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Static compensator for maintaining voltage stability of wind farm integration to a distribution network

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ABSTRACT

Electricity generation from wind has grown sharply and its growth potential is still significant. However, the decentralized nature of the wind opposes the historically centralized structure of national networks. Unlike conventional sources, wind does not provide reactive power, which is necessary to maintain acceptable voltage conditions on the network. The use of Flexible AC Transmission Systems (FACTS) in distribution network to compensate for vagaries such as production related to wind energies and to control the voltage is an optimal solution.

This paper is aimed at presenting a point of view on the wind power generation control issues. 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, i.e., 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.

1. Introduction

The main problem regarding wind power systems is the major discrepancy between the irregular character of the primary source (wind speed is a random, strongly non-stationary process, with turbulence and extreme variations) and the exigent demands regarding the electrical energy quality: reactive power, harmonics, flicker, etc. Thus, wind energy conversion within the parameters imposed by the energy market and by technical standards is not possible without the essential contribution of automatic control.

The increased share of wind in electricity generation makes more and more complex integration in the system of electricity transmission [1,2]. The fluctuating and unpredictable nature of wind generation complicates network management: the presence of replacement capacity [3–5] is needed to offset periods of low production of wind turbines, because, the wind generator did not participate in the supply/demand balance or maintenance frequency, and does not provide reactive power, which is necessary to maintain acceptable voltage conditions on the network. In periods of high wind, stopping of conventional power plants in favor of wind power can result in a shortage of reactive power. This deficit must be offset by dedicated devices. For these reasons, the rate of wind in the electricity production beyond who are the fluctuations of the production become very complex to manage is estimated between 20% and 30% of the total power.

It may be more advantageous for the network operator to invest in means of production of reactive energy that reward the production of energy by independent producers. Especially since the compensators are free to be displaced in the network to respond to changes in operating conditions. Such systems are to be considered in decentralized networks to overcome the vagaries of production.

Technological innovations based on power electronics, which are the FACTS devices such as STATCOM allow the parks to participate in system services through, inter alia, the remote control and output voltage adjustment [6,7]. The introduction of remote control and operating systems, can further contribute to increasing the reliability of power systems and to improving the quality of the so-called "electricity" product.

2. Purpose of the work

Wind turbines can have considerable fluctuations in the output power, due to the stochastic nature of the wind. As a result of that,

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the grid suffers slow voltage flickers and current variations that are large enough to be detected as flickers in fluorescent lights.

The flicker mitigation of grid-connected wind turbines is realized by using auxiliary devices, such as reactive power compensation and energy-storage equipments. Various papers have suggested methods to control the bus voltage with FACTS devices such as Static Var Compensator (SVC) and Static Compensator (STATCOM) on the system. Examples of using Static Var Compensator (SVC) for flicker mitigation can be found in the literature [8–10]. The use of STATCOM is shown to be superior of that of SVC [11], with respect to flicker mitigation.

This paper contributes to modeling and numerical simulation of the new direction which is the contribution to improve the voltage profile in an electrical network with wind generator using STATCOM. This new device has been reported in technical papers in various journals, but no one has been published on this subject.

3. Power extracted from the wind

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 [1,2,12,21].

The aerodynamic power which can be extracted from the wind determines by means of the following expression:

$$P_t = \frac{1}{2}\cdot\rho\cdot S\cdot v^3\cdot C_p(\lambda,\beta) \tag{1}$$

Where ρ is the air density, S the surface swept by the turbine, the v wind speed and C_p, the power coefficient.

This coefficient corresponding to the aerodynamic efficiency of the turbine has a nonlinear evolution according to the tip speed ratio, λ.

$$\lambda = \frac{\Omega_t\cdot R_t}{v} \tag{2}$$

Where R_t is the blade length and Ω_t is the angular velocity of the turbine.

4. Voltage stability

The term "power quality" in relation to a wind turbine describes the electrical performance of the wind turbine electricity generating system. The main influences of a wind turbine on the power and voltage quality are voltage changes, fluctuations – leading to flicker – and harmonics for wind turbines with power electronics [3,11].

The flickers caused by wind fluctuations may be of concern in low-voltage transmission lines connecting to the grid. The voltage drop related to power swing is small in high-voltage lines because of the small current fluctuation for a given wind fluctuation.

4.1. *Voltage profile improvements*

The shunt capacitors reduce the amount of inductive current in an electric circuit. The reduction in the line current decreases the R.I and X.I voltage drops, thereby improving the voltage level of the system from the capacitor location back to the source. In both the distribution and transmission systems, there is a need to maintain a voltage in the range 0.95–1.05 pu. Therefore, maintaining acceptable voltage levels in the power system is an important objective. A one-line diagram of a power system for the voltage drop analysis is shown in Fig. 1.

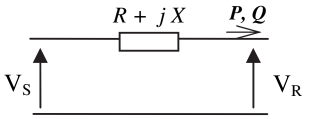

Fig. 1. Simplified equivalent diagram of a line.

The phase diagram of the system without shunt capacitors is shown in Fig. 2.

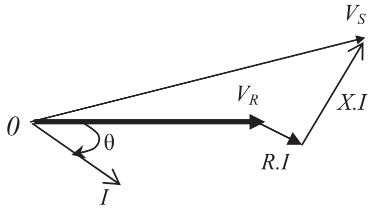

Fig. 2. Phase diagram of the system without shunt capacitor.

For the very simple case of a load fed through a line by a source of constant voltage (Fig. 1), the voltage drop in line ($\Delta V = V_S - V_R$), can be writing in an approximate way as [13]:

$$\Delta V = \frac{RP + XQ}{V_R} \tag{3}$$

P and Q respectively are the active and reactive powers flow on the line. The corresponding voltage relations are [5]:

$$V_R = V_S - I(\cos\theta \pm j\sin\theta)\cdot(R + jX) \tag{4}$$

Where,

V_S: sending end, voltage/phase
V_R: receiving end, voltage/phase
I: line current, A
R: resistance, Ω/phase
X: reactance, Ω/phase
θ : power factor angle, degrees

For the high-voltage lines, $X \geq 10.R$ the expression (3) can thus be simplified:

$$\Delta V = \frac{XQ}{V_R} \tag{5}$$

The active power generated by the wind generators is fluctuate by nature, which tends according to the expression (3) to induce fluctuations of voltage in the zone of the network close to the point of connection of these wind generators. In the transmission network, made up of high-voltage lines, the expression (5) shows that the variations of voltage are induced by the reactive power transits contrary with the distribution networks.

The phase diagram of the system with shunt capacitors is shown in Fig. 3. The corresponding current relations are:

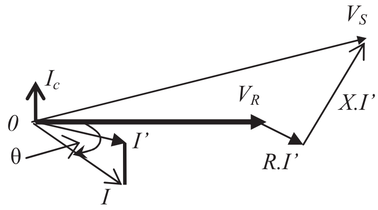

Fig. 3. Phase diagram of the system with shunt capacitor.

$$I' = I(\cos\theta \pm j\sin\theta) - jI_C \tag{6}$$

Where the capacitor current is $I_C = V_R/X_C$

The improved voltage profile at the load is due to the decrease in the line current and reduced voltage drop.

4.2. *Static compensator (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. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. A STATCOM is a controlled reactive power source.

It provides the desired reactive power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage source converter (VSC). A single-line STATCOM power circuit is shown in Fig. 4, where a VSC is connected to a utility bus through magnetic coupling. In Fig. 5, 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 [3,4,14].

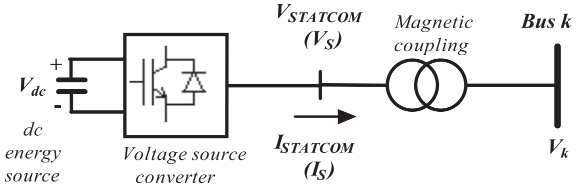

Fig. 4. Static compensator (STATCOM) system.

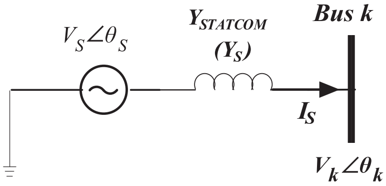

Fig. 5. Equivalent circuit.

A STATCOM can improve power system performance in such areas as the following:

- The dynamic voltage control in transmission and distribution systems
- The power-oscillation damping in power-transmission systems
- The transient stability
- The voltage flicker control, and
- The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

4.3. *Principle of operation*

The exchange of reactive power is done by regulating the output voltage of the inverter $V_{STATCOM}$ (V_S), which is in phase with the mains voltage V_k. The operation can be described as follows (Fig. 6):

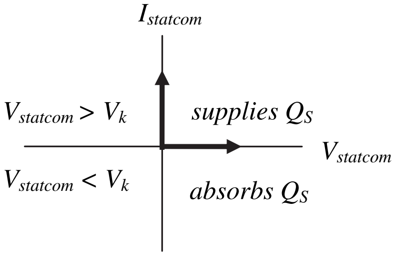

Fig. 6. STATCOM operation.

- If the voltage V_S is below V_k, the current through the inductor is phase shifted in relation to the voltage V_k which provides an inductive current, then Q_S becomes positive and the STATCOM absorbs reactive power.
- If the voltage V_S exceeds V_k, the current through the inductor is phase shifted in relation to the voltage V_k which provides a capacitive current, then Q_S becomes negative and the STATCOM generates reactive power.
- If the voltage V_S is equal to V_k, the current through the inductor is zero and therefore there is no exchange of energy.

4.4. *STATCOM power flow modeling*

The insertion of FACTS in power systems usually requires a numerical simulation study to prepare this integration. To do this, FACTS devices, as well as networks in which they appear, must be modeled. If the numerical simulation is designed to size the FACTS in determining the stresses in the latter, the internal behavior of FACTS should be taken into account in modeling using Newton–Raphson algorithm [14–17].

The STATCOM has the ability to either generate or absorb reactive power by suitable control of the inverted voltage $|V_S|\angle\theta_S$ with respect to the AC voltage on the high-voltage side of the STATCOM transformer, say node k, $|V_k|\angle\theta_k$.

In an ideal STATCOM, with no active power loss involved, the following reactive power equation yields useful insight into how the reactive power exchange with the AC system is achieved.

$$Q_S = \frac{|V_k|^2}{X_S} - \frac{|V_k|\cdot|V_S|}{X_S}\cdot\cos(\theta_k - \theta_S) = \frac{|V_k|^2 - |V_k|\cdot|V_S|}{X_S} \tag{7}$$

Where $\theta_S = \theta_k$, for the case of a lossless STATCOM.

According to the equivalent circuit of the STATCOM shown in Fig. 5, suppose $V_S = |V_S|\angle\theta_S, V_k = |V_k|\angle\theta_k$, then the power flow constraints of the STATCOM are:

$$P_S = 0$$

An alternative way to model the STATCOM in a Newton–Raphson power flow algorithm is described in this section. It is a simple and efficient model based on the use of a variable voltage source, which adjusts automatically in order to achieve a specified voltage magnitude.

In this case, the nodal at which the STATCOM is connected is a controlled node where the nodal voltage magnitude and the nodal active and reactive powers are specified while the source voltage magnitude is handled as a state variable.

Based on the representation given in Fig. 5, the following equation can be written:

$$I_S = Y_S\cdot(V_S - V_k) \tag{8}$$

Where,

$$Y_S = \frac{1}{Z_S} = G_S + jB_S \tag{9}$$

The active and reactive powers injected by the source may be derived using the complex power equation,

$$S_S = V_S \cdot I_S^* = V_S \cdot Y_S^* \cdot \left(V_S^* - V_S^*\right) \tag{10}$$

Taking the variable voltage source to be $V_S = |V_S| \cdot (\cos\theta_S + j\sin\theta_S)$, and after performing some complex operations, the following active and reactive power equations are obtained [11,18]:

$$P_S = |V_S|^2 G_S - |V_S||V_k|\{G_S\cos(\theta_S - \theta_k) + B_S\sin(\theta_S - \theta_k)\} \tag{11}$$

$$Q_S = -|V_S|^2 B_S - |V_S||V_k|\{G_S\sin(\theta_S - \theta_k) - B_S\cos(\theta_S - \theta_k)\} \tag{12}$$

The power flow equations of the system with STATCOM connected to Bus k, are the same as power flow equations of the system without STATCOM for all buses, except for Bus k which are given below:

$$P_k = P_S + \sum_{j=1}^{N} |V_k| \cdot |V_j| \cdot \left|Y_{kj}\right| \cos\left(\theta_k - \theta_j - \theta_{kj}\right) \tag{13}$$

$$Q_k = Q_S + \sum_{j=1}^{N} |V_k| \cdot |V_j| \cdot \left|Y_{kj}\right| \sin\left(\theta_k - \theta_j - \theta_{kj}\right) \tag{14}$$

Where, N is the number of busbars in the power network, j represents all busbars connected to busbar k, $Y_{kj} = 1/Z_{kj} = 1/R_{kj} + X_{kj}$ is the admittance between busbars k and j, θ_{kj} is the angle of the admittance Y_{kj}

$$\begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_j} & \frac{\partial P_k}{\partial V_s} & \frac{\partial P_k}{\partial V_k} & \frac{\partial P_k}{\partial V_j} & \frac{\partial P_k}{\partial \theta_s} \\ \frac{\partial P_j}{\partial \theta_k} & \frac{\partial P_j}{\partial \theta_j} & 0 & \frac{\partial P_j}{\partial V_k} & \frac{\partial P_j}{\partial V_j} & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_j} & \frac{\partial Q_k}{\partial V_s} & \frac{\partial Q_k}{\partial V_k} & \frac{\partial Q_k}{\partial V_j} & \frac{\partial Q_k}{\partial \theta_s} \\ \frac{\partial Q_j}{\partial \theta_k} & \frac{\partial Q_j}{\partial \theta_j} & 0 & \frac{\partial Q_j}{\partial V_k} & \frac{\partial Q_j}{\partial V_j} & 0 \\ \frac{\partial P_s}{\partial \theta_k} & 0 & \frac{\partial P_s}{\partial V_s} & 0 & 0 & \frac{\partial P_s}{\partial \theta_s} \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \Delta\theta_j \\ \Delta V_s \\ \Delta V_k \\ \Delta V_j \\ \Delta\theta_s \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta P_s \end{bmatrix}$$

$$\text{With, } \Delta P = \begin{pmatrix} \Delta P_k \\ \Delta P_j \end{pmatrix} \text{ and } \Delta Q = \begin{pmatrix} \Delta Q_k \\ \Delta Q_j \end{pmatrix} \tag{15}$$

5. Modeling and numerical simulation

In this paper, the 3 buses test system is used as shown in Fig. 7. The busbar 1 is the slack bus, busbar 2 is a P, $|V|$ and busbar 3 is the P, Q bus. The wind generator is connected to busbar 3. The Newton–Raphson algorithm is applied in calculation of power systems voltage. The results are obtained for three cases of the network state:

- Network without the wind generator and the STATCOM
- Integration of the wind generator
- Integration of the STATCOM

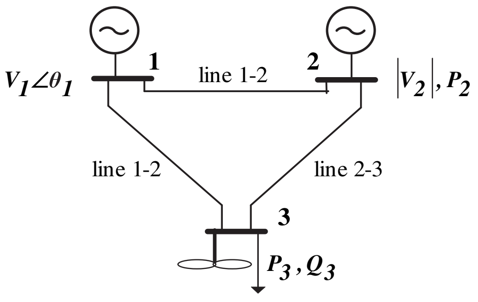

Fig. 7. Base case network with 3 nodes and wind generator.

Table 1
Line data.

Line	R (pu)	X (pu)	B (pu)
1–2	0.0200	0.0600	0.0600
1–3	0.0800	0.2400	0.0500
2–3	0.0600	0.1800	0.0400

Table 2
Busbar data.

Bus	V (pu)	θ (°)	Generation		Loads	
			P (pu)	Q (pu)	P (pu)	Q (pu)
1	1.000	0.000	0.000	0.000	0.000	0.000
2	1.020	0.000	0.400	0.000	0.200	0.100
3	1.000	0.000	0.000	0.000	0.450	0.150

The characteristics of lines and busbars of the network are summarized in Tables 1 and 2, respectively.

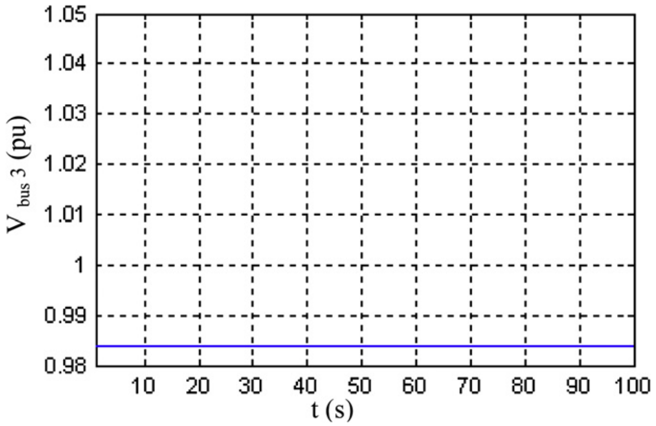

Fig. 8. Voltage magnitude at the bus 3.

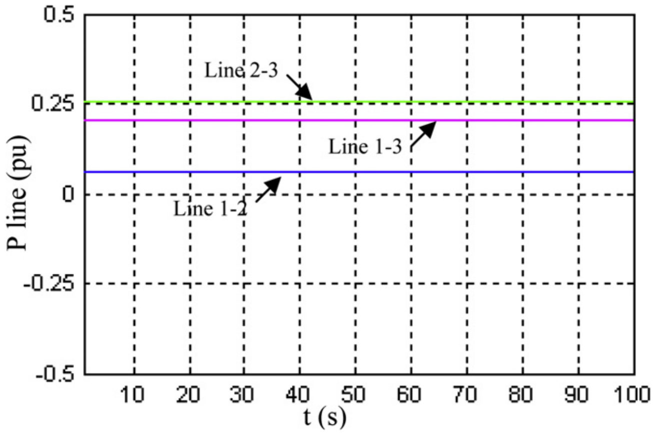

Fig. 9. Active powers flow on the lines 1, 2, and 3 before integration of wind generator.

5.1. Network without the wind generator

The voltage magnitude at bus 3 and the active and reactive powers forwarded in the lines are represented in Figs. 8–10 respectively.

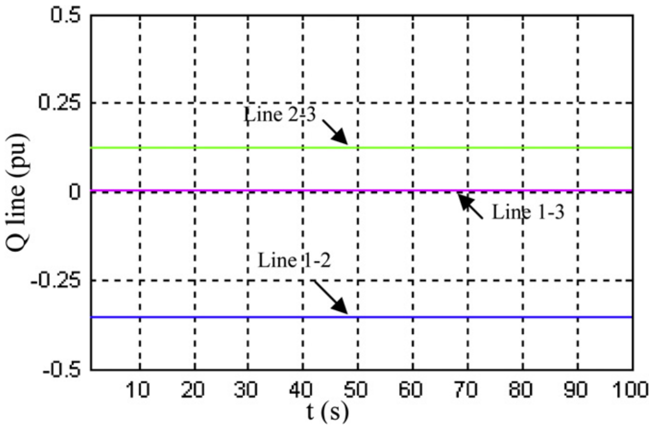

Fig. 10. Reactive powers flow on the lines 1, 2, and 3 before integration of wind generator.

5.2. Integration of the wind generator

The power provided by a wind generator is always variable, due to the wind speed variations. Other side, it is the consumer or the network who must receive a smoothed power and stable voltage. The Fig. 11 shows the pace of the active power injected by the wind generator P_{wind} inserted into the bus 3 and the Fig. 12 its influence on the voltage at bus 3.

In Fig. 12 although the voltage in busbar 3 is improved but bad quality since it is fluctuating.

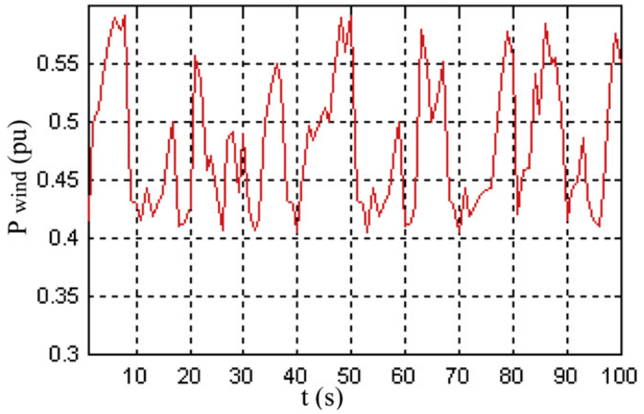

Fig. 11. Active power injected by the wind generator inserted into the busbar 3.

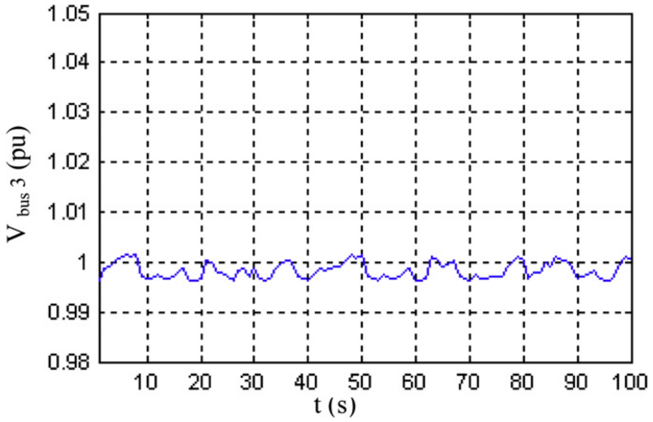

Fig. 12. Voltage magnitude at bus 3 after integration of the wind generator.

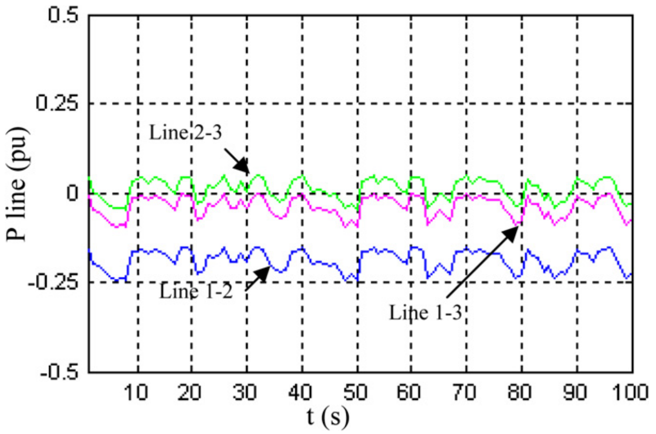

Fig. 13. Active powers flow on the lines after integration of wind generator.

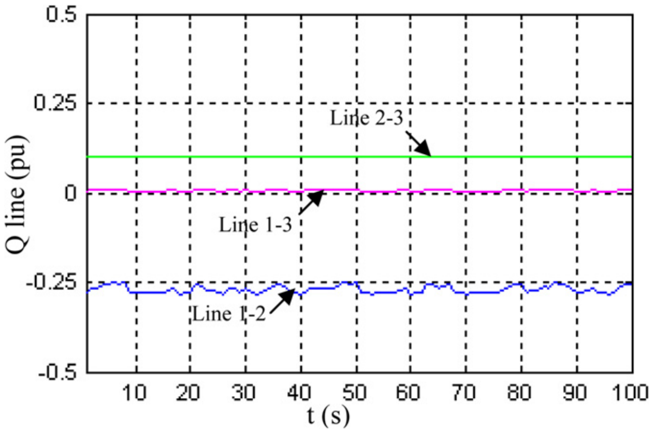

Fig. 14. Reactive powers flow on the lines after integration of wind generator.

Figs. 13 and 14 show the evolution of the active P_{line} and reactive Q_{line} powers forwarded in lines 1–2, 1–3, and 2–3 after the insertion of the wind generator in the network.

The power injected by wind 'P_{wind}' makes decrease the quality of energy and causes disturbances of the voltage busbars and power forwarded into the network. In this case, the introduction of regulation device is necessary.

5.3. Integration of the STATCOM

For the STATCOM device, the model and how the device affects the equations for calculating the distribution of power (admittance matrix, injection) are presented in the Section 4.4. To highlight the effect is inserted in the network for the case shown in Fig. 15.

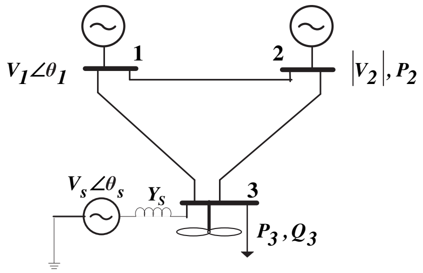

Fig. 15. STATCOM integrated in the network.

The STATCOM is introduced as a state variable in power flow and combined with the nodal voltage magnitudes and angles of the power network for iterative solutions, i.e., to find reactive power necessary for, either to compensate the hollow voltage or to decrease this value in order to obtain a stable voltage. Noting that the parameters of the STATCOM are the inductor reactance $X_S = 1.05$ pu, the voltage is initially set at $V_s = 1.00$ pu and have the phase angle $\theta_s = 0$ rd, for iteration processes.

Figs. 16 and 17 present respectively, the evolution of the voltage magnitudes at bus 3 and STATCOM after injection of the reactive power "Q_{statcom}" at bus 3, and the evolution of the reactive power under to the evolution of the active power delivered by the wind generator. Fig. 16 shows that the voltage of the node which is connected to the compensator, following the biggest changes, the voltage at busbar 3 is no longer maintained as effectively.

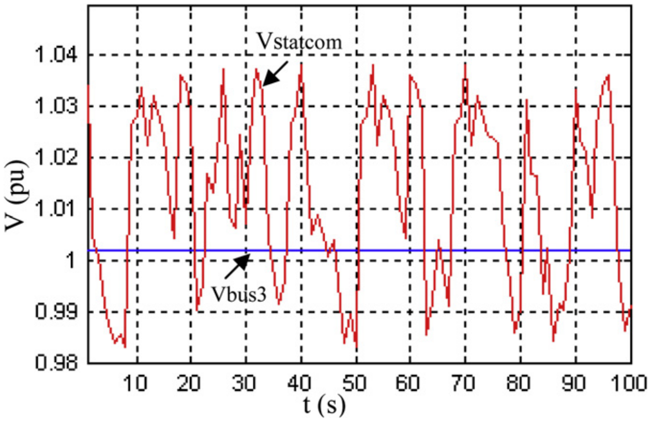

Fig. 16. Voltage magnitude at bus 3 after integration of the STATCOM and the output voltage of the inverter V_{STATCOM}.

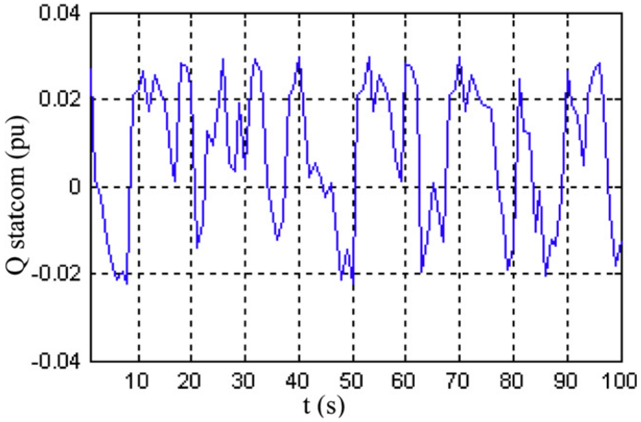

Fig. 17. Reactive power injected by the STATCOM inserted at bus 3.

The goal is to have a stable voltage at bus 3 although the variation of the power injected by the wind generator, and that by injecting or absorbing a reactive power "Q_{STATCOM}" to compensate the voltage disturbances if it exceeds the desired voltage magnitude. The results showed a better behavior with regard to the voltage support on the load busbar and the voltage drop within the limits 5%.

Fig. 18 illustrates the distribution of powers active in the network when the value of STATCOM varies (behavior capacitive and inductive behavior in relation to that). It shows that the transit of active power are virtually unaffected by the presence of STATCOM. The effect on the active power transit is similar to that observed when the device is not installed. Variations from the case without the device are almost negligible (Fig. 19). Fig. 19 illustrates the distribution of powers reactive in the network when the value of STATCOM varies.

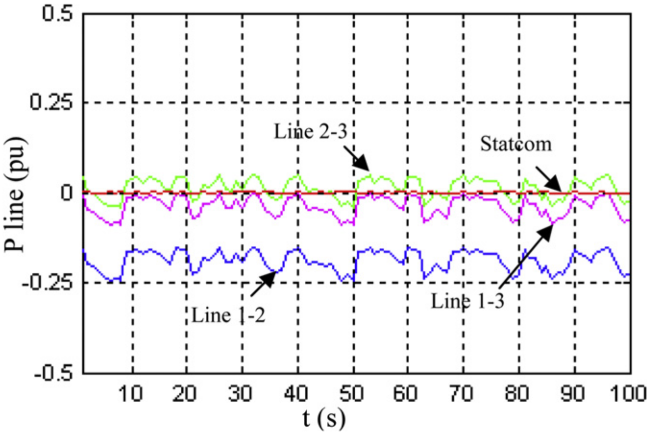

Fig. 18. Active powers flow on the lines 1, 2, 3 and delivered by STATCOM.

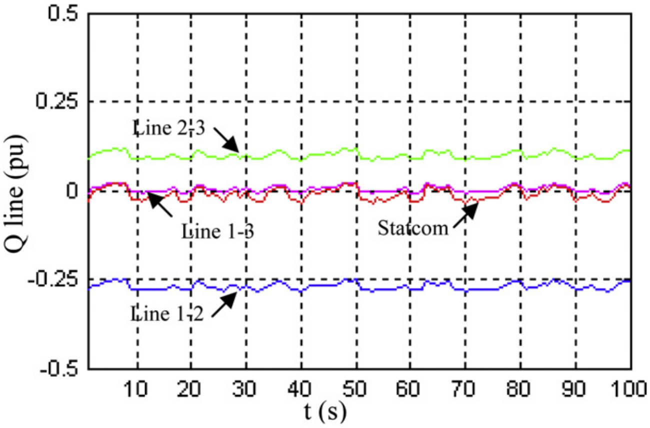

Fig. 19. Reactive powers flow on the lines 1, 2, 3 and delivered by STATCOM.

The STATCOM can provide a capacitive or inductive current independent of voltage. It can provide the maximum capacitive current even at low-voltage values. Its ability to support the network voltage is better than the SVC [19,20]. Moreover, the STATCOM can temporarily increase the nominal current (capacitive or inductive).

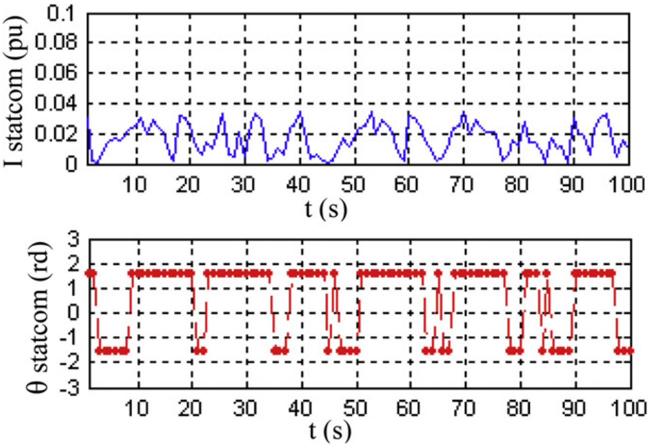

Fig. 20. current through the inductor (I_{STATCOM}) and phase angle ($\theta_{\mathrm{STATCOM}}$).

Fig. 20 show the current profile through the inductor (I_{STATCOM}) and the phase angle ($\theta_{\mathrm{STATCOM}}$) as a function of voltage variation at busbar 3.

From Figs. 16 and 20, the behaviors of the STATCOM towards changes in voltage busbar 3 are very well illustrated:

When the voltage V_{STATCOM} is less than V_{busbar3}, the current through the inductor is phase shifted by $-\Pi/2$ versus voltage V_{busbar3} giving an inductive current.

When the voltage V_{STATCOM} exceeds V_{busbar3}, the current through the inductor is phase shifted by $+\Pi/2$ versus voltage V_{busbar3} giving a capacitive current.

When the voltage V_{STATCOM} is equal to V_{busbar3}, the current through the inductor is at zero, therefore in no exchange of energy.

6. Conclusion

This paper demonstrated the effect of wind energy generation in power systems due to the inherent characteristics of wind turbine (aerogenerator), which causes variations in system voltage. Therefore, a wind turbine requires high reactive power compensation. Flexible AC Transmission System (FACTS) device such as Static Compensator “STATCOM” is power electronic switches used to control the reactive power injection, thereby regulating the bus voltages.

The controller parameters of STATCOM are combined with the nodal voltage magnitudes and angles for unified iterative solutions via Newton’s method to satisfy specified power flows.

Results are presented to show that the voltage stability of the entire power system during small and large disturbances, due to integration of wind production on the electrical network, is improved.

References

[1] da Rosa Aldo V. Fundamentals of renewable energy processes. 2nd ed. UK/USA: Academic Press/Elsevier; 2009.
[2] Sorensen Bent. Renewable energy: its physics, engineering, use, environmental impacts, economy and planning aspects. 3rd ed. UK/USA: Academic Press/Elsevier; 2004.
[3] Munteanu I, Bratcu AI, Cutululis N-A, Ceanga E. Optimal control of wind energy systems, towards a global approach. London: Springer-Verlag; 2008.
[4] Mathur RM, Varma RK. Thyristor-based FACTS controllers and electrical: transmission systems. John Wiley & Sons; 2002.
[5] Natarajan R. Power system capacitors. Taylor and Francis Group; 2005.
[6] Zhang X-P, Handschin E, Yao M. Multi-control functional static synchronous compensator (STATCOM) in power system steady-state operations. Electric Power Systems Research 2004;72:269–78.
[7] Zhang Yankui, Zhang Yan, Wu B, Zhou J. Power injection model of STATCOM with control and operating limit for power flow and voltage stability analysis. Electric Power Systems Research 2006;76:1003–10.
[8] N Dizdarevic, M Majstrovic. FACTS-based reactive power compensation of wind energy conversion system. IEEE Bologna Power Tech Conference. Bologna, Italy; June 23-26 2003.
[9] Sao T, Chen Z. Flicker study on variable speed wind turbines with doubly fed induction generators. IEEE Transactions on Energy Conversion 2005;20(4).
[10] Aouzellag Lahaçani N, Mendil B. Modelling and simulation of the SVC for power system flow studies: electrical network in over-voltage. Journal of Electrical Engineering 2009;9. 2nd ed.
[11] Acha E, Egelidis VG, Anaya-Lara O, Miller TJE. Power electronic control in electrical systems. In: Newnes power engineering series. 1st ed.; 2002.
[12] Patel MR. Wind and solar power systems: design, analysis, and operation. 2nd ed. Taylor and Francis Group; 2006.
[13] Das D. Electrical power systems. New Delhi: New Age International Publishers; 2006.
[14] Crappe M, Dupuis S. L’instabilité de tension: stabilité et sauvegarde des réseaux électriques. Paris: Hermès, Lavoisier; 2003.
[15] Hingoran NG. High power electronics and flexible AC transmission system. IEEE Power Engineering Review; 1988:3–4.
[16] Heydt GT, Gotham Douglas J. Power flow control and power flow studies for systems FACTS devices. IEEE Transactions on Power Systems 1998;13(1).
[17] Acha E, Fuerte-Esquivel CR, Ambriz-Perez H, Angeles-Camacho C. FACTS, modelling and simulation in power networks. Chichester, Angland: John Wiley and Sons; 2004.
[18] Radman G, RAJE RS. Power flow model/calculation for power systems with multiple FACTS controllers. Elsevier, Electrical Power Systems Research; 2006.
[19] Aouzellag Lahaçani N, Aouzellag D, Mendil B. Contribution to the improvement of voltage profile in electrical network with wind generator using SVC device. Renewable Energy 2010;35:243–8.
[20] Aouzellag Lahaçani N, Mendil B. Modelling and simulation of the SVC for power system flow studies: electrical network in voltage drop. Leonardo Journal of Sciences 2008;7(13):153–70.
[21] Boyle G. Renewable electricity and the grid: the challenge of variability. James & James, Science Publishers; 2007.