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Improved Dynamic Performance of Wind Energy Conversion System by STATCOM

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***Abstract*— The renewable energy plays an important role to provide electrical energy other than conventional sources. Wind power is one of the renewable energy sources used to minimize the environmental impact on conventional plant; it is one of the fastest growing sources of energy in the world. However, when the wind power is connected to an electric grid may cause problems important in terms of power quality. The effects of the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operations. the paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this paper, we propose a study of the importance use of STATCOM when it installed in a wind farm. The STATCOM is connected at a point of common coupling to mitigate the power quality issues. Simulation studies are carried out in the MATLAB/Simulink environment to examine the performance of the wind farm with and without STATCOM for improving Power Quality of wind farms connected to electrical network.**

***Keywords:* renewable energy, Wind farm, Power system, STATCOM, Power Quality**

I. INTRODUCTION

Renewable energy resources are receiving considerable attention in the continued growth and development of electric power systems, being the wind power production the fastest growing type of renewable energy [1]. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant. However, wind power may cause problems to the existing grid in terms of power quality. One of the fundamental definitions to power quality problems is any power problem manifested in voltage, current or frequency deviations that results in failure or miss operation of customer equipment. Power quality decrement is generally caused by many factors such as impulsive and transients, over voltage or under voltage variations, voltage imbalance, wave distortion, such as dc offset, harmonics, notching and noise, voltage fluctuation and frequency variations.[2]

Voltage stability has been a major concern for power system utilities because of several events of the changes in power systems such as increase in loading, generator reaching reactive power limits, action of tap changing transformers, load recovery dynamics and line or generator outages. They may cause a progressively and uncontrolled fall of voltages leading to voltage instability or voltage collapse.

The major difficulty associated to the wind energy sources is that in general they don't take part in the services system (adjustment of the voltage, of the frequency, possibility of operation in patrolling the block) whose flow is not easily foreseeable and very fluctuating.

Nowadays, the development of power electronics and microelectronics makes it possible to consider active power filters, which can provide flexible current harmonic compensation and contribute to reactive power control and load balancing [3]. Hence by implementation of the power electronic based FACTS devices ,such as Static Var Compensator (SVC) and static synchronous compensator(STATCOM) which can be effectively utilized to improve the quality of power supplied to the customers. Its principal function is to inject reactive power into the system which helps to support the system voltage profile, but it can also be used to reduce the phenomenon of flicker in the presence of fluctuating loads, to moderate the power oscillations and to increase the power transfer and to reduce the hypo-synchronous oscillations, the power system performance has improved [2].

The aim of this paper is to demonstrate the superiority of STATCOM to compensate the voltage dips presented by integration of wind turbine with Induction Generator in the grid systems 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.

II. ANALYSIS OF POWER QUALITY PARAMETERS, ISSUES AND ITS CONSEQUENCES

Power quality phenomena are the most important problem in power system which with improving of those, power system performance can be improved. In this section

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some of these phenomena like voltage sag, swell and harmonic distortion will be investigated.

A. Voltage Variation

The voltage variation issue results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under: [4]

- ✓ Voltage Sag/Voltage Dips.
- ✓ Voltage Swells.
- ✓ Short Interruptions.
- ✓ Long duration voltage variation.

The voltage flicker issue describes dynamic variations in the network caused by wind turbine or by varying loads.

B. Harmonics

The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. [4]

C. Wind Turbine Location in Power System

The way of connecting the wind generating system into the power system highly influences the power quality. Thus the operation and its influence on power system depend on the structure of the adjoining power network.

D. Self Excitation of Wind Turbine Generating System

The self excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of WTGS with local load. The risk of self excitation arises especially when WTGS is equipped with compensating capacitor. The capacitor connected to induction generator provides reactive power compensation. The disadvantages of self excitation are the safety aspect and balance between real and reactive power[5].

E. Consequences of the issues

The voltage variation, flicker, harmonics causes the mal-function of equipments namely microprocessor based control system, programmable logic controller. It may leads to tripping of contractors, tripping of protection devices, stoppage of sensitive equipments like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipment's[4].

III. WIND ENERGY CONVERSION SYSTEM

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. The mechanical power which can be extracted from the wind determines by means of the following expression [6],[7]:

$$P = \frac{1}{2}\rho S V^3 C_p(\lambda.\beta) \quad (1)$$

$$C_p(\lambda.\beta) = \frac{1}{2}(\Gamma - 0.022\beta^2 - 5.6)e^{-0.17\Gamma} \quad (2)$$

$$\Gamma = \frac{r.(3600)}{\lambda.(1609)} \quad (3)$$

Where, P is the extracted power from the wind, ρ is the air density, $S = \pi r^2$ is the surface swept by the turbine, the v wind speed, β is blade pitch angle and Cp the power coefficient. This coefficient corresponding to the aerodynamic efficiency of the turbine has a nonlinear evolution according to the tip speed ratio, λ as indicated in Table I.

Table I: Values of the coefficient Cp and λ of wind

λ	0	1.3	2.1	2.7	3.4	5	5.8	6.3
Cp	0	0.1	0.2	0.3	0.4	0.3	0.2	0.1

Where:

$$\lambda = \frac{w.r}{v} \quad (4)$$

r: is the blade length and w is the angular velocity of the turbine.

Wind turbines use squirrel cage induction generators are shown in Fig. 1. The stator winding is connected directly to the grid and the rotor driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction speed must be slightly above the synchronous speed but the speed variation is typically so small that the WTIG is considered to be affixed speed wind generator.

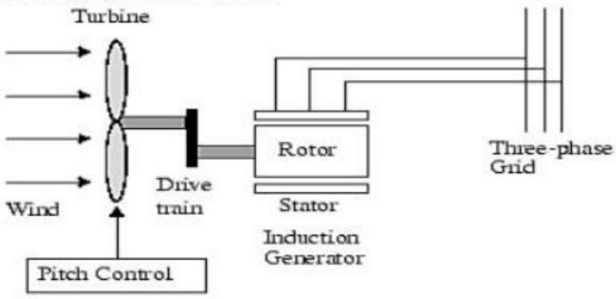

Fig. 1 Wind turbine and induction generator

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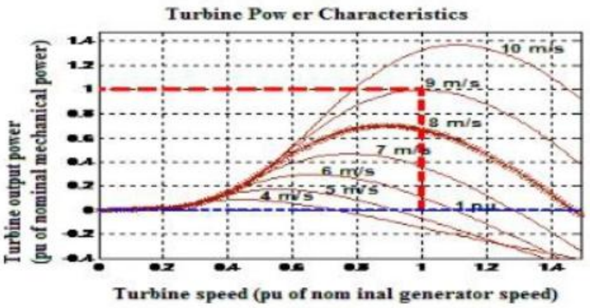

Fig. 2: Turbine characteristic with maximum power point tracking for IG

Figure number two (Fig.2) above shows wind turbine characteristic used for this study with the turbine input power plotted against the rotor speed of the turbine. The turbine mechanical power as function of turbine speed is displayed for wind speeds ranging from 4 m/s to 10 m/s.

IV. Static synchronous compensator (STATCOM)

A. Definition ,principle operating and control strategy

According to the IEEE, The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids and enhances the capacity of the transmission line. These controllers are fast and increase the stability operating limits of the transmission systems when their controllers are properly tuned [9].

The STATCOM is a FACTS controller based on voltage sourced converter (VSC) and a source of storage for the DC side [10]. A VSC generate a synchronous voltage of fundamental frequency, controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer, the resulting STATCOM can inject or absorb reactive power to or from the bus to which it is connected and thus regulate the bus voltage magnitude.

When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).

The variation of reactive power is performed by means of a Voltage -Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source. The principle of operation of the STATCOM and its control strategy is detailed on the figure below (fig.3). this figure show the active and reactive power transfer between a source V_1 and a source V_2. In this figure, $V_1\angle$ represents the system voltage to be controlled and $V_2\angle$ h is the voltage generated by the VSC. The terminal voltage of STATCOM must keep synchronous with the system voltage. Their amplitude and angle relations decide STATCOM to offer system power or absorb power from the system. [6],[7],[8]

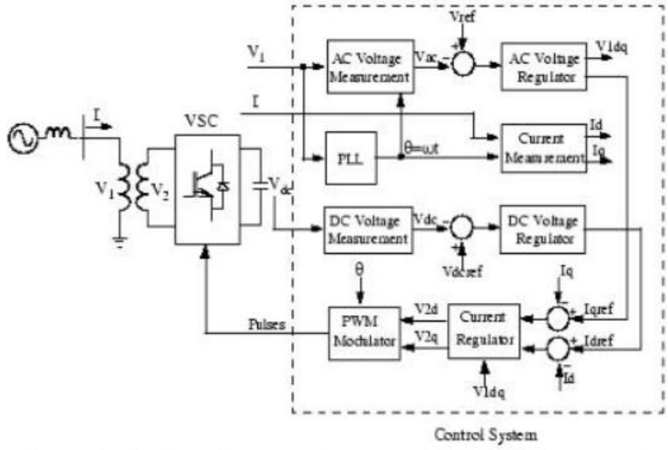

Fig.3: Single-line Diagram of a STATCOM and Its Control System Block Diagram

The real and reactive power (P and Q) flow from STATCOM to system bus is given by following equations [11],[12]:

$$P = \frac{V1V2 \sin \delta}{X} \quad (5)$$

$$Q = \frac{V1(V1 - V2 \cos \delta)}{X} \quad (6)$$

Where, X is the equivalent reactance of coupling transformer, and is angle of $V_1$with respect to V_2.

The power flow situation between STATCOM and the AC power system is presented in Table II. In general, STATCOM is usually used for reactive power compensation, which means that the angle α and real power P are small value, just only replenish the internal losses of the inverter and transformer and keep the capacitor voltage at the desired level in steady-state.[13] The mechanism of phase angle adjustment can also be used to control the VAR generation or absorption by increasing or deceasing the capacitor voltage, and thereby the amplitude of the output voltage produced by the STATCOM.

Table.II: power exchange between STATCOM and AC system

Voltage relation	**Power exchange** **STATCOM ⟺ AC system**
V2> V1	**Q:** STATCOM →AC system
V1 < V2	**Q:** STATCOM ← AC system
Angle relation	
$\alpha < 0$	**P:** STATCOM ← AC system
$\alpha > 0$	**P:** STATCOM → AC system

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The amount of reactive power exchange is decided by STATCOM voltage and system voltage. When the inverter voltage V_2 is higher than the system voltage V_1, the STATCOM is considered to be operating in a capacitive mode, and STATCOM generates reactive power to the system. Similarly, when the inverter voltage V_2 is lower than the system voltage V_1, the STATCOM is considered to be operating in an inductive mode, and STATCOM absorbs reactive power from the system. Finally if the modules of V_1 and V_2 are equal, there won´t be neither current nor reactive flow in the system. The amount of reactive can be given as: [14],[15]

$$Q = \frac{V_1(V_1 - V_2)}{X} \quad (7)$$

In summary, by controlling the amplitude and the phase angle of the V_2 voltage source, the direction of flow of active and reactive power to the node where STATCOM connected can be controlled.

- The active power flow is controlled by the phase angle between the V_1 and V_2 tensions.
- The reactive power flow is controlled by acting on the amplitude of the voltage V_2.

V. SIMULATION RESULTS AND DISCUSSION

To verify the performance of the proposed wind generation system with and without STATCOM, simulation tests have been carried out by MATLAB SIMULINK software in following conditions:

Case 1: Disturbance state results without compensation (STACOM and PFC (Power Factor Capacitor) are not included)

Case 2: performance the system under fault (0.1 sec.) at Generator 2 (wind generation system 2) with and without STATCOM (PFC now is included)

Case 3: performance the system under Three Phase Fault (0.1 sec.) at Generator 2 with STATCOM 3Mvar and STATCOM 30Mvar

For our case, we used a six-1.5MW wind turbines connected to 25-kV distribution system that is simulated as an ideal 3-phase voltage source of constant voltage and frequency through 25 km. The STATCOM (3Mvar) is connected near the midpoint of the system to increase the WTG damping and to provide support to the system during fault conditions.

A. Case 1: Simulation results without compensation

The first test (Figure 4 without compensation) is done without intervention of any compensation (no STACOM and no PFC), to the end of the simulation set during 20s, observes that the voltage at the connection node B25 is less than 1 pu, it is around 0.94 which is caused by fluctuations due by the variation Wind This is influes on the active power that presented in the form of an oscillatory signals and stabilizes at 6MW, and dropped reactive power until the value of 4Mvar [16],[17]

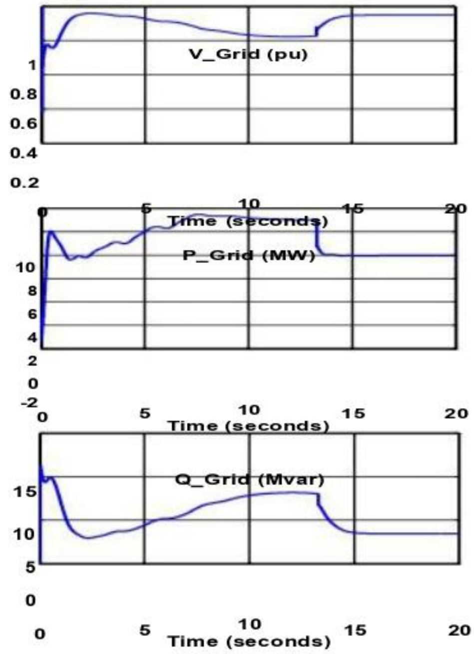

Fig. 4: The impact integration of wind turbine

B. Case 2: Simulation results under fault with and without compensation

In the second test frame, we use an STATCOM for the need of provision of good power quality, to see the performance and the profitability of this type of FACTS.

At t=15 s, a phase to phase fault is applied at wind turbine 2 terminals, causing the turbine to trip at t=15.11 s.

Only wind turbine 3 continues to work, and wind farm 1 is tripped at t=13.43sec because of over current protection and wind farm 2 is tripped because of under voltage protection.

Therefore, the third wind turbine is responsible for supplying active and reactive power and delivering them to 25kV bus that after fault occurrence on t=15sec. The reactive power is injected to the 25kV bus via 400kvar fixed capacitor, which is connected to terminal wind turbines. After fault clearance, the reactive power injection decreases.

After the simulation during 20s, the set of signals about voltage, current and active power /reactive are shown in Figure 5 (with compensation)

Observing the Fig.5.a and Fig.5.b it can be seen that angle oscillations starts at the moment of fault (that is 15 s), then at the moment of tripping of wind turbine 2 starts to oscillate again and reaches steady state value approximately at t=15.2 sec. This means that from the time of the failure, and

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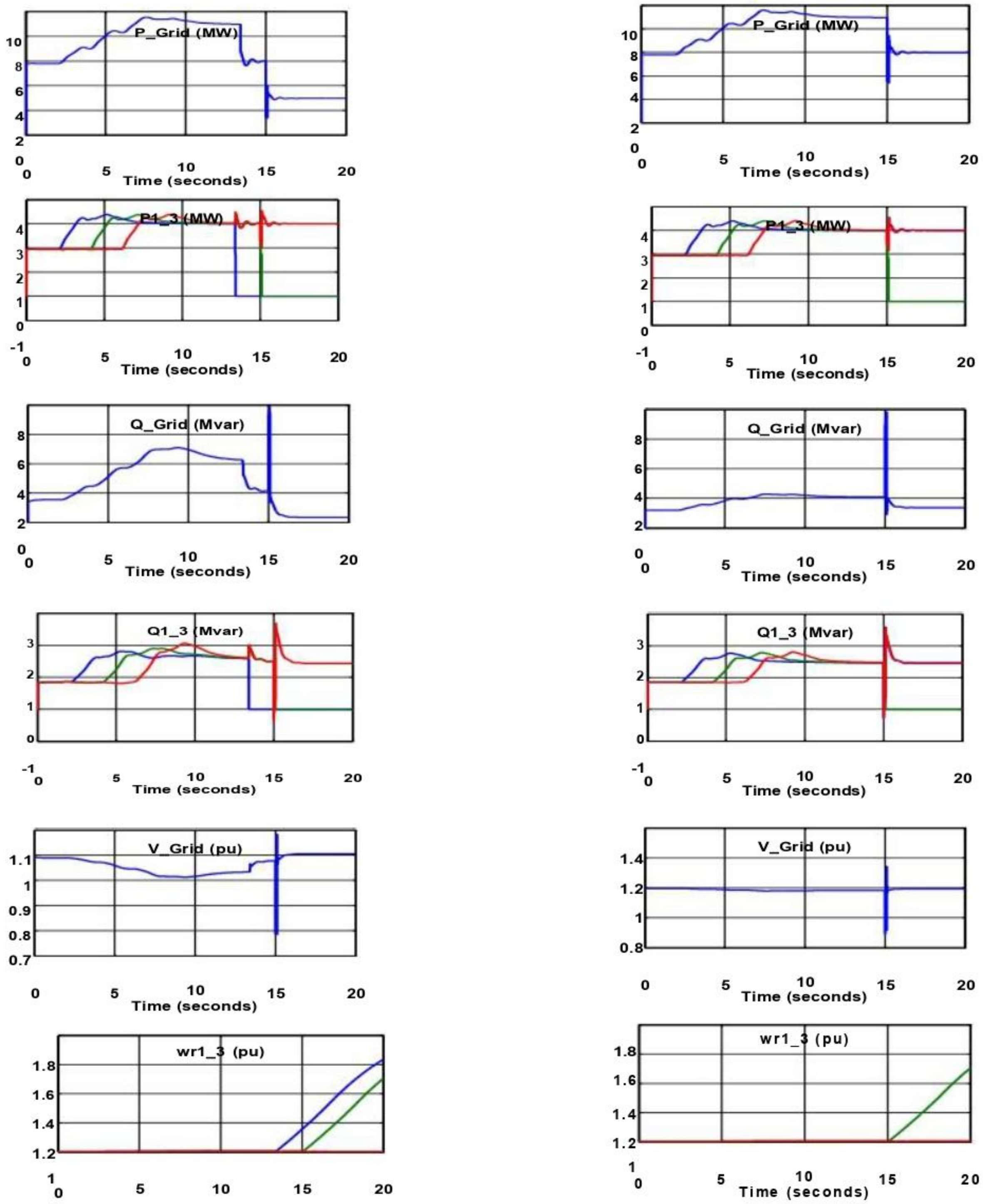
tripping wind farm 2 has passed around 0.2 sec, and change of voltage angle shows that system will remain stable.

For Figure 5, notes that the device of compensation used in this study presents -the STATCOM- power to intervene on wind behavior where compensates for fluctuations in the power and wind speed and the rating may power stability reactive thereof.



A: without STATCOM (PFC now is included)

B: with STATCOM (PFC now is included)

Fig. 5: Performance the system under fault at Generator 2

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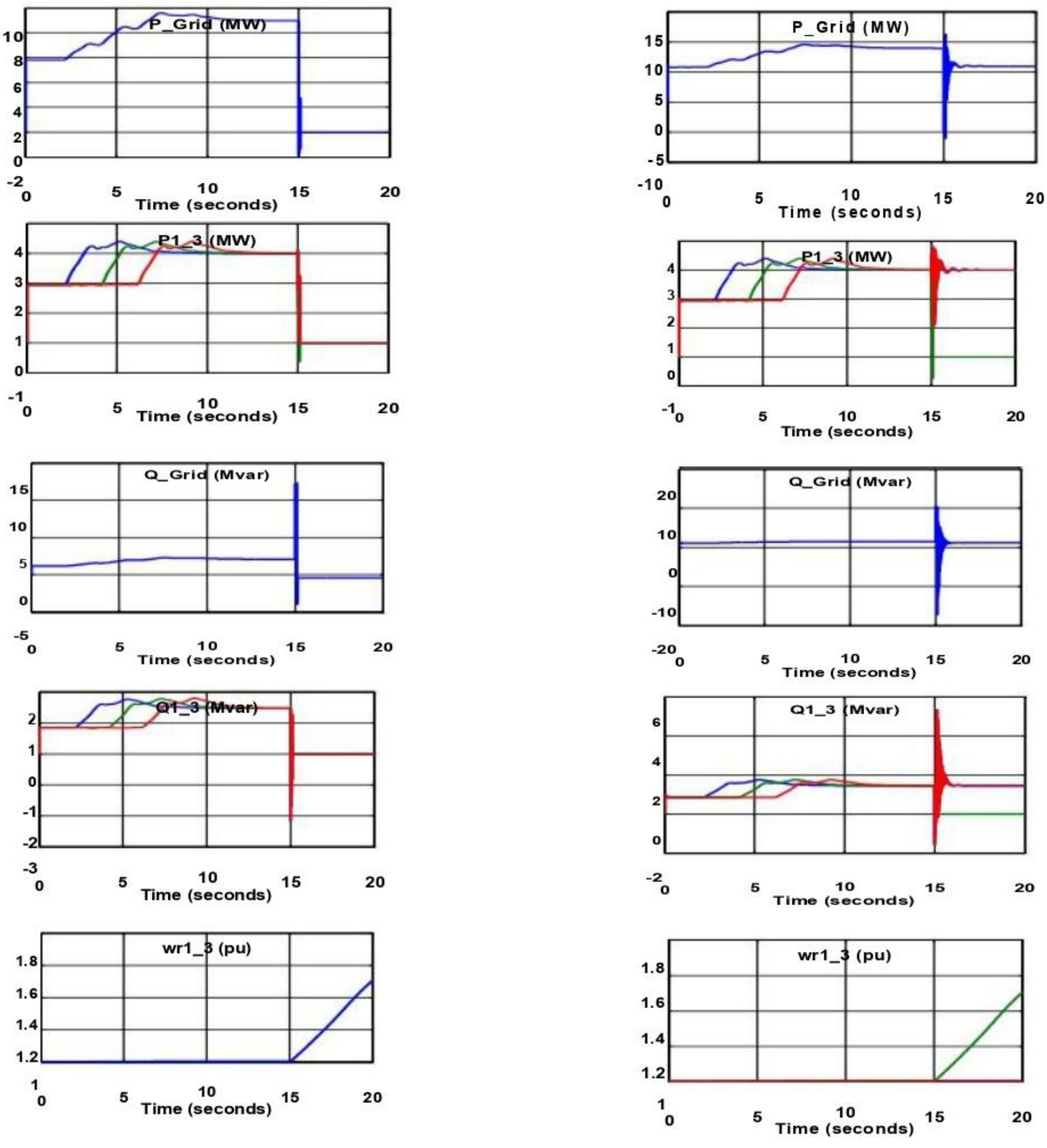
C. Case 3: Simulation results under Three Phase Fault (LLL fault) with STATCOM 30Mvar

In the Third test, the studied system was subjected to three phase fault occurred at wind turbine 2 only and cleared after 100ms from 15sec. Without STATCOM, it is clear that the first wind turbine is tripped because of the lack of reactive Power support, the voltage at bus 25kV, drops to 0.91pu at t =13.43sec. Then the occurrence of three phase fault, which the wind turbines 2, and 3 will begin to accelerate. Two wind turbines are tripped by protection system as shows Fig 6(a) at t=15.1sec and t=15.11sec respectively,



A: with STATCOM 3 Mvar

B: with STATCOM 30Mvar

Fig. 6: Response of the system under LLL fault (0.1 sec.) at Generator 2 with STATCOM

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When STATCOM 3Mvar is connected, three wind turbines cannot continue its service because of insufficiency capacity of STATCOM to supply necessary reactive power and it is tripped as Fig. 6(a), it is seen that active power of 25kV bus power decrease to zero. After fault occurrence on t=15sec.

With increase in capacity of STATCOM from 3Mvar to 30Mvar, the wind park remains in normal operation and the wind system restores back to initial state after duration of post-disturbance period. On the other side, in case of 3 MVAR STATCOM the delivered reactive power to the grid is still decreased to zero and the wind system is disconnected from the grid using the protection systems.

VI. CONCLUSION

This paper has demonstrated the effect of wind energy generation in power systems and its impacts on power quality of distribution system due to the uncertain characteristics of wind turbine system which causes variations in system voltage. Flexible AC Transmission System (FACTS) device such as Static Compensator "STATCOM" is power electronic based switch is used to control the reactive power and therefore bus voltages. Hence STATCOM was used to inject reactive power to maintain voltage level within limits and also eliminates power fluctuations and this confirms the excellent performance of the proposed system for power quality improvement.

Results are presented to show that the studied wind farm cannot stay connected under the studied voltage dip without STATCOM connection to its terminal and, with low rating STATCOM, while through 30 MVAR STATCOM connections at the main bus of the studied wind farm, it can stay connected and hence power quality of the entire power system due to integration of STATCOM with wind generation is improved.

REFERENCES

[1] Maheswari Muthusamy, Sathish kumar C, "New STATCOM control scheme for Power Quality improvement in wind farm '' ,Hindustan University, Padur, Chennai

[2] Author1a, *, Author2b, Author3c , "Contribution of SVC to Improve Voltage Profile in a Wind Generators Connected Electrical Network with Increased Load Demand", International Conference on Emerging R esearch in Computing, Information, Communication and Applications (ERCICA-13)

[3] Haniyeh Marefatjou, Mohammad Sarvi ,''Power Flow Study and Performance of STATCOM and TCSC in Improvement Voltage Stability and Load ability Amplification in Power System'' , International Journal of App lied Power Engineering (IJAPE) Vol. 2, No. 1, April 2013, pp. 15~26

[4] R. Vibin1, K. Malarvizhi2 , " Power Flow Control Scheme for Wind Energy Conversion System using FACTS Controller ",International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.3, May-June 2012 pp-644-648

[5] N.Nirmala, V.Suresh Kumar, "A STATCOM-Control Scheme for Wind Energy System to Improve Power Quality".

[6] M. N. Tandjaoui,C. Benachaiba, O. Abdelkhalek, B. Dennai, '' Renewable energy and its impact in power quality of distribution systems'', College of Applied Sciences. Umm Al-Qura University Makkah, April 16-18, 2012

[7] M. N. Tandjaoui, M. Haidas & C. Benachaiba, "Intégration des éoliennes pour la Production d'Energie Electrique en Algérie - Site Tindouf-"SIPE'10, Journal of Scientific Research N° 0 vol. 1 (2010.)

[8] Okedu K. E., A Study of Wind Farm Stabilization Using DFIG or STATCOM Considering Grid Requirements, 2010, jestr 3(1), pp. 200-209.

[9] Huang Shao-Ping, Li Yong-Jian, Jin Guo-Bin, Li Ling, "Modeling and Dynamic Response Simulation Of GTO-Based STATCOM", 2010 International Conference on Electrical and Control Engineering, DOI 10.1109/iCECE.2010.321

[10] K. Merini, F.Z. Gherbi, S. Hadjeri, K.F. Elatrech , ''Study the best location of STATCOM to improve the voltage'' Sidi Bel Abbes, Algeria

[11] Guizhen Tian, Shengtie Wang, Guangchen Liu ,''Design and Realization of STATCOM for Power Quality Improvement of Wind Turbine with Squirrel-cage Induction Generator'', 2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia June 2-5, 2012, Harbin, China

[12] R. F. Kerendian, M.M Manzari Tavakoli ,M. Ataei D. Apra ''Controlling Harmonic of STATCOM'', International Journal of Science and Advanced Technology (ISSN 2221-8386) Volume 2 No 4 April 2012 http://www.ijsat.com

[13] Tzeng-Shong Yeh, Huang-Fu Jhu , Hsiao-Wei Sung, ''Modeling and Control of Three-Phase Multilevel Inverter-Based STATCOM'',2nd IEEE International Symposium on Power Electronics for Distributed Generation Systems , 2010

[14] D.K Sharma , Aziz Ahmad , Richa Saluja , Reena Parmar ''Voltage Stability in Power system Using STATCOM'', International Journal of Electronics and Computer Science Engineering, Available Online at www.ijecse.org

[15] ADITYA JAYAM PRABHAKAR ,'' application of STATCOM for improved dynamic performance of wind farms in a power grid '' MISSOURI university . 2008.

[16] Mekkaoui Ali, Laouer Mohamed ,''Etude de l'effet compensatoire d'un parc éolienne à vitesse fixe '',The INTERNATIONAL CONFERENCEONELECTRONICS&OIL March 05-06, 2013, Ouargla, Algeria

[17] BOUHADOUZA Boubekeur ''Amélioration de la Stabilité Transitoire des Fermes Eoliennes par l'utilisation du STATCOM'', thèse Magister UNIVERSITE FERHAT ABBAS

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