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Voltage Stability Enhancement in a Wind Generator Connected Electrical Network Using FACTS Devices

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Abstract— ***This paper presents voltage stability in an electrical network when connected by wind generators. Due to several advantages wind energy is the growing renewable energy. Nowadays, wind energy is penetrating into the conventional power network. Due to random variations in wind speed, the output power and terminal voltage fluctuates continuously. The influence of wind generators on the power quality is becoming an important issue; non-uniform power production causes variations in system voltage and frequency, therefore, a wind farm requires high reactive power compensation. The advances in high power semiconductor devices have led to the development of Flexible AC Transmission System(FACTS).This paper presents the impact of wind energy integration on voltage stability and the goal of FACTS devices to control the reactive power injection. Power flows, nodal voltage magnitudes and angles of the power network are obtained by iterative solutions using MIPOWER , thereby regulating the bus voltages.***

Keywords— Power flow, Newton-Raphson method, Wind generator, FACTS devices, Voltage regulation

I. INTRODUCTION

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.

The fact of not taking part in the service systems brings to this type of source behaves like passive generators from the electric view point. The penetration rate must then be limited to 20% or 30% of the consumption according to certain experience feedbacks, in order to be able to guarantee the stability of the network under acceptable conditions.

The integration of the wind production unit in the network causes some problems such as the absence of voltage adjustment and the sensitivity of voltage drops. Because the loads and the wind farms output fluctuate during the day, the use of reactive power compensation is ideal for the power system network[1–3].

Applied to the electrical networks, the Flexible AC Transmission System (FACTS) devices [4,5] allow an effective dynamic state as well as a static state of the voltage control in the power transmission and distribution as well as the power quality control, by implementation of the power electronic devices, such as Static Var Compensator (SVC) and static synchronous compensator(STATCOM). 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. The aim of this paper is to demonstrate the superiority of using FACTS devices to regulate the desired power flow in a power network and to provide the best voltage profile in the system as well as to minimise the system transmission losses when inserting the wind generator in the electrical network.

The Newton–Raphson algorithm [6,7] is applied in calculation of power systems voltages. The results are obtained for three cases of the network state: without the wind generator and the FACTS devices, with integration of the wind generator and with integration of the FACTS devices at the bus of wind generator integration

II. WIND GENERATOR

The major problems of wind are the great variability of its production and especially the difficulty in envisaging this production precisely several hours in advance. The dynamic changes of the wind speed return the quantity of the power injected to a strongly variable network. According to the intensity and rate of change, the difficulties with the frequency and the voltage control could seem making a direct impact on the level of the provided electric power quality [8–10].

The problems induced by the integration of wind generators in the electrical network are caused by:

- Their random and not easily foreseeable production;
- An absence of power-frequency adjustment;
- A participation in the voltage adjustment limited for the wind generator to variable speed, and any participation in this adjustment for the wind generators whose generator is directly coupled with the network;
- A high sensitivity of voltage hollows and the variations of frequency for some technologies;
- A significant sensitivity to the fast variations of the wind force.

A. Voltage Adjustment

The production units must ensure a control of the voltage and/or reactive power at delivery point [9–14]. Three types of primary adjustment are possible: adjustment with constant reactive power, adjustment of the voltage to a value varying linearly according to the power reactive with an adjustable slope and adjustment of the voltage according to an instruction controlled to the orders coming from the secondary adjustment of the voltage. All the production units, including the wind generators, must be able to function in an operation range determined by a graph the voltage (U) in function of the relationship between the reactive power and the maximum active power (Q/Pmax). 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 ($\Delta V=V_1-V_2$) can be writing in an approximate way as [2,3,11]:

$$\Delta V = (rP+xQ)/V_2 \quad (1)$$

with r and x respectively the resistance and reactance of the line in Ohm, P and Q respectively the active and reactive powers flow on the line.
For the high voltage lines, $x \geq 10r$ expression (1) can thus be simplified:

$$\Delta V = xQ/V_2 \quad (2)$$

The active power generated by the wind generators is fluctuate by nature, which tends according to expression (1) to induce fluctuations of voltage in the zone of the network close to the point of connection of these wind generators.

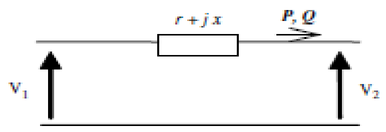

Fig.2.1 Simplified equivalent diagram of a line.

In the transmission network, made up of high voltage lines, expression (2) shows that the variations of voltage are induced by the reactive power transits contrary with the distribution networks.

This is why; it is requested from the wind generators currently connected to the transmission network to take part in the voltage adjustment via an adjustment of the reactive power. This adjustment is possible with the wind generators connected to the network via power electronics.

B. The Wind Energy

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:

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

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.

$$\lambda = \Omega_{t.} R_t/v \quad (4)$$

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

III. SHUNT CONNECTED CONTROLLERS

Shunt controllers are mainly concerned with the absorption/generation of reactive power and maintaining constant voltage profiles. These controllers are highly effective in maintaining the desired voltage profile along the transmission line and to control the reactive power flow in the line.

SVC and STATCOM are a controllable reactive power source. Early applications of SVC were for load compensation of fast changing loads like arc furnaces, and steel mills for dynamic power factor improvement and load balancing in the three phases. Recently, SVCs and STATCOMs are mainly used as voltage regulators.

To solve the power flow problems, the FACTS devices offer an alternative to the traditional means of regulation. These devices based on the power electronics, make it possible to control the voltage level and/or the power transit in the electrical network lines [12,13]. The FACTS devices can be used for the control of the active power as well as for that of the reactive power or the voltage.

To study the impact of the introduction of the SVC device and STATCOM into a network, the Newton–Raphson algorithm is applied in calculation of power systems voltages. Initially, the introduction of the FACTS is carried out, varying the control parameter of the FACTS and by observing the changes on the bus voltages and the transit powers in the lines. The second stage consists in fixing a consign value of (voltage or power) for which the simulation program will find the value of the control size. This way, it will check, if it is possible to regulate a size (voltage or power) to a value consign without deteriorating the static performances of the network

IV. PROPOSED METHODOLOGY

MiPower is a highly interactive, user-friendly windows based Power System Analysis package. It includes a set of modules for performing a wide range of power system design and analysis study. MiPower features include a top notch Windows GUI with centralized database. Steady state, transient and electro-magnetic transient analysis can be performed with utmost accuracy and tolerance.

Initially Newton-Raphson algorithm is applied to proposed network without integration of wind generator and FACTS device. From the load flow results, a low voltage bus was selected to integrate a wind generator . On insertion of wind generator and by conducting load flow results the voltages at the all PQ buses increases. It leads to voltage instability in the system, since output of wind generator is fluctuating in nature. To overcome this problem system requires high reactive power compensation, this is acheived by using FACTS devices. A FACTS device is integrated at the place where wind generator is integrated and load flow results are obtained. It is seen that the voltages are regulated, to remain the system stable. Standard 5 bus and 14 bus systems are used in this paper.

Fig. 5.1 shows the 14 bus test system, where the bus bars are numbered from 1 to 14 and the lines from 1 to 20. The bus bar 1 is the slack bus, buses 2,3,6,8 are P,|V| buses and buses 4,5,7,9,10,11,12,13,14 are P,Q buses[16]. The Newton-Raphson algorithm is applied in calculation of power systems voltages.

V. SIMULATION RESULTS

The results are obtained for three cases of the network state:

- Network without the wind generator and the Shunt FACTS device
- Integration of the wind generator
- Integration of the Shunt FACTS device

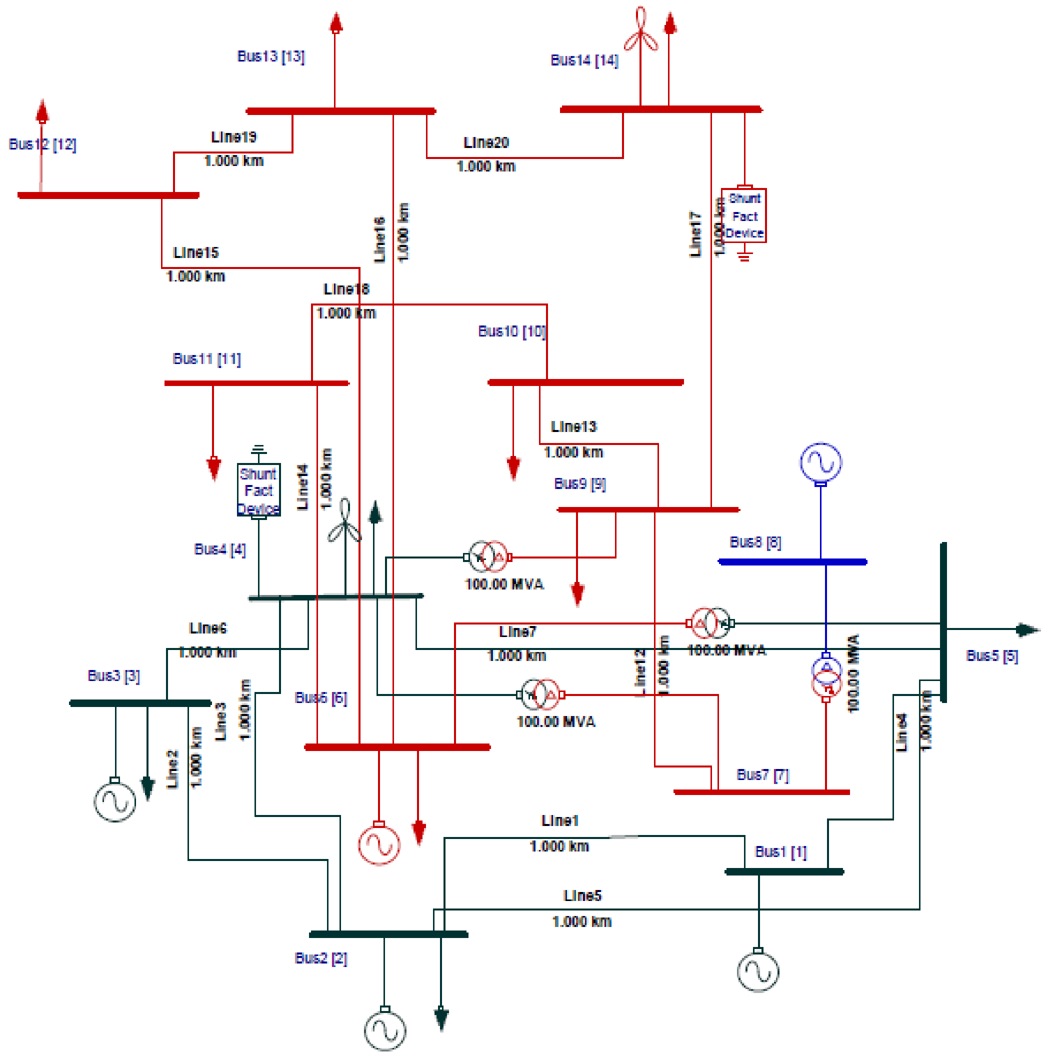

Fig. 5.1 The proposed 14 bus network structure

A. 5 Bus network without the wind generator and the FACTS device

The bus voltage magnitudes/angles from the load flow results are represented in Table-I respectively. It can be seen that a voltage unstable area is formed by bus 4 and bus 5; where bus 5 has the lowest voltage.

The network state is given in Table-I.

Table-I : Without Wind Generator and Shunt FACTS Device Integration

Bus	*Voltage(p.u)*	*Angle(^{o})*
3	1.0243	-5.00
4	1.0236	-5.33
5	**1.0179**	**-6.15**

B. 5 Bus network with Integration of a wind generator

The standard 5 bus system, was modified to incorporate a 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 active power injected by the wind generator P_{wind} inserted into the bus 5 and the Table-II its influence on the voltages in the other buses. Then according to the results of simulation, the first impact to be observed, it is the reduction in the powers delivered by the generators 1 and 2 to network, which flow on the lines 2, 3, 4 and 5, that are relieved by insertion of the aerogenerator, on the other hand, it is the improvement of the voltages at the buses.

Table-II : With Wind Generator Integration

Bus	*Voltage (p.u)*	*Angle(^{o})*
3	1.0478	-1.73
4	1.0498	-1.61
5	**1.0720**	**2.03**

C. 5 Bus network with the wind generator and the Shunt FACTS device

This is been conditioned with the participation in the service systems of this production; the participation in the adjustment of the voltage is related to the adjustment of the reactive power injected. The FACTS device which is installed at bus 5 near the wind generator is the shunt device. This device is most suitable for voltage control and provides reactive support by injecting a reactive power ‘‘Qshunt’’. The evolution of the voltage magnitudes at buses after injection of the reactive power ‘‘Qshunt’’ at bus 5, place of the integration of the wind generator, and the evolution of the reactive power under to the evolution of the active power delivered by the wind generator.

The goal is to have a stable voltage at buses, no matter what is the variation of the power injected by the wind generator, and that by injecting a reactive power ‘‘Qshunt’’ to compensate the voltage hollows or to fall off the voltage if it exceeds the desired voltage magnitude. The results showed a better behaviour with regard to the voltage support on the load bus bars and all the voltage drops within the limits 5%.

Then the voltage instability at the buses is overcomed and the voltage at the buses come to stable condition. The network state on integration of shunt FACTS device at the point where wind generator is integrated is given in Table-III and Table-IV.

Table-III :With both Wind Generator and SVC Integration

Bus	*Voltage(p.u)*	*Angle(^{o})*
3	1.0139	-1.28
4	1.0114	-1.07
5	**1.0000**	**3.77**

Table-IV : With Both Wind Generator and STATCOM Integration

Bus	*Voltage(p.u)*	*Angle(^{o})*
3	1.0139	-1.28
4	1.0114	-1.07
5	**1.0000**	**3.77**

D. 14 Bus network without the wind generator and the FACTS device

The bus voltage magnitudes/angles from the load flow results are represented in Table- IX respectively. It can be seen that a voltage unstable area is formed at bus 4 and bus 14;

The network state is given in Table-V.

Table-V : Without Wind Generator and Shunt FACTS Device Integration

Bus	*Voltage(p.u)*	*Angle(°)*
4	**1.0271**	**-5.12**
5	1.0279	-4.41
7	1.0550	-2.25
9	1.0427	-5.57
10	1.0404	-6.28
11	1.0519	-7.22
12	1.0536	-8.60
13	1.0488	-8.45
14	**1.0271**	**-7.84**

E. 14 Bus network with Integration of a wind generator

The standard 14 bus system, shown in Fig.5.1, was modified to incorporate a 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 active power injected by the wind generator P_{wind} inserted into the bus 4 and bus 14 and the Table-VI its influence on the voltages in the other buses. Then according to the results of simulation, the first impact to be observed, it is the reduction in the powers delivered by the generators to network, which flow on the lines, that are relieved by insertion of the aerogenerators, on the other hand, it is the improvement of the voltages at the buses.

Table-VI : With Wind Generator Integration

Bus	*Voltage(p.u)*	*Angle(°)*
4	**1.0500**	**6.53**
5	1.0447	5.43
7	1.0625	13.89
9	1.0496	12.64
10	1.0462	11.61
11	1.0549	9.91
12	1.0571	9.13
13	1.0659	10.55
14	**1.1086**	**19.75**

F. 14 Bus network with the wind generator and the Shunt FACTS device

Adjustment of the voltage is related to the adjustment of the reactive power injected. The FACTS device which is installed at bus 4 and bus 14 near the wind generators are the shunt devices. This device is most suitable for voltage control and provides reactive support by injecting a reactive power ‘‘Qshunt’’. The evolution of the voltage magnitudes at buses after injection of the reactive power ‘‘Qshunt’’ at bus 4 and bus 14, place of the integration of the wind generators, and the evolution of the reactive power under to the evolution of the active power delivered by the wind generator.

The goal is to have a stable voltage at buses, no matter what is the variation of the power injected by the wind generator, and that by injecting a reactive power ‘‘Qshunt’’ to compensate the voltage hollows or to fall off the voltage if it exceeds the desired voltage magnitude. The results showed a better behaviour with regard to the voltage support on the load bus bars and all the voltage drops within the limits 5%.

Then the voltage instability at the buses is overcomed and the voltage at the buses come to stable condition. The network state on integration of shunt FACTS devices at the point where wind generators are integrated is given in Table- VII and Table-VIII.

Table-VII : With both wind generator and SVC integration

Bus	*Voltage(p.u)*	*Angle(°)*
4	**1.0285**	**6.88**
5	1.0263	5.67
7	1.0361	14.57
9	1.0054	13.24
10	1.0015	12.11
11	1.0099	10.26
12	1.0051	9.47
13	1.0089	11.25
14	**1.0198**	**22.56**

Table-VIII : With Both Wind Generator and STATCOM Integration

Bus	*Voltage(p.u)*	*Angle(°)*
4	**1.0289**	**6.88**
5	1.0266	5.67
7	1.0366	14.56
9	1.0062	13.23
10	1.0023	12.10
11	1.0107	10.25
12	1.0061	9.46
13	1.0099	11.24
14	**1.0213**	**22.56**

VI. CONCLUSION

The wind production systems are extremely sensitive to the network disturbances. The voltage hollows or the frequency variations involve often the disconnection of the production at the time of incident on the network. This disconnection can worsen a production/consummation imbalance and consequently, accelerate the advent of a major incident in the network. The impacts of the integration of a wind generator in an electrical supply network on the voltage stability and on the powers forwarded in this network are presented. The solution of this problem is done by inserting a FACTS device which is the Shunt device at the place of integration of the wind generator for the voltage adjustment.

VII. FUTURE SCOPE

Application to the systems with increased number of Buses .Different types of compensating devices can be used to inject reactive power.

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