MODELING OF WIND POWER PLANTS GENERATORS IN TRANSIENT STABILITY ANALYSIS

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Abstract - The fast development of wind power generation brings new requirements for wind turbine integration into the network. After clearance of an external short-circuit fault, grid-connected wind turbines should restore their normal operation. This article presents theoretical issues about transient stability and about wind power plants generators modelling. It describes the types of wind generators used today: double fed induction generator and full scale convertor. In programs developed by different vendors (Eurostag 4.5 and PSS/E 32) have been shown a few simple examples. The transient stability was monitored.

Keywords: transient stability, dynamic modelling, wind power plants.

1. THEORETICAL ASPECTS ABOUT TRANSIENT STABILITY

According to the literature [1], [8], [9], the stability of the power systems is defined by their ability to remain in a steady state after the appearance of a small perturbation and return to an acceptable steady state after the occurrence of a large disturbance. A disturbance is defined as a sudden change or as a sequence of abrupt changes of one or more parameters of the electrical system.

Large disturbances (strong or severe) - are those disturbances that do not allow a linearization of the system of equations, that model the power system operating mode. In this case is used a system of nonlinear equations to model dynamic phenomena. Such large disturbances can be considered: three-phase short circuits, disconnections of generators, consumers or parts of the transmission network.

Small disturbances – are those disturbances that allow linearization of the system of equations, which model the regime of the system around the initial operating point. Such disturbances occur frequently in the power system, such as small variations in the consumed or generated power.

2. MAIN TYPES OF CONSTRUCTIVE SOLUTIONS

In terms of velocity, wind generators are of two types: with fixed speed and with variable speed. The ones with fixed speed use squirrel cage induction generator and the ones with variable speed can be with asynchronous or synchronous generator [2].

2.1. Fixed speed wind generator

Initially, the wind generators were operating at fixed speed. Regardless of wind speed, the rotor speed of the generator is fixed and determined by the frequency of the network, by the speed multiplier ratio and by the generator type. They are designed to achieve maximum efficiency for a given wind speed. To increase power production, some wind generators were equipped with two types of coils: one for low wind speeds (typically 8-pole) and one for medium and high wind speeds (usually 4-6 poles). Obviously these tricks were hindering the plant and led to increase of the overall equipment price.

The asynchronous generator is equipped with condensers to produce reactive power, soft starters for proper start-up and step-up transformer (0, 6 / 20 kV). The soft starter is used because the starting current of the asynchronous machine is very large (about 6 to 8 I_n), which can lead to voltage variations in a weak network.

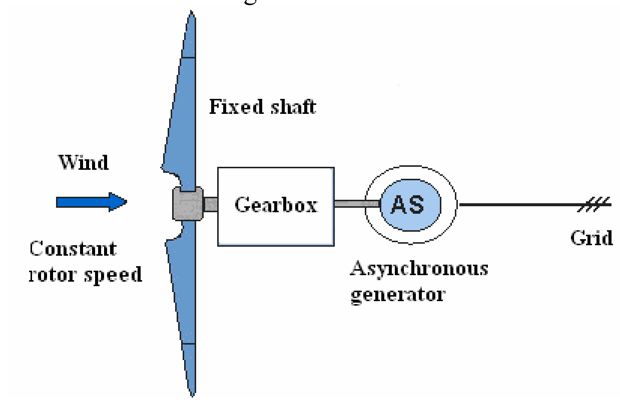

Fig. 1 - The diagram of a fixed speed wind generator

2.2. Variable speed double fed induction wind generator

This machine has the stator directly connected to the grid and the rotor connected to the grid through a bidirectional converter AC / DC / AC (figure 2). Dual fed means that the stator voltage comes from the network

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and the rotor voltage is induced by the converter. This allows operation over a relatively wide range of variable speed.

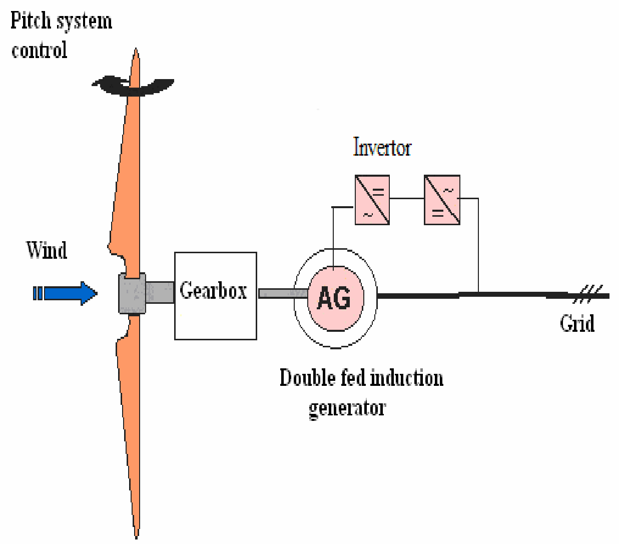

Fig. 2 - The diagram of a double fed induction wind generator

2.3. Synchronous wind generator

It contains a synchronous generator and a bidirectional frequency converter AC / DC / AC, through which it can connect to the network. The synchronous generator is more expensive and mechanically complex than the double fed induction generator. It is also used in applications where all nominal power produced crosses the converter, which is smaller than the one at double fed asynchronous generators. Synchronous generator has the great advantage that it doesn't need a magnetizing reactive current from the grid. The magnetic field can be created by permanent magnets (figure 3) or classical excitation coil – with wound rotor.

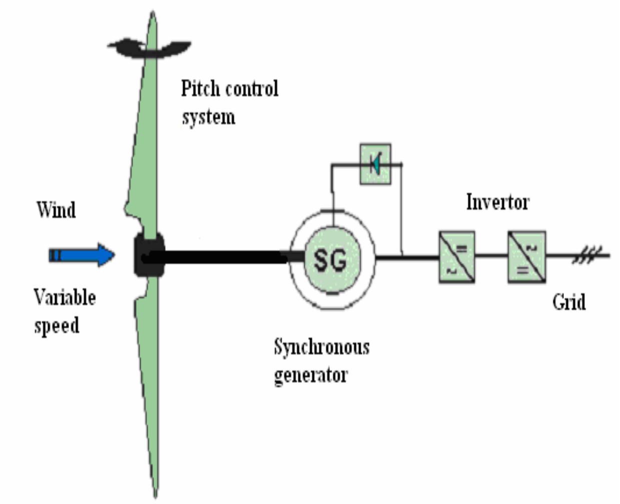

Fig. 3 - The diagram of a synchronous wind generator

Synchronous generator is more expensive at 1.6 times the double fed induction generator.

Main advantages of variable speed wind generators in relation to the fixed speed are:

- Improved dynamic behaviour which results in reduced mechanical application of the shaft and reduces power fluctuations;
- Better quality of electricity;
- Increasing the power produced.

Disadvantages compared with fixed speed wind generators are:

- More complicated electrical system;
- Use of multiple components;
- Losses of power in the incorporating power electronics items;
- High cost.

3. MODELLING OF WIND POWER PLANTS

3.1. The dynamic modeling of wind power plants (WPP) in Eurostag

The Eurostag standard model library contains seven different models of wind turbines [4]:

1. **Model of wind turbine coupled with an asynchronous generator. This model represents a fixed speed wind turbine**. The turbine is connected to a squirrel-cage asynchronous machine.

2. **Model of wind turbine with pitch control coupled with an asynchronous generator.** This model represents a fixed speed wind turbine. The turbine is connected to a squirrel-cage asynchronous machine whose speed is controlled with pitch control.

3. **Model of wind turbine equipped with a doubly-fed induction generator (DFIG).** This model represents a variable speed wind turbine. The turbine is connected to an asynchronous generator whose stator is directly connected to the grid while rotor is connected to the grid via power electronics. The DC link of such power electronics is not represented. The machine disconnects and reconnects to the grid in case of fault.

4. **Model of wind turbine equipped with a doubly-fed induction generator (+ crow bar +chopper).** This model is based on the DFIG model mentioned here above. The DC link is here represented with a crowbar and a chopper. This allows the machine to remain connected to the grid in case of fault.

5. **Model of variable-speed wind turbine with direct driven synchronous generator**. This model represents a variable speed wind turbine. The turbine is connected to a synchronous generator with permanent magnets excitation. The generator is connected to the grid through a full load frequency converter.

6. **Universal model of wind farm**. This model represents a wind power plant (of doubly-fed induction generators or direct driven

synchronous generators). Global injection and dynamic behaviour are considered. It is suitable for power system studies of a grid where wind farms are connected or for wind farm connection studies. There is no single representation of a wind turbine and it does not detail the internal grid of the wind farm.

7. **Universal model of wind farm with power/frequency control**. This model is based on the Wind farm model mentioned here above. The farm is here equipped with a power/frequency control for primary reserve participation.

3.1.1. Example using the double fed induction generator (DFIG) model

We consider the following simple system (figure 4) consisting of: three generators (one equivalent synchronous machine (P_N=55000MW) at node NHV3, a classical generator at node NGEN and one double fed induction generator DFIG), 3 substations (380/150 kV, 380kV/24kV and 150/0.69/0.69 kV), a consumer at node NLOAD and three electrical lines (380kV).[3]

The double fed induction generator (DFIG) driven by wind (wind turbine) is represented by an induction machine (WT_STAT) with the rotor connected to a converter (WT_GSC).

WT_STAT is a DFIG connected to node NST and represents an aggregated model of 10 wind turbines of each 2MW.

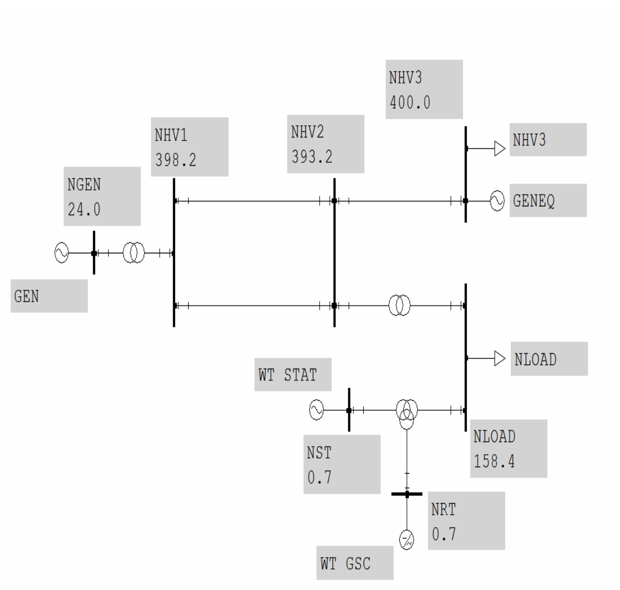

Fig. 4 - The analyzed system for the double fed induction generator model (DFIG)

The behavior of the DFIG WT_STAT is controlled by three dynamic models. The structure and the links between the macroblocks of the DFIG model are shown in the diagram hereunder.

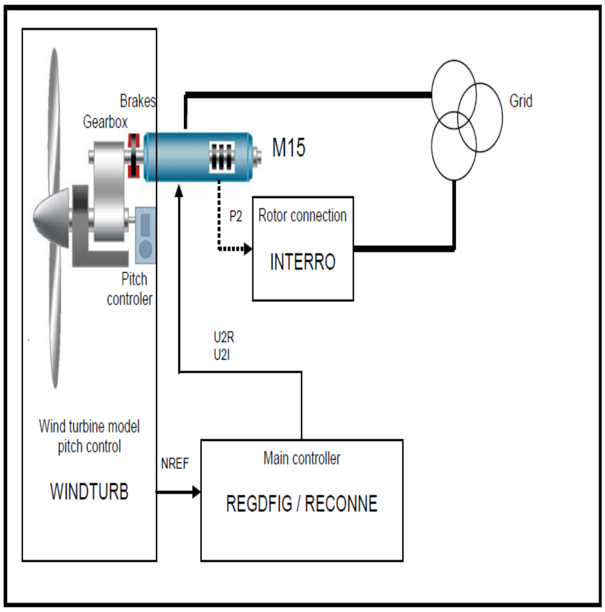

Fig. 5 - Structure and the links between the macroblocks of the DFIG model

The macroblock WINDTURB calculates the mechanical torque CM and the optimal rotor speed based on the actual wind speed @VENT. The reference rotor speed NREF is transmitted to the macroblock REGDFIG.

The macroblock REGDFIG calculates the rotor voltages U2R and U2I to control the rotor currents and calculates the rotor active power R2.

The macroblock RECONNE manages the operation of the induction machine while the stator is disconnected in case of disturbance on the network. The rotor voltage regulation is then carried out in the macroblock RECONNE and the calculated values are used in REGDFIG. The stator opening and reclosing is managed by an automaton (DFIG stator protection).

The macroblock INTERRO controls the converter WT_GSC and models the grid side converter. The value of the active power generated by the rotor P2 is transmitted to INTERRO via a measurement block. So WT_STAT and WT_GSC are coupled.

In case of a voltage drop, due to a short-circuit for example, an automatic device (DFIG stator protection) is able to disconnect temporarily the stator from the network, and to reconnect it when the situation has become normal again. While the stator is disconnected from the network, the functioning of the DFIG is managed by the macroblock RECONNE. The rotor voltage regulation is made in RECONNE and the calculated values are used in REGDFIG.

Recently Transmission System Operators have imposed more restrictive grid connection conditions to wind farm in Europe. Wind turbines are now required to remain connected to the grid during voltage dips of certain depths and durations. Also active power production has to be restored as soon as the grid voltage drop is allowed, provided the wind turbine reconnects as soon as the voltage is restored. In the case that the voltage drops below the thresholds set by the TSO or the voltage is not restored within the specified time, the wind turbine will disconnect from the grid, reduce its speed (or

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even initiate a complete stop) and a slower reconnection will occur.

The default values for the stator disconnection thresholds are:

-terminal voltage below:

-0.75 p.u. for at least 0.08s,

-0.85 p.u. for at least 0.4s,

-0.9 p.u. for at least 60s.

-the output current above: 2 p.u. for at least 0.3s.

There were considered the following events to be simulated:

-from **t=20s** to **t=30s**: an increase of the wind speed;

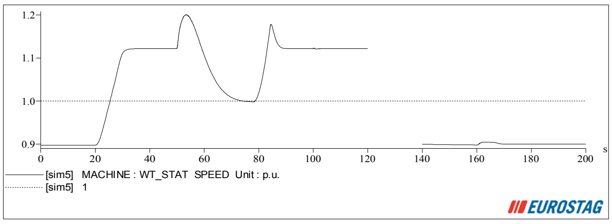
-when **t=50s**: short-circuit at 50% of the line NHV1-NHV2-1;

-when **t=100s**: decrease by 50% of the load at NLOAD;

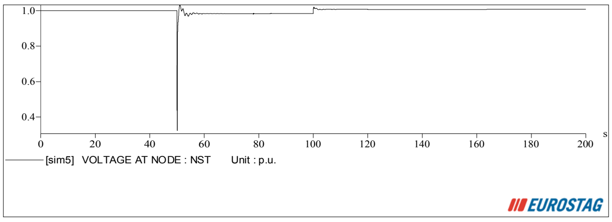
-when **t=120s**: shut down of the wind turbine;

-when **t=140s**: start-up of the wind turbine. The machine is connected to the network and its speed is set to the “rotor speed for synchronisation” specified for the DFIG in the dynamic file(.dta). The pitch angle is set to BETADEM specified by the macroblock parameter and the wind speed is set to VENTDEM. BETADEM is a pitch angle value for which the output power is zero for a wind speed of VENTDEM.

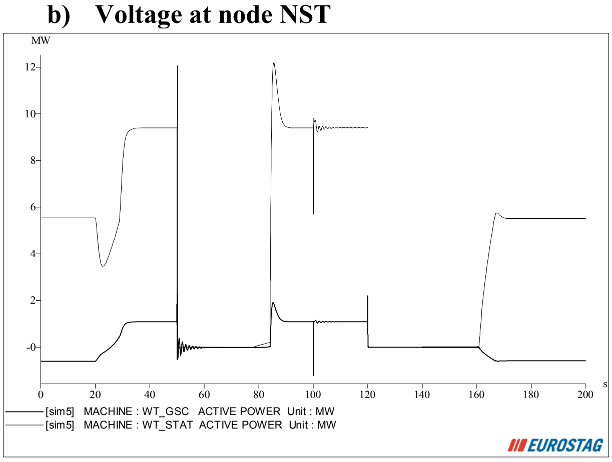
-when **t=160s**: enabling the pitch angle regulator and the wind turbine begins to inject power into the network.



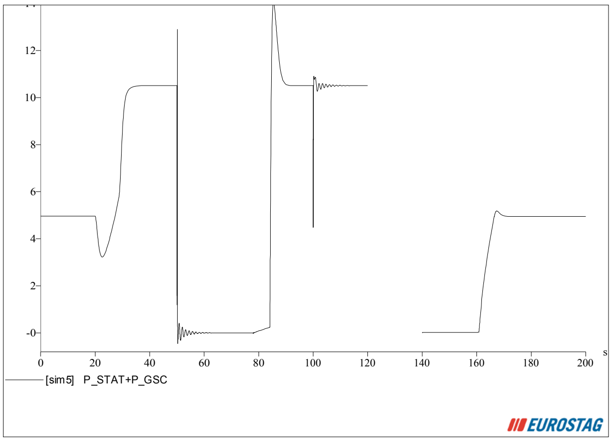
a) Speed of the machine WT_STAT



b) Voltage at node NST



c) Active power at WT_GSC and WT_STAT



d) Sum of Active power at WT_GSC and WT_STAT

Figure 6 - The simulation results

3.2. The dynamic modelling of wind power plants (WPP) in PSS/E

The program PSS/E 32 (Power System Simulator for Engineers), supplied by Siemens, has four standard models for wind power plants (WPP) [6], [7]:

- **Type 1**: Wind turbine with directly grid connected induction generator with fixed rotor resistance (typically squirrel-cage);
- **Type 2:** Wind turbine with directly connected induction generator with variable rotor resistance;
- **Type 3**: Wind turbine with double-fed asynchronous generators (directly connected stator and rotor connected through power converter);
- **Type 4**: Wind turbines connected fully through a power converter.

Table 1 presents the main models in PSS/E 32 library for wind power plants.

Table 1. The main modules for wind power plants in PSS/E 32

Generic model	WT1 (type 1)	WT2 (type 2)	WT3 (type 3)	WT4 (type 4)
Generator	WT1G	WT2G	WT3G	WT4G
Controller		WT2E	WT3E	WT4E
Turbine	WT12T	WT12T	WT3T	
Pitch system			WT3P	
Pseudo governor	WT12A	WT12A		

We will continue with transient stability case studies for type 3 of wind generators.

3.2.1. Example for type 3 wind generator (DFIG)

The figure below illustrates the connection between the four modules in the type 3 of wind generator [5].

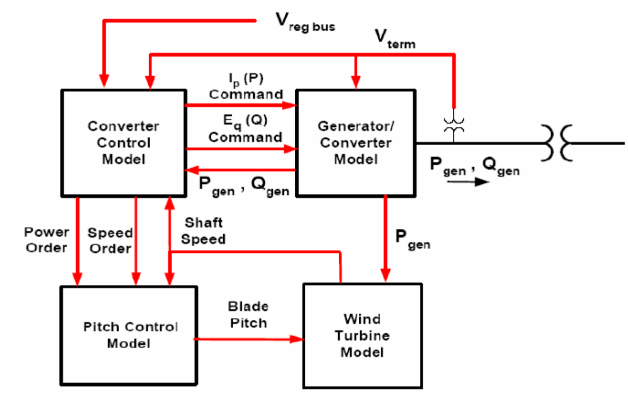


Fig. 7 - The interaction between the four modules of type 3 wind generator

The most important module is the one that shapes the electrical part of the generator (Figure 8). In this module, parameter VARFLG can cause constant reactive power control (VARFLG = 0), reactive power control (VARFLG = 1) and power factor control (VARFLG = -1). The parameter VLTFLG is operating the control voltage at the terminal (if VLTFLG is different from 0).

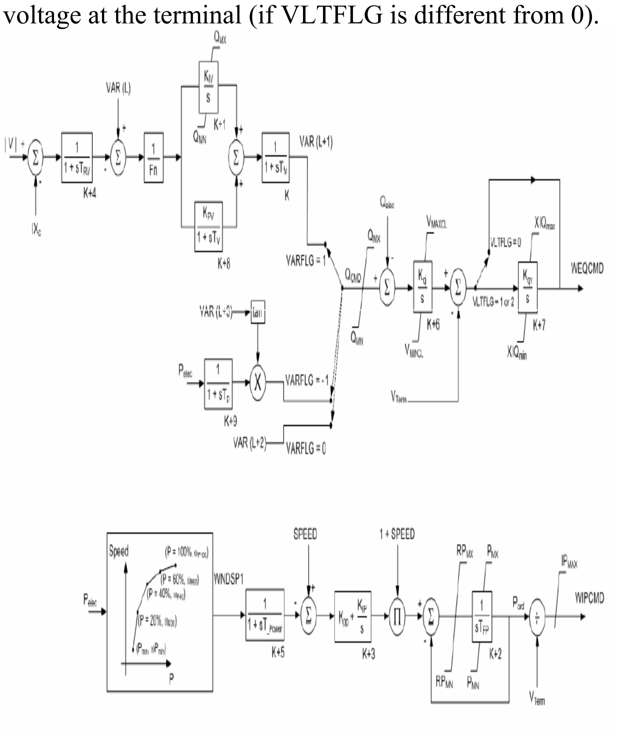


Fig. 8 - Electric control module (WT3E)

We consider the following simple system (figure 9) consisting of: two generators (one classical and one double fed asynchronous wind generator), two substations (154/34 kV and 34/0.6 kV), a consumer and three electrical lines. The active power of the wind power plant is considered the equivalent of 67 turbines of 1.5 MW. Parameter VARFLG was considered equal to -1 (control power factor)[7].

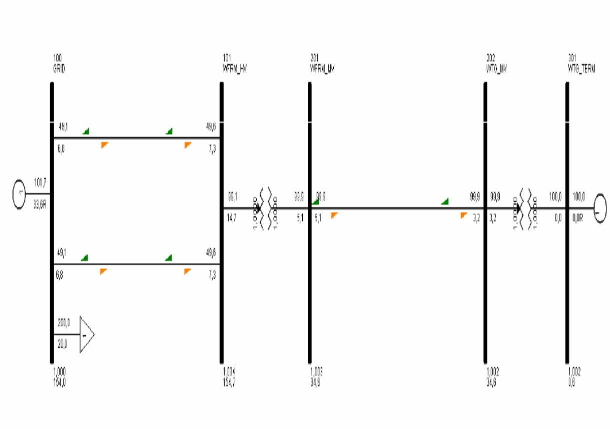
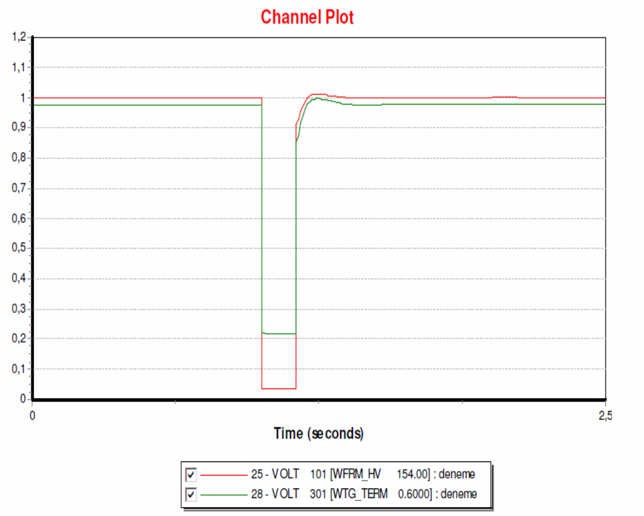
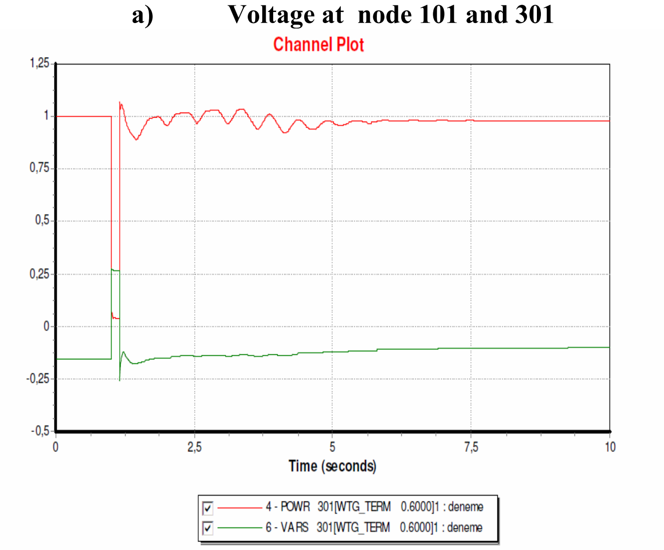


Fig. 9 - The analyzed system for type 3 of wind generator

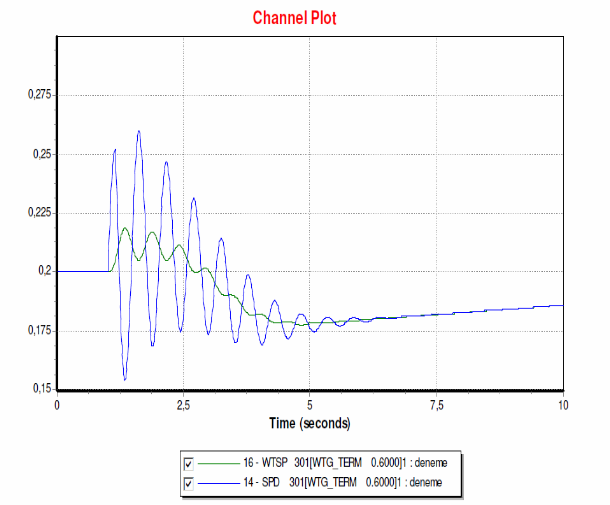
It is considered a fault (three phase short circuit) on line 100-101. Short circuit is removed in stage I of the basic protection (Zl = 150 ms). The results are shown in the figures
below.



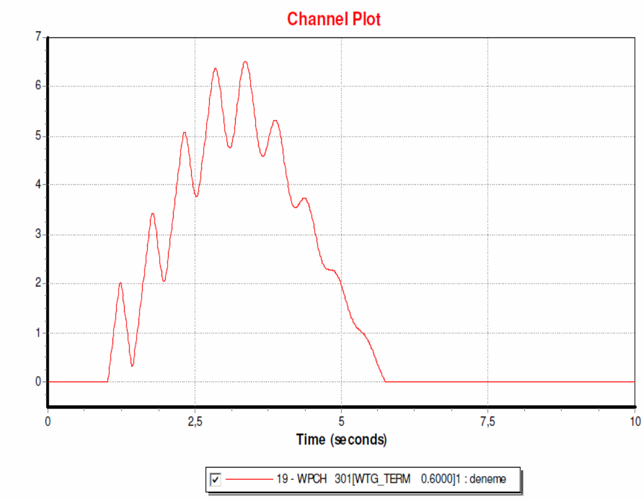
a) Voltage at node 101 and 301



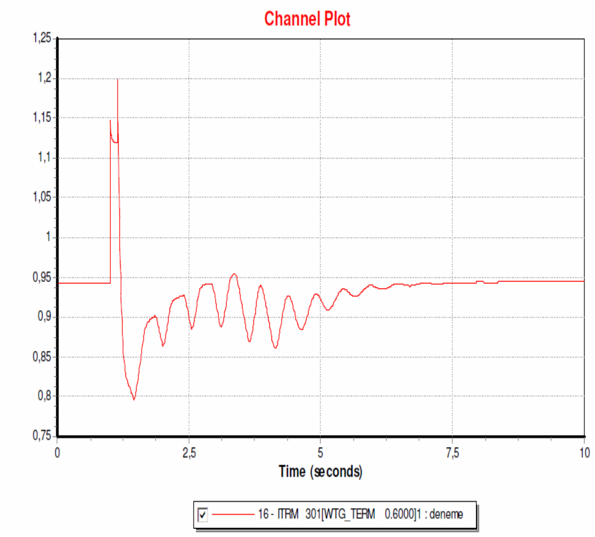
b) Active and reactive power at node 301



c) Rotor speed at node 301



d) Pitch control system speed at node 301



e)The exitation current at the classical generator

Fig. 10 - The simulation results

4. CONCLUSIONS

This article presented theoretical issues about transient stability and wind power plants generators modelling. It described the types of wind generators used today: double fed induction generator and full scale convertor. It presented a few simple examples in programs developed by different vendors (Eurostag 4.5 and PSS/E 32) and the transient stability was studied, when applying an external short-circuit fault in the system.

It is necessary to compare these models with models developed by generic manufacturers of wind generators, to correct the dynamic behaviour associated to the wind power plant in the models used in transient stability analysis.

Eurostag gives the facility to model a large variety of wind power plants types and in detail.

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