Impact of wind energy integration in a distribution electric network

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Abstract.

This paper deals with the integration of wind farms in a medium voltage isolated grid. Two main aspects are developed and concerns the regulation of the voltage plan of the grid without and after with the participation of the wind machines in the regulation of the voltage control.

Keywords

wind energy, grid integration, power factor regulation, isolated grid.

1. Introduction

At the present time, renewable energies are more and more developed. This is due to a current phenomena which is the rise of the petrol price (about 55$ by barrel) and to the setting of the Kyoto protocol. This protocol defines the percentage of renewable energy participation in the national electricity production. The aim of this agreement concerns the reduction of greenhouse gas effects. During the last weeks, one of the biggest world country, the Russia, ratified this protocol. This fact implies that another countries will ratify it.

In this context, the France has announced that 21 % of its electricity production would be supplied by renewable energies. It can be noted that 14% of this energy are already produced by hydroelectricity centrals. In this aim, the development of another production devices, such as photovoltaic, wind energy, fuel cells, cogeneration, … is necessary. The wind energy is the system which takes the most important part of new renewable energy production. At the present time, the wind machines develop some active power from a few kilowatts to 3 megawatts. For the biggest wind machines and in function of the connecting grid power, some problems are present. In first, about voltage plan, the fact to integrate wind energy productions implies some limit overtakings of the norms. In a second time, there are some frequency regulation problems when wind machines are embedding in small grids (low short-circuit power, isolated grid).

This paper deals with the impact of the wind machine integration into an existing electric network. The first part concerns the modelling of wind machines and their grid connection. The second part concerns the voltage control plan without wind energy production in order to characterise the network. A second study is realised with wind energy production in order to analyse its impact. From these results, a solution to implicate the wind machine in the voltage control is presented.

These studies have been realised in the context of the CNRT (Centre National de Recherche Technologique) in electric engineering of Lille.

2. Wind machine modelling

For the mechanical part, the wind machine modelling is based on the Betz theory which expresses the power (P_w) in function of the wind speed (V_{wind}), the blade area (S), the air density (ρ) and the rotor power coefficient (C_p) as following :

$$P_w = \frac{1}{2}\rho S C_p V_{wind}^3 \qquad (1)$$

The rotor power coefficient (C_p) is a non linear relation function of the tip-speed ratio (λ). The latter is defined by :

$$\lambda = \frac{R_p \Omega_w}{V_{Wind}} \qquad (2)$$

where R_p is the blade length and Ω_w is the angular blade speed.

The mechanical torque (Γ_w) can be defined by :

$$\Gamma_w = \frac{1}{2}\frac{C_p}{\lambda}\rho S R_p V_{wind}^2 \qquad (3)$$

The mechanical shaft model is based on a rigid model where the inertial constants and damping coefficients are supposed constant.

Two models of mechanical part of wind machines are taken into consideration :

- the stall control,
- the pitch control.

In order to better establish the wind machine laws and model, all modelling developments are done with the use of the GIC (Graphe Informationnel Causal) (fig. 1.) [1].

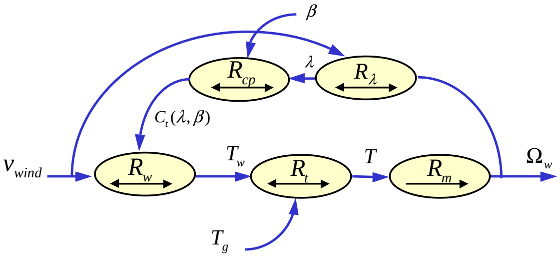

Fig. 1. GIC of the wind machine

where Γ_g is the electrical machine torque and β is the blade pitch angle when the pitch control is used. When the stall control is used, the angle β is constant. For the mechanical modelling, the characteristics of C_p in versus λ and for different angle β, presented in figure 2, are used.

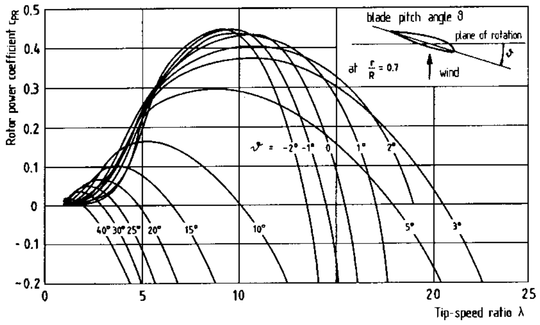

Fig. 2. Rotor power coefficient in versus of the tip ratio And for different blade pitch angle

The electrical machine modelling is based on the vectorial control and the park transformations. The studied electrical machines are induction machines directly connected to the grid, induction machine connecting to the grid with power electronic converter (stator), doubly-fed induction machine and synchronous machine with power electronic.

3. Study of wind machine voltage control

This study has been realised with an existing grid. At the origin, the latter integrates decentralised wind energy production. It is an isolated grid which is presented in the next paragraph.

A. *Grid presentation*

This grid is an existing network. Its electrical power is about 15MW. The latter is due to a leak charge level which is the consequence of a poor industry. It is presented in figure 3.

Its principal characteristics are :

- two different voltage levels (15.5kV and 34kV)
- the short circuit power is about 120MVA,
- the line sections are 93.3mm^2, the linear resistance and reactance values are respectively 0.48Ω/km and 0.448Ω/km,
- the load modelling repartition is done as following : in the grid 15.5kV, the load are only impedance loads. In the grid 34kV, they are constituted by 50% of motor loads and the other 50% are impedance loads,
- the consumed maximum power in the 34kV is about 5MVA,
- the consumed maximum power in the 15.5kV is about 9.9MVA. It can be noted that 90% of loads are connecting to the secondary transformer 34kV/15.5kV.

As the length of the lines is very short, they are modelled without taking into account their capacitive effect. The transformers are supposed without changer tap.

Two wind farms are already existing and they are connected to the nodes PRONY and NEGANDY. The used wind machines are stall effect wind machines equipped with induction machines directly connected to the grid. The nominal powers of these wind farms are respectively 2.5MW and 4.5MW in the 34kV and 15.5kV grids. Some capacitance banks are used in order to regulate the power factors. The latter are considering to be equal to the unity. This type of electrical machine consumes a reactive power which is not negligible

B. *Voltage control in the initial network*

Before studying the different controls in this network type, it is interesting to establish its characteristics with its initial configuration, without wind machines and, in a second time, with the two wind farms. The simulations are made with EUROSTAG. Two load cases are simulated. The first one, the max load which is characterised by the nominal load as described in figure 3. The second one, the min load which represents a third of the max load.

The maximal limits are fixed by the norm EN60150. The latter fixes the maximal variations to ±5% of the rated value. These values are expressed in the per unit system (pu) and are respectively equal to 0.95pu and 1.05pu. In the rest of this paper, all values are expressed in the per unit system.

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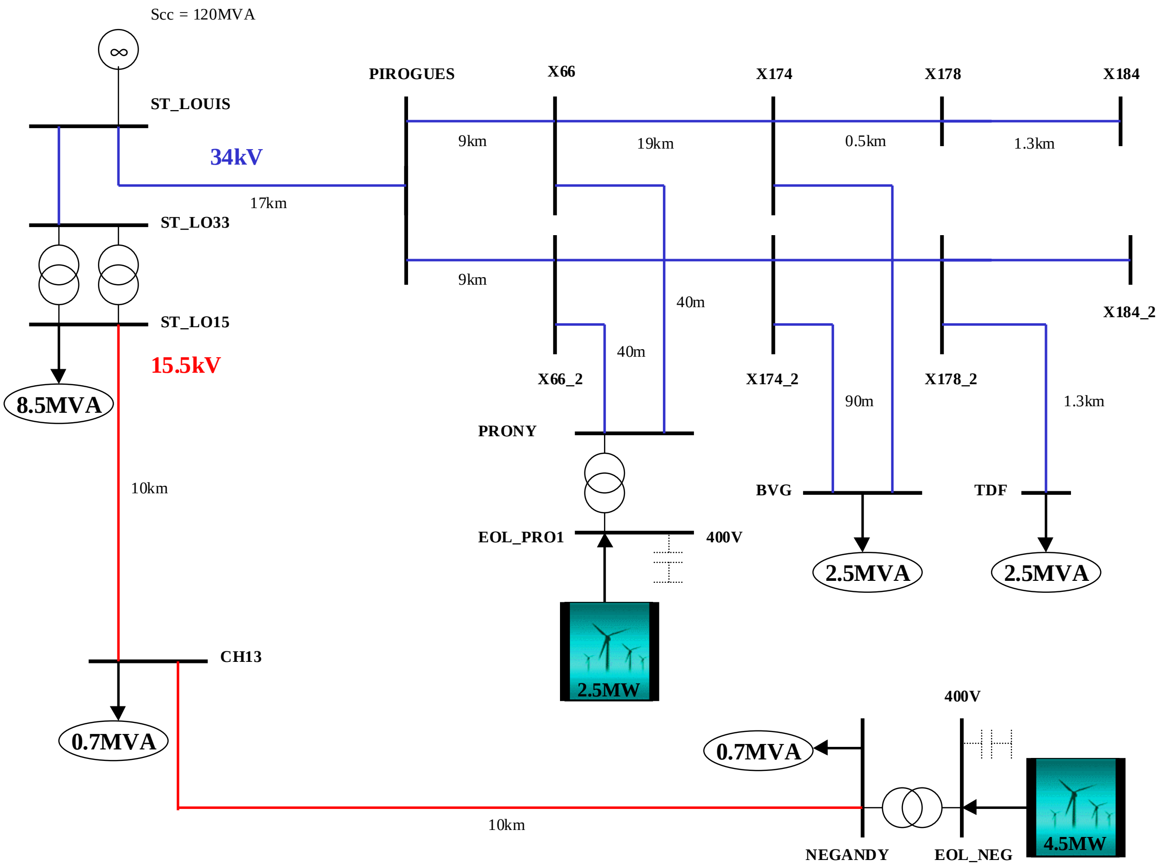

Fig. 3. Distribution electric network

The wind farms are supposed operating at their rated point. From the previous simulation, only two electric nodes of this network have some problems. The Table I shows the values of the problematic nodes in function of different load cases without and after with wind energy production. At the NEGANDY node, without energy production, the maximal voltage variation is about the twice of the limit permitted by the norm. With energy production, this value reaches four times the permitted norm value. These variations are the consequence of a line with a small section. These ones are related to the active power flow.

TABLE I : Voltage values in function of the network load taking into account the wind energy production or not

	Node	Ch13	Negandy
Without wind energy	**Min load**	0.961	0.922
	Max load	0.954	0.901
With wind energy	**Min load**	1.038	1.182
	Max load	1.010	1.132

A complementary study shows that the capacitor banks delivering only the half of the reactive power (not operating with a power factor equal to the unity), all voltage nodes of this grid stay in the limits imposed by the norm.

In order to better quantified this grid, some supplementary studies, in dynamic mode as the impact of a line default, are done. From these studies, it can be deduced that the grids in 34kV and in 15.5kV are relatively independent. Taking in consideration the previous remark, it is possible to reduced the electric grid of the figure 3 to the network presented in the figure 4,

where :

- m_1 and m_2 are respectively the transformer ratios of T1 and T2 equal to 1pu and 1.033pu.
- R_L and X_L are respectively the resistance and the reactance of the 15.5kV lines equal to 2.0027pu and 1.8681pu (U_{base}=15.5kV and S_{base}=100MVA).
- R_{CC} and X_{CC} are respectively the resistance and the reactance of the short circuit impedance equal to 0.3814pu and 0.6747pu (U_{base}=34kV and S_{base}=100MVA).
- R_{T1} and X_{T1} are respectively the resistance and the reactance of the transformer T1 brought back to the secondary and equal to 0.07pu and 1pu (U_{base}=15.5kV and S_{base}=100MVA).
- R_{T2} and X_{T2} are respectively the resistance and the reactance of the transformer T2 brought back to the secondary and equal to 4.638pu and 7.302pu (U_{base}=0.4kV and S_{base}=100MVA).

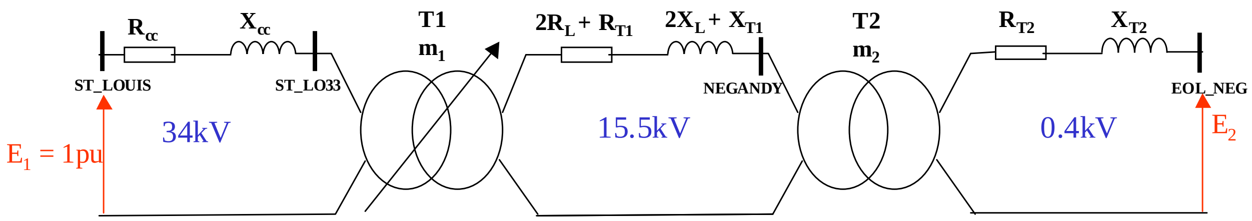

Fig. 4. Reduced network

As a leak load consumption on this line, the following scheme can be simplified as this one presented in figure 5 [2]. The latter leads to compute easily the voltage drops.

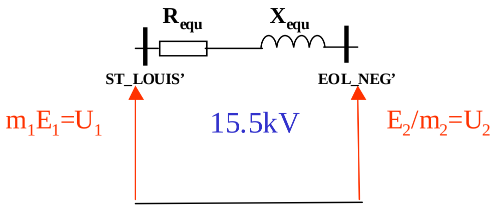

Fig. 5. Reduced scheme used for calculus

The equivalent parameters R_{equ} and X_{equ} are defined by :

$$R_{equ} = \left(2 * R_L + R_{T1} + m_1^2 R_{CC}\right) + R_{T2} / m_2^2 \quad (1)$$

$$X_{equ} = \left(2 * X_L + X_{T1} + m_1^2 X_{CC}\right) + X_{T2} / m_2^2 \quad (2)$$

When the critical case is studied, the totality of the load is placed at the end of line. The expression of the end line voltage (U_2) is presented under the following form [3]:

$$U_2^4 + U_2^2\left(2\left(R_{equ}.P + X_{equ}.Q\right) - U_1^2\right) + \left(R_{equ}.P + X_{equ}.Q\right)^2 + \left(R_{equ}.P - X_{equ}.Q\right)^2 = 0 \quad (3)$$

with : $P=P_g+P_{load}$ and $Q=Q_g+Q_{load.}$
P_g and Q_g are respectively the active and reactive powers of the wind farm. P_{load} and Q_{load} are respectively the active and reactive powers of the load connected at the end of line. Powers are counted positively when they are absorbed by the receptor.
The voltage drop is null when the following equation is respected :

$$R_{equ} / X_{equ} = -Q / P \quad (4)$$

In this grid, the maximum power connected at the end of line is about 2MVA with a rear power factor equal to 0.8.

C. Voltage control study with the existing configuration

This part of this paper deals with the voltage control for different load levels with wind energy production. The most interesting node is EOL_NEG. The latter is a 400V node and must be within the classical limits imposed by the norm (U_n±10%). To maintain this voltage in these limits, the wind energy production has to operate with a rear power factor (PF). The figures 6 and 7 represent the end line voltage evolutions with different power factors for max load and min load.
From theses figures, when the energy production operates with a rear power factor between 0.85 and 0.95, it can be easily concluded that the connection node stays within the limits imposed by the norm.
A supplementary consideration must be taking into account. This one is that all loads are connecting to the medium voltage grid which must satisfy the EN60150 norm (maximum voltage variations equal to ±5%).

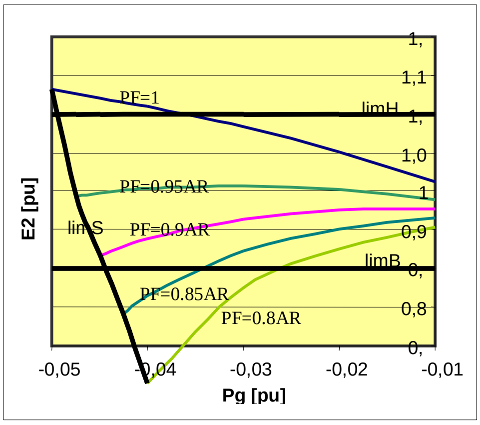

Fig. 6. Voltage E_2 in function of active power generated by the wind farm, for max load and different rear power factors (PF)

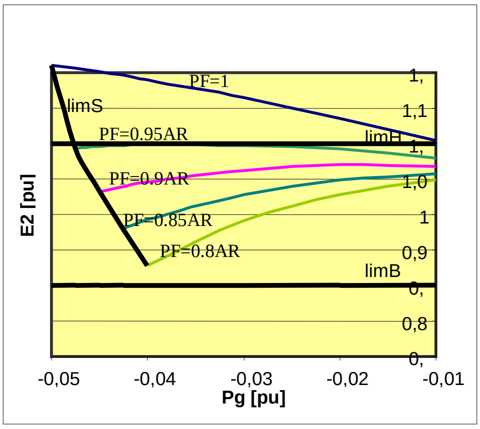

Fig. 7. Voltage E_2 in function of active power generated by the wind farm, for min load and different rear power factors (PF)

Remark : The wind machines initially integrated in this grid are equipped by induction machines with direct connection to the grid. This type of electric machine has a natural evolution of the power factor in function of the generated active power. The choice of this generator type is particularly well adapted for the voltage control of this type grid [4]. Their main drawbacks is these wind machines operate a with a rotor speed quasi constant without possibility to optimise the output power.

D. Voltage control for wind machines with variable speed

At the present time, the device of energy production connected to the grid with a nominal power superior to 1MW must be equipped with a voltage control device [5].

1) Operating Principle

This device is only applicable to wind machines equipped with electronic power converter. These wind machines operate with a variable rotor speed. They have a power control in order to optimise the developed blade power. The principle scheme of the voltage control device is presented in figure 8. From the connection node voltage, this device determines the reference power values (P_{REF}, Q_{REF}) or the active reference power value and reference power factor (P_{REF}, $\cos\varphi_{REF}$). In the case of this study, the device determines the reference active power and the reference power factor (P_{REF} and $\cos\varphi_{REF}$). The reference value P_{REF} is in relation to the wind speed. This implies to measure the wind. From the previous studies of voltage control, a production of wind energy with a constant power leads to respect the limits imposed by the norm. The best regulation is this one which gives a power factor in function of the voltage measure at the connecting point. The principle of this regulation law is presented in figure 9, where C(s) is the corrector and F(s) takes into account the time response of the device. A saturation device is present in this device. The limits are deduced from the PF values presented in the previous paragraph C.

When several production devices are present in the same grid and in order to avoid instability problems, the previous control must use a statism rule.

2) Simulations results

The figure 10 shows the results obtained when a wind machine equipped with control voltage device is used. The electrical machine is a synchronous one connected to the grid via a power converter. The reference voltage node is fixed about 1pu. This node is the connecting point of the windfarm to the grid. The wind speed is variable and comprises between 10 to 14m/s. This figure shows the wind speed, the PF and the voltage evolutions at the connecting node.

E. Voltage control conclusion

From the previous studies, it has been showed that the fact to consume reactive power is good for the voltage control of this grid. The choice to equip wind machines with induction machines directly connected to the grid was a good choice. Unfortunately, this type of wind machines is not adapted to the actual market where the majority of these ones is equipped with a power electronic device. In order to control this network, it is necessary that this type of machine is equipped with a voltage control device at the connection node [6]. When few wind machines are connected to the grid, it will be necessary to use a supervisor device to regulate the voltage plan. This device will imply a supplementary cost at the installation, but it could participate to other functions as frequency control.

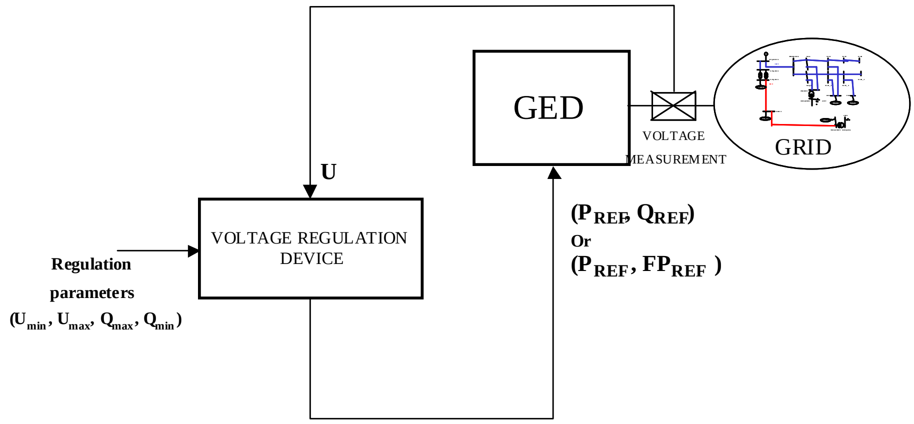

Fig. 8. Voltage control regulation device scheme

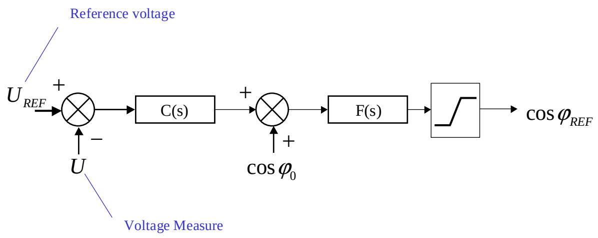

Fig. 9. Control voltage law for a variable speed wind machine

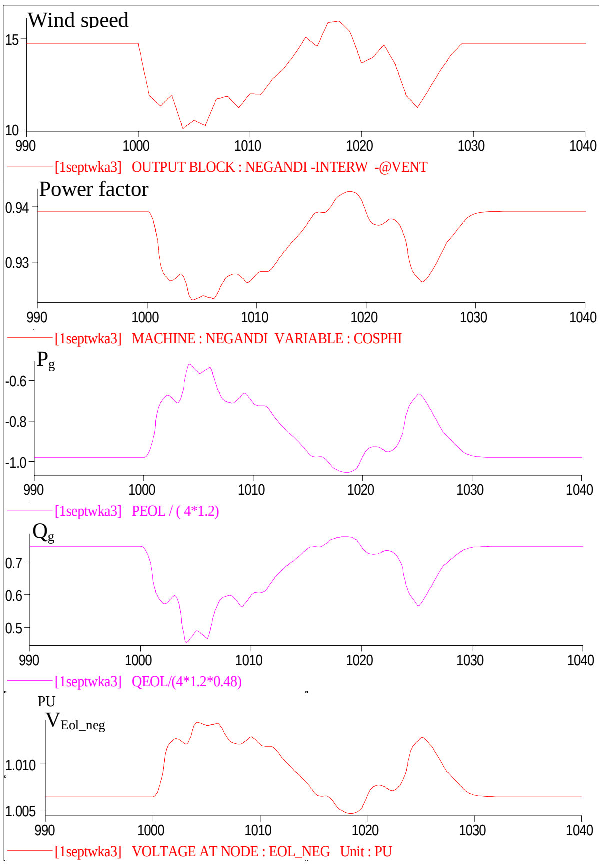

Fig. 9. Network simulation results: use of a wind farm equipped with a voltage control regulation

4. Conclusion

This paper has shown the fundamental laws for wind machine modelling. From these previous studies and considerations about wind machines, it has been shown the efficiency of the wind energy production in the electric grid voltage control. The voltage is controlled at the grid connecting point. This control is realised acting on the power factor of the wind machine device. Only wind machine with power electronic device can participate to the voltage control in function of their recoverable power issued from the blades and available in the operating reserve. When several windfarms are connecting to the same grid it is necessary to use a grid supervisor in order to avoid instability problem.

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