligent grids was presented. The DFIG have proved best performance comparing to PMSG generator about system stability for brief-circuit error in comparison to IG, because of its capability of separately control of active and reactive energy. The chosen model contains wind system energy (6 x 1.5 MW) is attached to a voltage distribution that transforms electricity into an electric grid. This electricity has a total energy of 9 MW simulated by the model of 06 pairs of 1.5 MW wind turbines and the model of STATCOM that allow studies of transient stability type with long simulation times. Simulation results show the efficiency of STATCOM to control wind farm and how the system do the management of renewable energy sources. Finally, this paper investigated the effects of wind farm in combination with a STATCOM. The selection of this model was justified by simulation in MATLAB. The results showed that the STATCOM could control the quick-change voltage at the connection point between the wind power and the grid in normal condition. In addition, it can furnish the active energy over the brief condition. Therefore, this good opportunity offers the chance of attaching the wind power to the electric grid.

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