Improvement of Transient Stability of Algerian Power System Network with Wind Farm

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Abstract— **Although Algeria is ranks fourteenth country in proven petroleum reserves, Algeria is Conscious of the need to face its environmental problems and anxious to take part in the fight against the climatic change. It is in this optic that the Algerian government creates Funds earmarked for a renewable energy supplied from 0.5% of petroleum rental. While solar energy remains the main focus of efforts to boost production from renewable energy, Algeria is looking at wind power by several projects, which will be integrated in the Algerian network. The main objective of this research work is to investigate the power quality issue to the transient stability problem caused by the wind power connection and consequently the enhancement of the rate of the wind power penetration limit without overloaded line and with an acceptable voltage level ensured by integration of flexible Ac transmission system (FACTS) device such as Static Synchronous Compensator (STATCOM). Furthermore, in order to choose the adequate type of wind turbine, a comparative study between several types is established. It must be noted that all simulations are carried out on PSAT/Simulink. Finally, some meaningful conclusions and comments are given in this paper.**

Keywords- ***Wind power penetration; Algerian Power system; Transient stability; STATCOM; Wind turbine.***

I. INTRODUCTION

Last Japanese nuclear crises comes to proved that today more than ever, everyone is convicted that the energy solution must pass obligatorily by the development of new clean, non-polluting and non dangerous sources of energy for the environment and must necessarily guarantee durability on a human scale contrary to the current energy solutions.

Algeria has decidedly chosen sustainable development as its energy strategy, the legal and regulatory framework adopted during the past years underscores our strong commitment [1].

According to Elimax [2], Algeria is among 15 African countries (South Africa, Eritrea, Mauritania, Cap avert, Algeria, Lesotho, Seychelles, Madagascar, Somalia, Djibouti, Morocco, Chad, Egypt, Maurice, Tunisia) which have the good potential of wind energy.

The country's first wind farm – built in the south-western region of Algeria exactly in Adrar province and also several projects [1]. It generates 10 MW of electricity which will be integrated in Algerian network. Therefore, it is very imperative to understand the new aspects that the integration of wind power brought to the conventional system, especially the aspects of the transient stability by enhancement of the limit wind power amount connected to western Algerian power system network.

To accomplish this purpose, the main idea is to propose the use of a FACTS such as the STATCOM, which is a compensation device that is capable of generating and or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system and improve the quality of the energy provided to regulate the desired power flows in a power network and to provide the best voltage profile in the system as well as to minimize the system transmission losses when inserting the wind generator in the electrical network.

The choice of the study case is referred to the high level of speed wind in west Algeria according to the Algerian wind power map. In this work, also a comparative study between different types of wind turbines is established referred to their transient behavior based on index of maximum amount of wind power penetration.

This paper is organized as follows. After a shirt introduction, the wind model and the Algerian atlas wind potential in Algeria is presented in Section II. Sections III and IV offer respectively briefs reviews of the transient stability and STATCOM studies. Section V gives a detailed description of the new western Algerian power system network. Obtained results with analysis and conclusions are presented in Sections VI. Finally the paper concludes with a summary in Section VII.

II. WIND MODEL

The principle of kinetic transformation energy of the wind into electric power and the detailed description of the various types of aero-generators are presented in several references [11, 12]. The aerodynamic power which can be extracted from the wind determines by means of the following expression:

$$P_t = \tfrac{1}{2}\rho\pi r^2 v^3 C_p \tag{1}$$

Where ρ is the air density, r is the turbine radius, ν is the wind speed, and C_p is the turbine power coefficient which represents the power conversion efficiency and a further about general expression for C_P is given by a generic equation used to model C_p (λ,β). This equation, based on the modeling turbine characteristics [4]:

$$C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda \qquad (2)$$

with :

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^2 + 1} \qquad (3)$$

The coefficients c_1 to c_6 are: $c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and c_6 0.0068.

The $C_{p1} - \lambda$ characteristics, for different values of the pitch angle β (deg).

The maximum value of C_p is $C_{p\,max} = 0.48$ which is achieved for $\beta = 0$ degree and for tip speed ratio of the rotor blade tip speed to wind speed $\lambda = 8.1$. This particular value of λ is defined as the nominal value (λ _nom).
Such disturbances are the most common in the grid, the grid disturbances considered in this paper are of short duration, maximum a few hundreds of milliseconds. Since the considered grid disturbances are much faster than wind speed variations, the wind speed can he assumed constant. Therefore, natural wind variations need not be taken into account [5]. The wind speed is set to a constant 6 m/s.

A. *Wind resource assessment in Algeria*

Several studies [6], [9] and others were focus on assessment of wind resource in Algeria as a Fig. 1 represents. The map [9] shows clearly that the western region and a specially Adrar and Tiaret situated respectively in southern and northern west, have higher wind energy potential with annual wind speed average of 6 m/s at height of 10 m above ground level (AGL).

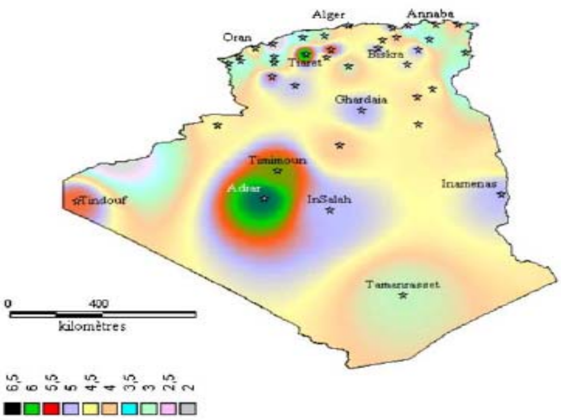

Figure 1. Annual maps of wind speed in Algeria at 10 m high

That makes the two sites candidates for installation of wind farm to provide electricity and later on its integration in Algerian power system grid. It must be noticed that the wind farm eventually installed in Tiaret department integrated in western Algerian power system represents the case study in this work.

III. Transient Stability

The stability of power systems has been and continues to be of major concern in system operation. Modern electrical power systems have grown to a large complexity due to increasing interconnections, installation of large generating units and extra-high voltage tie-lines etc. Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance, such as a fault on transmission facilities, sudden loss of generation, or loss of a large load. The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages, and other system variables [7].

A. *Swing equation*

For a system to be transiently stable during a disturbance, it is necessary for the rotor angle, to oscillate around an equilibrium point. If the rotor angle increases indefinitely, the machine is said to be transiently unstable as the machine continues to accelerate and does not reach a new state of equilibrium. So for maintain this equilibrium, the power system must at any time keep one's balance between all torques applied on rotor of synchronous generators, as its behavior described by the swing equation [7] presented by equation (2):

$$\frac{2H}{w_{syn}} w_{pu}(t)\left(\frac{d^2\delta(t)}{dt^2}\right) = P_{mpu}(t) - P_{epu}(t) - \frac{D}{w_{syn}}\left(\frac{d\delta(t)}{dt}\right) \qquad (4)$$

Where *t* is time in seconds, p_{mpu} is mechanical power supplied by prime mover minus mechanical losses, per unit and p_{epu} is electrical power output of the generator plus electrical losses, per unit w_{pu} and w_{syn} represent the per-unit frequency and the synchronous radian frequency respectively, as to δ is rotor angular position with respect to synchronously rotating reference in rad. D represents a damping torque anytime the generator deviates from its synchronous speed. Finally, it is convenient to work with a normalized inertia constant, called the H constant, which is defined as:
The swing equation is a second-order differential equation and it is also non linear. In many cases, transient stability is determined during the first swing of machine power angles following the disturbance which typically lasts about one second, where often the mechanical output power and internal voltage of generating units are assumed constant.

In this paper the resolution of the swing equation is ensured by Rung kutta numerical method and the power flow calculation is given by Newton Raphson algorithm.

It's important to note that the type of the disturbance in this paper is a symmetrical three phase to ground fault, the fault initiates the over-current protection action, which is followed by isolation of the fault location region.

Critical Clearing Time (CCT) is defined as maximal fault duration for which the system remains transiently stable during disturbance. Mathematically, CCT is a complex function of prefault system conditions (operating point, topology and system parameters), fault structure (type and location) and postfault conditions that themselves are dependent on the protective relaying policy employed. It would be highly desirable to define this relation analytically but the diversity of variables makes this task extremely complicated.

In this work we adopt the approach based on singular solution of power flow equations, starting with an initial value of CCT, the transient instability is reached when the Newton Raphson algorithm doesn't converge .We repeat the simulation for several values of CCT on restructuring the interval of research using dichotomy method.

IV. FLEXIBLE AC TRANSMISSION SYSTEMS

Power electronic network controllers, the so called FACTS-devices, are well known having several years documented use in practice and research. Several kinds of FACTS-devices have been developed.

In order to promote the integration of wind farms into the electrical network, Flexible AC Transmission Systems, FACTS, are widely used. The Static Compensator (STATCOM) is one of them [8], in this section a review of its modeling and how it is introduced in power flow calculation are developed.

A. Modeling of STATCOM

The STATCOM is a shunt-connected reactive power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. A single- line STATCOM power circuit is shown in Fig. 2

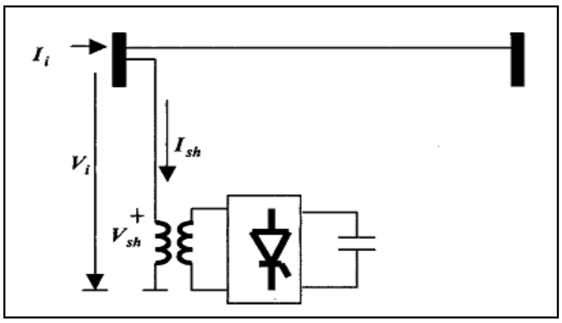

Figure 2. Static compensator (STATCOM)

On the other hand, In Fig. 2, the STATCOM is seen as an adjustable voltage source behind a reactance meaning that capacitor banks and shunt reactors are not needed for reactive power generation and absorption, thereby giving a STATCOM a compact design, or small footprint, as well as low noise and low magnetic impact [10].

B. Introduction of STATCOM in power flow calculation

Usually the power flow equations are represented by active power (P_k) and reactive power (Q_k) injection at bus k defined in the following equations [10]:

$$P_k = \sum_{j=1}^{N} |V_k||V_j||Y_{kj}|\cos(\delta_k - \delta_j - \theta_{kj}) \quad (5)$$

$$Q_k = \sum_{j=1}^{N} |V_k||V_j||Y_{kj}|\sin(\delta_k - \delta_j - \theta_{kj}) \quad (6)$$

Where $|V_k|\angle\delta_k$ and $|V_j|\angle\delta_j$ represent the complex voltage of a generic Bus k and Bus j respectively and $|Y_{kj}|\angle\theta_{kj}$ represents the (k, j)-entry of the Y-matrix. The above set of power flow equations are iteratively solved using the linearized Jacobean equation given by Fig. 3, where the sub-Jacobean matrixes are defined as $J1 = \partial P/\partial\delta$, $J2 = \partial P/\partial|V|$, $J3 = \partial Q/\partial\delta$ and $J4 = \partial Q/\partial|V|$.

ΔP and ΔQ are bus active and reactive power mismatches while $\Delta|V|$and $\Delta\delta$ are bus magnitude and angle, respectively.

The presence of FACTS controllers is accommodated and accounted for by adding new equations to the set of the power flow equations and modifying some of the existing power flow equations as needed. The Jacobean equation is extended/modified accordingly shown as follow:

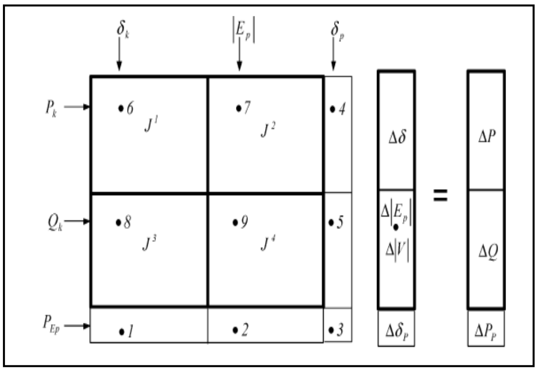

Figure 3. Augmented Jacobean Matrix

The equations for P_p and Q_p are found to be:

$$P_p = +G_p|V_k|^2 - |V_k||E_p||Y_p|\cos(\delta_k - \delta_p - \theta_p) \quad (7)$$

$$Q_p = -B_p|V_k|^2 - |V_k||E_p||Y_p|\sin(\delta_k - \delta_p - \theta_p) \quad (8)$$

Where $|E_p|$, δ_p, $|Y_p|$ and θ_p are defined in Fig. 3 and other variables were previously defined, addition of STATCOM introduces two new variables ($|E$p$|$ and δp); however, $|Vk|$ is now known. Thus, one more equation is needed to solve the power flow problem. This equation is found using the fact that the power consumed by the source E_p (called P_{Ep}) must be zero in steady state.

The original Jacobian matrix must be modified to reflect (7) and (8). All entries of the column related to $|E_p|$ are made zeros except for elements 7 and 9 as shown above. All other elements of the Jacobian matrix remain unchanged. Further details are given in [10].

V. CASE STUDY

In this work we considered the current data base of Algerian power system network. Particularly, we focus on its western region which includes several departments like: Oran, Mustaganem, Tlemcen, Bechar, Tiaret, Naama, Ghazawat, Mascara; as Fig. 4 denotes.

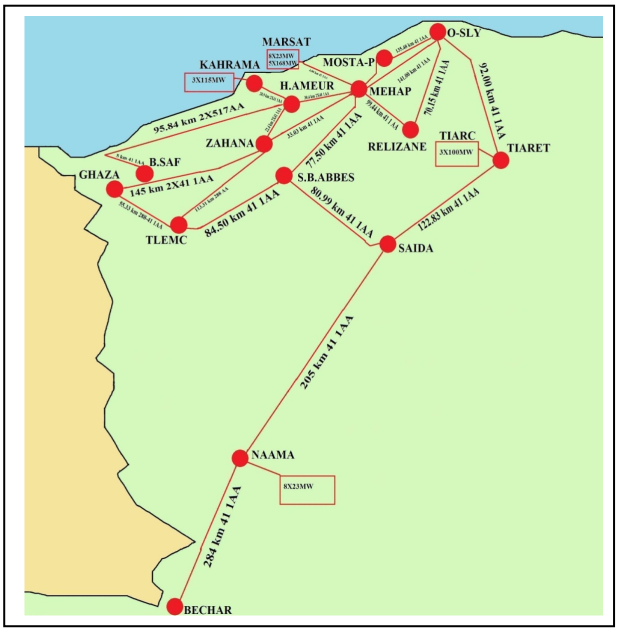

Figure 4. Case Study

It consists of 15 buses, 17 branches (lines and transformers) and 4 generators where the wind power source is connected at Bus N°11.

STATCOM parameters: 500 KV, ±100 MVAR, R = 0.071, L = 0.22, V dc = 40 kV, C dc = 375 ± μ F, Vref = 1.0 p.u. The STATCOM used in this study is operating point changes from fully capacitive (+100 MVAR) to fully inductive (-100 MVAR), the maximum voltage is 500 kV and Vref=1.0 p.u. Voltage base: U_{base}=200 kV. Power base: S_{base}=100 MVA.

VI. RESULTS AND DISCUSSION

This study has been performed in two parts. In the first part, the aim is the computation of the maximum amount of wind power penetration which is evaluated based on time-domain simulation studies in the PSAT 2.1.6/MATLAB software environment, in the second part, the work focuses on enhancement of rate penetration level of wind power in Algerian power system network by introducing a STATCOM device.

Above all, an adequate choice of wind turbine referred to transient stability behavior is desirable.

A. *Choice of wind turbine*

In order to determine the effect of type of generator technology to transient behavior of grid, three main types of generators are studied with keeping the same fault which is a three phase symmetrical fault in the same location then the critical clearing time (CCT) corresponding is computing .The CCT can be determined using transient simulations in cases quoted above.

Case 1: A squirrel cage induction generator

The wind source is connected to Tiaret Bus in accordance with above study. Fig. 5 shows the speed rotor of each generator in comparison for a fault clearing time close to the critical clearing time later on.

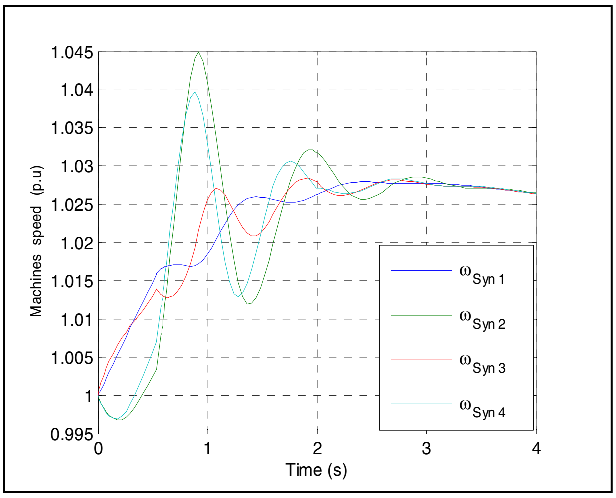

Figure 5. Generator Rotor speed at t=544 ms

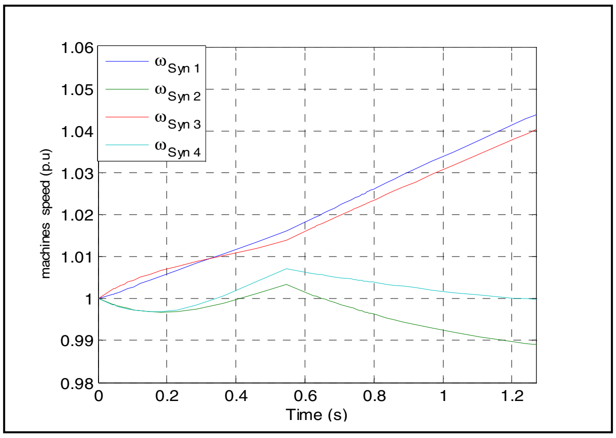

Figure 6. Generator Rotor speed at t=545 ms

As shown in Fig. 5 and 6, after 545 ms of post fault the power system network loses its stability therefore the result is CCT = 544 ms. By the same way, we deduce values of CCT for other cases shown in table I.

TABLE I. CRITICAL CLEARING TIME OF DIFFERENT WIND TURBINES GENERATOR

Wind turbine generator	A squirrel cage induction	doubly-fed induction	synchronous
CCT(ms)	498	544	475

According to results, it is very clearly that the DFIG generator increase the critical clearing time, consequently this type of generator presents best performance than a squirrel cage induction and synchronous generators concerning the transient stability of grid connected to wind power.

The induction generators used in wind farms does not participate in voltage regulation of the network. They are reactive power consumers inherently, and absorb more reactive power as they produce more active power that is why Wind power generation with DFIG provides better performance for transient stability after fault clearance owing to its ability to control reactive power.

B. Effect of wind penetration on transient stability

It must be noted that all results below are carrying out with considering the wind turbine generator as doubly-fed induction generator (DFIG).

In this section, the effect of wind power on the rotor oscillations is investigated by gradually increasing the rate of wind source penetration (from 40 to 240 MW) while observing the transit behavior of system with keeping a same value of total grid power 1275 MW.

C. Influence of STATCOM

In this section, a STATCOM is introduced in order to checking its influence on wind power penetration where after several simulations important results are carrying out. Table II showed clearly that the effect of wind power on oscillations depends on the rate of wind power penetration; it oscillations depends on the rate of wind power penetration; it has been proven that a maximum amount of wind power allowed is 240 MW which represents 19% total grid power without STATCOM.

TABLE II. CCT FOR DIFFERENT RATES OF WIND POWER PENETRATION WITHOUT STATCOM

Installed capacity of Wind sources (MW)	40	80	120	160	200	240	>240
Rate of wind sources penetration (%)	3.14	6.27	9.41	12.55	15.69	18.8	≥ 19
Corresponding CCT (ms)	544	432	268	123	98	67	00

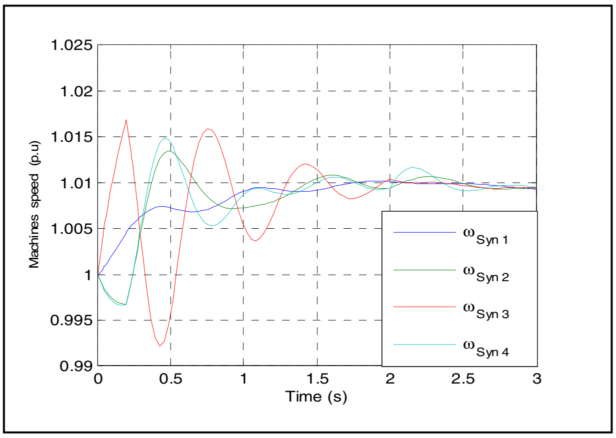

Figure 7. Generator Rotor speed at t=126 ms

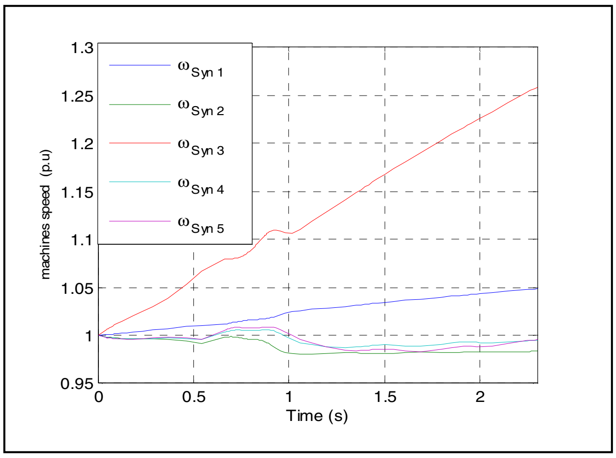

Figure 8. Generator Rotor speed at t=127 ms

TABLE III. CCT FOR DIFFERENT RATES OF WIND POWER PENETRATION WITH STATCOM

Installed capacity of Wind sources (MW)	240	260	280	>280
Rate of wind sources penetration (%)	18.82	6.27	21.96	≥ 22
Corresponding CCT (ms)	125	87	43	00

Referred to critical clearing time's values after introducing STATCOM device, we can conclude that the rate of wind source penetration has enhanced from 19 % to 22 % as shown in Table III which means that western Algerian power system will be able to accept the amount of wind power limit equal to 280 MW instead 240 MW without losing its stability.

As Fig. 9 and Fig. 10 showed, it's clearly that voltage magnitude profile of the case study is improved after STATCOM integration, especially in the bus which the wind power station is connected where the voltage magnitude is improved from 0.82 to 0.94 (p.u).

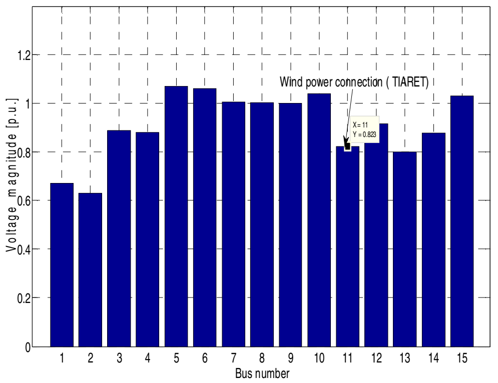

Figure 9. Voltage magnitude profile without STATCOM

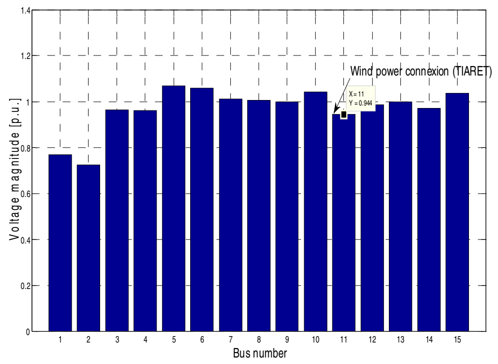

Figure 10. Voltage magnitude profile with STATCOM

The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive).When system voltage is high, it absorbs reactive power (STATCOM inductive).

VII. CONCLUSION

The increasing addition of wind power to the conventional generation system may cause some potential dangers to the grid. And without adequate knowledge of the behavior of large wind power plants, utilities are reluctant to integrate more wind power into the grid. Therefore, it is very imperative to understand the new aspects that the integration of wind power brought to the conventional system, especially the aspects of the transient stability.

In this paper, the western Power System network is modeled and simulated with PSAT/Simulink considering Wind source. The simulation results demonstrate that after using electronic converters such as STATCOM, the level of wind power penetration has enhanced from 19 % to 22 % which means that western Algerian power system will be able to accept the amount of wind power limit equal to 280 MW instead 240 MW without losing its stability.

Furthermore, it was demonstrated that the STATCOM reactive power output can also be controlled to keep the wind farm terminal voltage constant and improve a voltage magnitude profile for all buses.

In addition a comparative study was established between several types of wind turbines technology where from results, it is concluded that the Wind power generation with DFIG provides better performance for transient stability after fault clearance owing to its ability to control reactive power.

Finally, it's important to note that this work presents a first study application on a current Algerian power system network which offers an opportunity for the future studies relating to this network.

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