Effect of neglecting stator transients in squirrel cage wind generator model.

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Abstract. The study of the impact of the wind generation in the electrical grid is acquiring special importance in the last years. For these studies it is necessary to analyse its influence in the dynamics of the electrical systems of power. Therefore, it is necessary to obtain suitable dynamic models for each study.

In this paper two models of wind turbine generating systems are presented: a 5th order and a 3rd order model. The behaviour of both detailed models are described and compared. Both models match up with the squirrel cage technology.

Key words

Wind energy, simulation models, power system dynamics, squirrel cage wind turbine, comparison of models.

1. Introduction

As a result of the increasing care for the environment, the renewable energies are acquiring special importance in the last years.

The wind energy is one of the most important ways to generate electricity from renewable sources, and the number of wind turbines will be increased quickly over the next 10 years.

Nowadays, the main problem is to determine the influence of this generation on the dynamics of electrical power systems by interacting with conventional generation equipment. Thus, the wind energy impact on the dynamics of the power systems becomes an important matter in electrical and wind energy companies, and so, it is studied by means of power system dynamic simulations [1]. Therefore the models behaviour should be near the reality to get more accurate results.

The power system dynamic is evaluated by simulation, and companies usually use the dynamical module of software package as PSS/E [2], Eurostag,…

Numerous models to represent wind turbine generating systems can be found in the literature. However, most of them cannot be applied easily for fundamental frequency simulations because they contain time constants which are too short to be taken account in fundamental frequency simulations [3].

The models presented in this work have been implemented in PSS/E. This dynamic simulation tool is widely used by the electrical companies in the world.

Commonly the use of the 5th order generator model is recommended. The time simulation of the 5th order model with PSS/E is greater than the 3rd order model. In this paper a comparison of these two models behaviour is made.

2. Wind turbine model

Next the model of squirrel cage induction generator developed is described in detailed form.

The model must consider the performance of all the parts of the wind turbine:

- The blades catch the mechanical power of the wind and they behave according to their power curve.
- The mechanical set considers the system inertias.
- The generator transforms the dynamic energy from the axis in electrical energy.

A. Blades

In the first place, the turbine blades catch the mechanical energy of the wind. In this case, the modelled turbine does not have pitch control and the control will be made by means of stall control.

In normal operation with stall control, laminar flow is obtained at the rotor blades. Here the lift values corresponding to the angle of attack are reached at low drag components. Thus, the partial loading ranges a high degree of aerodynamic efficiency is attained. If the wind speed approaches the value at which the generator reaches its rated power, farther torque development at the rotor must be inhibited.

Extensive rigid coupling with the grid enables the generator to keep the turbine at almost constant speed. Wind speeds exceeding rated levels cause higher angles of attack and thus to stalling, when the airflow ‘unsticks’ from part of the blade profile, this causes a lower rotor torque and lower performance coefficients.

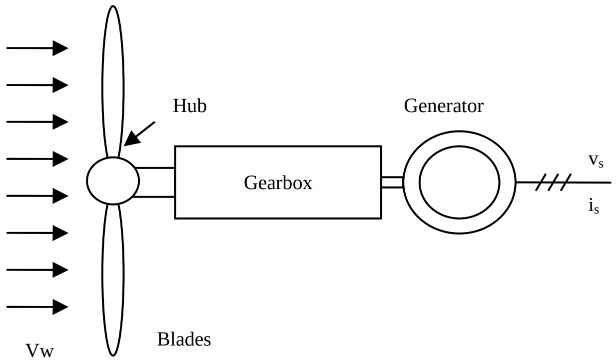

Fig 1. Wind turbine configuration.

The wind turbine capacity for extract the energy from the wind depends on three factors:

- The wind power available. Its value depends on the wind distribution, which is a characteristic of the wind farm location.
- The power curve of the machine which is function of the type of machine.
- The good behaviour of the machine to respond to fluctuations in the wind speed. This is a characteristic of turbine technology.

The mechanical power extracted from the wind is expressed as following:

$$P = 1/2 \cdot \rho \cdot A \cdot Cp(\lambda) \cdot V_w^{\ 3} \qquad (1)$$

Where

- ρ is the air density (commonly 1.225 kg/m^3)
- A is the swept area
- V_w is the wind speed (m/s)
- Cp is the power coefficient.

The power coefficient represents the relation between the power extracted by the wind turbine respect to the total power transported by the wind. In this case, as the Pitch angle is constant, the power coefficient only depends on λ, the tip step ratio.

The power curve represents the electrical to power produced by the wind turbine for each wind speed in permanent regime.

The power curve is a basic characteristic of the machine. This curve is an initial data given by the manufacturer.

The power curve allows calculating the energy produced by the machine from the wind distribution of the zone. The Fig 2 represents the power curve of the modelled turbine.

Several sections can be defined in the power curve:

- From calm (0 m/s) to a speed from 3 to 5 m/s the machine does not produce energy.
- From the starting speed (3 to 5 m/s) to the nominal speed (~12 to 14 m/s), is a section of increasing power. Due to the blade stall in generators CSCF, the curve has a characteristic section called commonly "hump", in which is reached the maximum power, followed by a section of higher speeds and smaller power produced.
- When the wind speed is greater than a value around 25 m/s, the generators stops to produce electrical energy to avoid problems of mechanical overload.

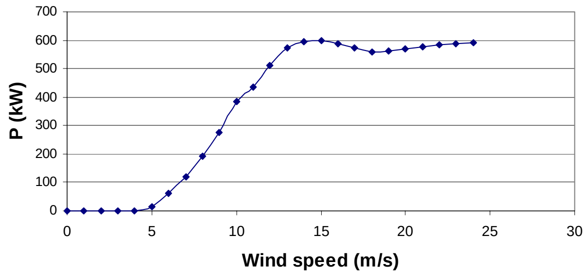

Fig 2. Power curve.

B. Mechanical set

In the dynamic models for stability studies the inertia constant of the mechanical set must be considered t. In this model the value of the moment of inertia is the total of the system. It includes the blades, the gearbox, and the generator.

The wind kinetic energy is caught by the blades of the wind turbine. The blades are made of composite material (polyester, glass and carbon fibber among others) which allows obtaining a high resistance with a reduced weight. The blades are the most flexible element of the set, but for this kind of studies infinite rigidity is usually considered.

The blades turn at an almost constant speed of approximately 20-30 rpm. Due to the fact that this speed is clearly insufficient to produce electrical energy, a multiplier is used to elevate the speed of 40 to 100 times the speed of the blades, so that nominal speed is obtained in the output axis (around the 1500 rpm).

The axis is jointed to the generator through a clutch. Due to the important rigidity of both axes (blades and generator) and the multiplier, infinite rigidity is considered for the set. Only the clutch elasticity and damping can be no despicable, mainly in the greatest machines.

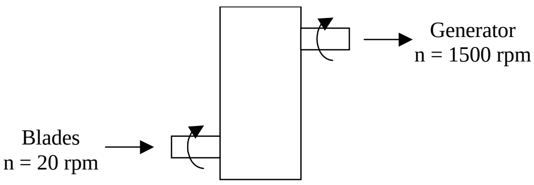

Fig 3. Gearbox layout.

The rest of the frictions (viscous and static) are very small and its existence does not affect the dynamic behaviour of the generator for this study.

The set has an elevated inertia. The elements that contribute more are the blades, due to the fact that the mass is very far from the rotate axis and its weight, although low for their spread, is really considerable (~2 tons/blade). In this paper it has been considered an equivalent inertia moment equals to the sum of inertia of the generator, multiplier, bushing and blades, all referred the axis of the generator:

$$J_{eq} = J_{gen} + J_{gearbox} + J'_{hub} + J'_{blades} \qquad (2)$$

Where

$$J'_{blades+hub} = J_{blades+hub} \cdot (1/r_r)^2 \qquad (3)$$

and

$$r_r = n_{generator} / n_{blades} \qquad (4)$$

Where J represents the inertia of the different parts from the system, r_r is the relation of the gearbox and n the speeds of the element.

In stability studies, the constant of inertia *H* is the fundamental variable. It gives an idea of the machine electromechanical response time before transitory event. It is referred to the power base of the machine, and can be defined as:

$$H = \frac{1/2 \cdot J \cdot (2\pi f_{network} / p)^2}{S_b} \qquad (5)$$

As it can be appreciated, *H* is the relation between the kinetic energy of the generator at the synchronism speed and the power base of the machine.

C. Generator model equations

The dynamic behaviour of the squirrel cage induction generator can be described by means of the behaviour equations.

In these equations the three-phase windings of stator and rotor are represented by means of two games of orthogonal fictitious windings.

In the presented model the following suppositions have been taken:

- The stator current is positive when it flows from the machine towards the network.
- The represented equations are in the synchronous reference frame.
- Q axis is advanced 90º of axis D in the rotation direction as shown in Fig 4.

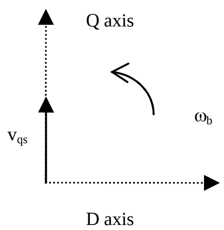

Fig 4. Direct (D) and quadrature (Q) axis

For power systems study is desirable to use the per unit representation. Fig 5 shows the generator equivalent circuit in the synchronous reference frame.

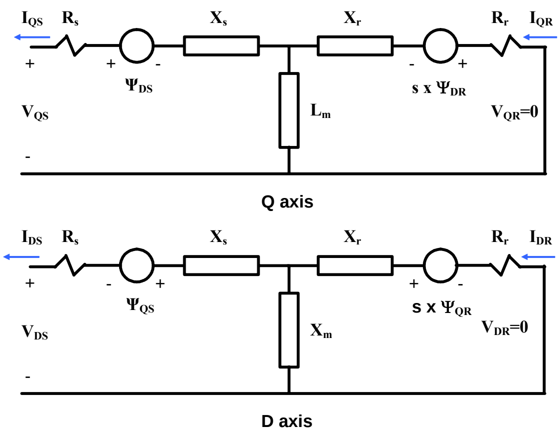

Fig 5. Equivalent circuit of the asynchronous generator in axes DQ

Next, the voltage equations of the induction machine are presented. All the amounts are in p.u except the angular frequency ($\omega_b = 2\pi f_{rated}$).

In these equations the capacitors batteries have not been considered, since they have been considered to be external to the generator. In addition, the squirrel cage induction generator has the rotor windings short-circuited, and therefore, the rotor voltage in D and Q axes will be constant and equal to zero.

$$\begin{aligned} v_{ds} &= -R_s \cdot i_{ds} - \Psi_{qs} + \frac{1}{\omega_b}\frac{d}{dt}\Psi_{ds} \\ v_{qs} &= -R_s \cdot i_{qs} + \Psi_{ds} + \frac{1}{\omega_b}\frac{d}{dt}\Psi_{qs} \end{aligned} \qquad (6)$$

$$\begin{aligned} v_{dr} &= R_r \cdot i_{dr} - s \cdot \Psi_{QR} + \frac{1}{\omega_b}\frac{d}{dt}\Psi_{dr} = 0.0 \\ v_{qr} &= R_r \cdot i_{qr} + s \cdot \Psi_{dr} + \frac{1}{\omega_b}\frac{d}{dt}\Psi_{qr} = 0.0 \end{aligned} \qquad (7)$$

Where:

$$\begin{aligned} \Psi_{ds} &= -(X_s + X_m)\cdot i_{ds} + X_m \cdot i_{dr} \\ \Psi_{qs} &= -(X_s + X_m)\cdot i_{qs} + X_m \cdot i_{qr} \end{aligned} \qquad (8)$$

$$\begin{aligned} \Psi_{dr} &= -X_m \cdot i_{ds} + (X_r + X_m)\cdot i_{dr} \\ \Psi_{qr} &= -X_m \cdot i_{qs} + (X_r + X_m)\cdot i_{qr} \end{aligned} \qquad (9)$$

Commonly, these equations are adapted for investigations of dynamic small-signal stability by neglecting the stator flux transients $\frac{d\psi_{ds}}{dt} = 0$ and $\frac{d\psi_{qs}}{dt} = 0$ [4]. This simplified representation corresponds to the 3rd order model, and it is often applied also in transient voltage stability [5] with large fluctuations of the voltage at transient grid disturbances researches.

The electromagnetic torque can be expressed by the following expression:

$$T_{ELEC} = \frac{X_m}{X_r + X_m}\left(-\Psi_{qr} \cdot i_{ds} + \Psi_{dr} \cdot i_{qs}\right) \qquad (10)$$

With this sign convention the active and reactive powers are:

$$\begin{aligned} P_{ELEC} &= v_{qs} \cdot i_{qs} + v_{ds} \cdot i_{ds} \\ Q_{ELEC} &= -v_{ds} \cdot i_{qs} + v_{qs} \cdot i_{ds} \end{aligned} \qquad (11)$$

3. Study

In order to investigate and to compare the behaviour of the two models, a double circuit, double busbar power system has been considered, as shown in Fig 6. The system short circuit level was assumed to be 16 MVA and X/R ratio was assumed to be 5.

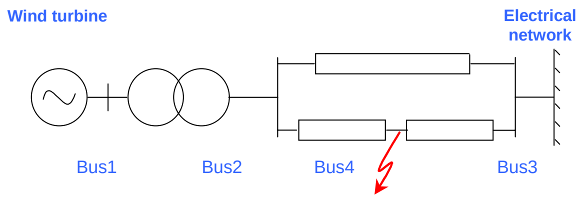

Fig 6. Double busbar power system.

Next, the results obtained with the 5th order and the 3rd order model are shown.

The made simulations have the following landmarks:

- Flat simulation from t = 0 s to t = 2 s.
- In t = 2 s a three-phase short circuit in bus 4 is applied taking place a voltage drop of 80 % in the wind generator bus.
- In t = 2.4 s is sprightly the continuous lack and the simulation until t = 5 s.

The next Figs show the behaviour of both models. In green colour the 5th order model and in blue colour the 3rd order.

Fig 7 shows the voltage results obtained by means of the simulation of both models.

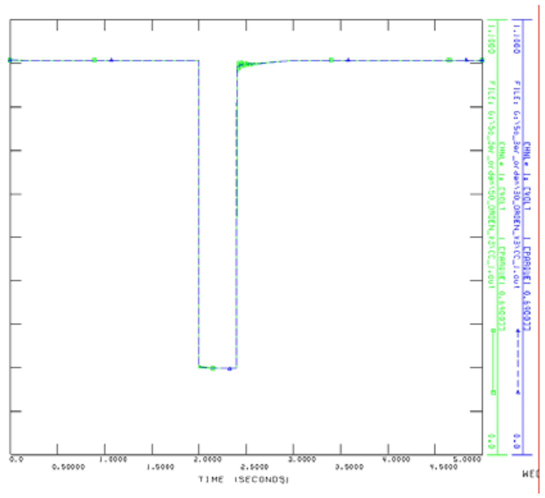

Fig 7. Response to a system fault

Fig 8 and Fig 9 show in detail the results obtained for both models in active and reactive power. As it can be appraised, the model of 3rd order can be described as the surrounding curve of the result obtained by means of the 5th order.

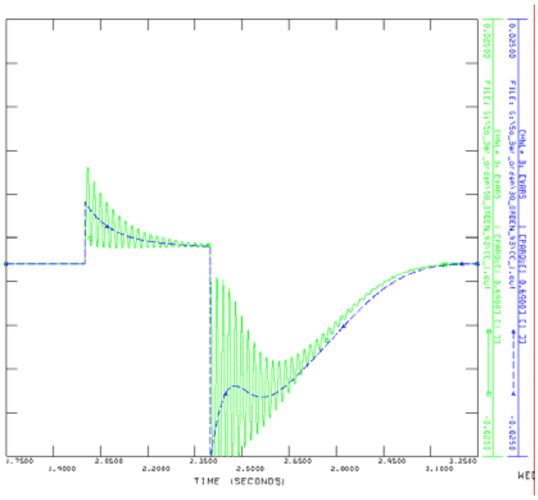

Fig 8. Reactive power obtained for the 5th and 3rd order model

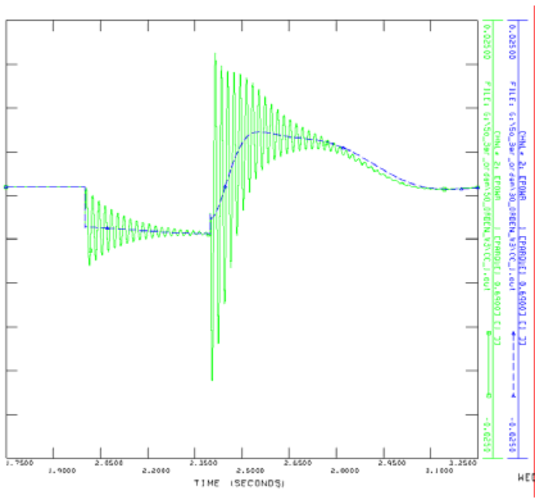

Fig 9. Active power obtained for the 5th and 3rd order model

4. Conclusions

This paper shows the behaviour of a squirrel cage induction wind turbine according to two generator models: the 5th and the 3rd order model.

In the squirrel cage induction generator, the fact of neglecting the stator transients does not imply to lose precision.

In addition using the 3rd order model, the simulation time is reduced approximately to the fourth part, reason why for simulation with great networks its use is advisable.

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