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Simulation of operation of wind power plants

This article is oriented in the area of wind power plant operation modelling. World installed power of wind power plants reached 200 GW in year 2010. Interest of investors in wind power plants installing is still very intensive. Installed capacity 2000 GW is expecting in 2020. Electric power systems are not adapted for this situation because these sources are dispersed. Therefore it is necessary to exam their impact on systems before their connection to the network. The article presents a brief description of possibilities of modelling of DFIG-based wind power plants in EUROSTAG software in case of network short circuits.

Keywords: wind power plant, simulation, operation conditions

I. INTRODUCTION

Wind is the important source of energy. The energy of air mass flow is approximately 500 times bigger than power of all power stations in the world. Today it is used only small part of this energy, but in year 2020, installed capacity growth to 2000 GW is expecting. Transformation from the wind kinetic energy to the mechanic energy was known in 1st century. However, in Europe, the wind mills were used from 10th century. An air circulation is developed because of unbalanced air heating by solar radiation. The air flows horizontally considering the earth surface. The air motion is characterised by direction and by velocity. Wind turbines use mainly the wind of velocity in range 5 – 13 m/s. They are disconnected from a network at a velocity exceeding 24 m/s. Wind speed has important impact on output power of wind power plants according to the following formula

$$P_e \approx 0.2 \cdot D^2 \cdot v^3. \tag{1}$$

The power of wind turbine P_e (W) depends on square of rotor diameter D (m) and on cube of wind velocity v (m/s). The wind velocity decrease by 1 m/s requires the diameter increase to (1.5 – 2)·D to keep the same level of the power. For the successful wind energy utilisation, it is the most important to choose suitable locality with small direct and speed variability and with a sufficient amount of hours per year with necessary velocity.

According to increasing of a number of wind power plants a fear from their negative impact on Electric Power System (EPS) operation exists. Therefore it is necessary to deal with operational problems of these sources in advance of their installation to EPS. For this purpose it is useful to use different simulation tools. There are many software packages capable to solve demanding power engineering problems [1], [2], [3]. The possibilities of wind power plants modelling in EUROSTAG software are mentioned in this article [1], [4].

II. MODELLING OF WIND POWER PLANTS

Wind power plants are dividing according to rotation axis of rotor into horizontal and vertical wind power plants. The most used ones are wind power plants with horizontal axis.

Main types of wind turbines with horizontal axis according to the technology are wind turbines with asynchronous generator with short-circuit armature, DFIG-based wind turbines and synchronous-based wind turbines. The most modern wind power plants with horizontal axis are DFIG-based wind power plants.

The model of the doubly fed induction generator (DFIG) is composed of the following different parts:

- Model of the doubly-fed machine and the converters;
- Aerodynamic model of the wind blades;
- Model of the wind turbine control (Pitch controller, Power controller and Main controller).

DFIG is an induction generator where the rotor windings are not short-circuited, and are connected through a back to back power electronics converter to the machine terminals (to the network). The converter controls the rotor speed and the reactive power injected on the network.

Rotor speed are able to change until 30 % around a synchronous speed and so to adapt on characteristic of wind turbine and so to increase an active power delivered into a network (according to [5] approximately about 5 %).

In the case of voltage dip a machine's behaviour depends on its construction. The most perfect applications are able to be disconnected from the network.

General control scheme of DFIG-based wind power plant is presented in Fig. 1.

The control functions are divided into 3 blocks called Main Controller, Pitch Controller and Power Controller.

The main controller manages the overall control functions, whereas pitch and power controller are subordinate units. The objective is to determine the optimal values of the WT speed and the pitch angle for a given wind speed in order to maximize the electrical power produced.

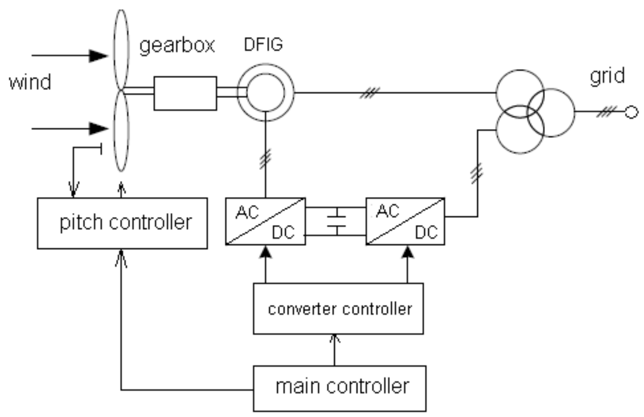

Figure 1. Control scheme of DFIG-based wind power plant.

There are two main operating modes:

1. When the wind speed is below a certain threshold, the turbine is not able to produce the rated power. In this case, the partial Load Controller is activated. It controls the turbine speed, for maximizing the produced power.
2. When the wind speed is above the rated value, the full Load Controller is activated. It controls the pitch angle limiting the produced power to the rated value.

Software's package is able to model and to visualise behaviour of EPS from a moment of fault occurred in a system to a moment of fault clearing (software uses so-called the conception of generalised stability). Conception of generalised stability covers a frequency range from 0.001 Hz to 10 Hz (from rotor's transient states to slow thermal states of boilers or slow states of central control units) [4].

EUROSTAG enables to study a large-scale power system over long periods with no modelling changes. Typical examples of these are: finding the critical clearing time, checking the keeping up of synchronism after various disturbances, strategies for automatic load-shedding, contingency analysis under abnormal operating conditions (preventive security), behaviour of the power system in emergency or in extreme conditions (voltage collapse, loss of synchronism, resynchronization, etc.), dynamic stability of the machines, regulations, transmission system around an operating point of the power system, design and tuning of the local control systems (Speed governors, AVR, transformer tap controllers, ...), design, co-ordination and adjustment of protection systems for power plants and transmission networks, design of centralized control and protection systems, opportunity studies on different technologies, analysis of the behaviour of industrial systems [6]

The structure and the links between the macroblocks of the DFIG model in EUROSTAG are shown in Fig. 2.

Model of the wind power plant consists of the model DFIG („M15“), the model of current's injector and so-called macroblocks WINDTURB, REGDFIG, RECONNE and INTERRO.

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

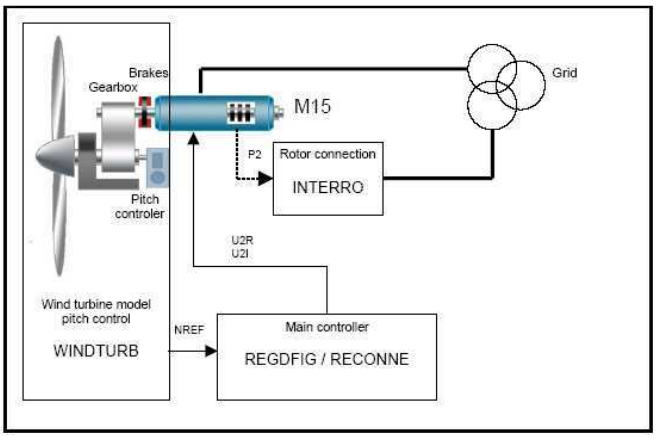

Figure 2. Macroblocks connection of the DFIG model.

The macroblock REGDFIG calculates the rotor voltages (U2R and U2I) to control the rotor currents and calculates the rotor active power (P2) based on NREF and actual rotor speed.

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 injector 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 parameterized interface variable. So WT_STAT and WT_GSC are coupled.

III. COLLABORATION OF WIND POWER PLANTS WITH ELECTRIC POWER SYSTEM

Modelling of collaboration of wind power plants with EPS was realised with 2 wind power plants operated in the power system according to Fig. 3.

Each of them has rated active power 20 MW. Each power plant consists of 10 DFIG-based wind turbines with rated power 2 MW. The model of each wind power plant is represented by comprehensive asynchronous generator WT_STAT and by comprehensive exciter WT_GSC which are interconnected with three-winding transformer WT. This transformer represents all three-winding transformers which are a part of DFIG-based wind power plant. Therefore EUROSTAG take into account two wind power plants (WT_STAT1 with 20 MW and WT_STAT2 with 20 MW). Next parts of the electric power system are generator with rated active power 220 MW and nominal voltage 15.75 kV, transformer T1 (15.75 kV/400 kV) and transformer T2 (400 kV/110 kV), power lines 185AlFe6 (NHV1-NHV2 and NHV2-NHV3 with length 20 km and NHV2-NLOAD1 and NHV2-NLOAD2 with length 10 km) and loads at the nodes NHV1 (200 MW, 60 MVAr) and NHV3 (20 MW, 6 MVAr).

Various operation conditions including network short circuits were examined. They were described in [1].

The following part describes a response of EPS and wind power plant to network short circuits in detail.

Three-phase short circuit on transmission power line NHV2 – NHV1 (1) close to node NHV2 occurred in time 101 s. After 100 ms the transmission power line was disconnected by line protection device. Three different cases were simulated in EUROSTAG software.

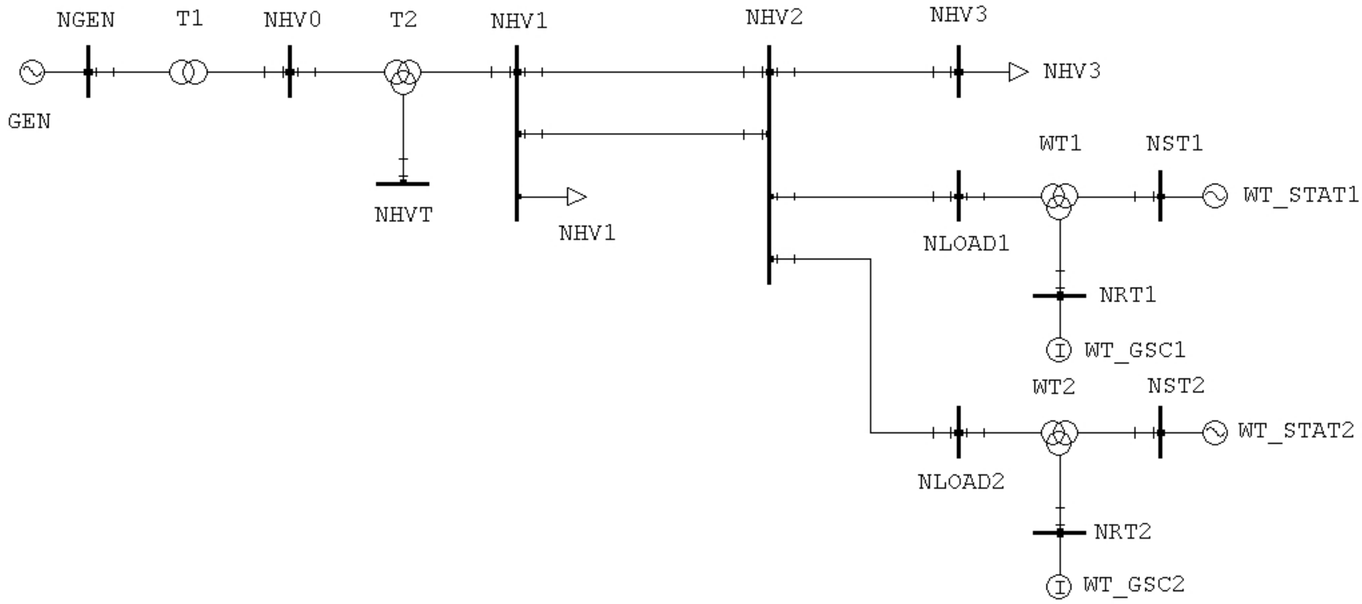

Figure 3. Scheme of modelled electric power system.

Case 1: DFIG stator protection device did not respond to this fault because a time delay of this device was set on 150 ms. The voltage at node dropped during short circuit. Elimination of fault led to quick reconnection of power plant (Fig. 4).

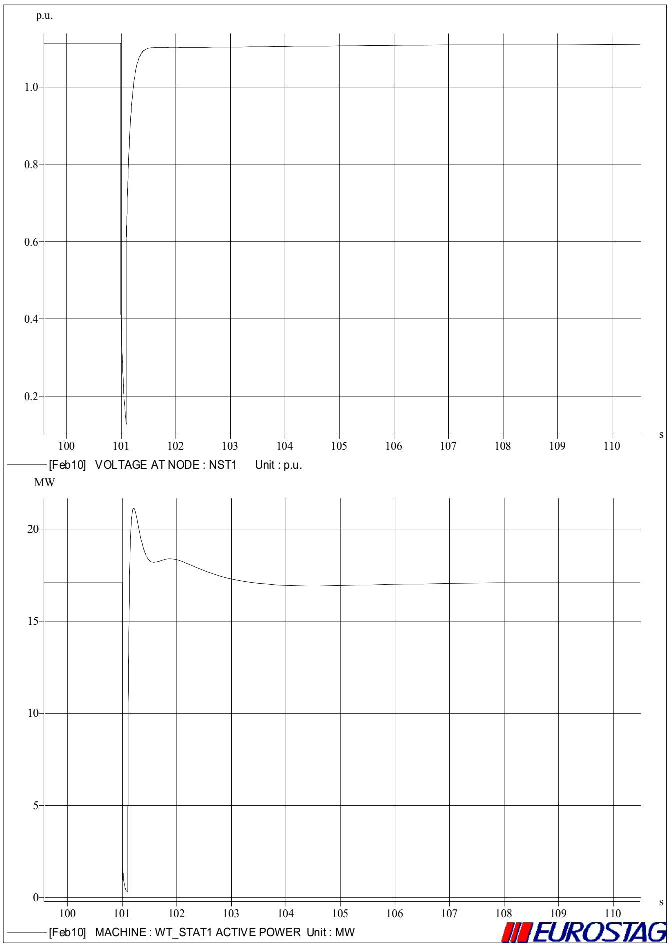

Figure 4. The evolution of the voltage at node NST1 and the active power produced by the WT_STAT1.

Case 2: DFIG stator protection device responded to this fault after 80 ms and power plant made slow reconnection. The slow reconnection solution brought the rotor to the synchronous speed and authorized the stator reconnection even if the voltage was not restored (Fig. 5).

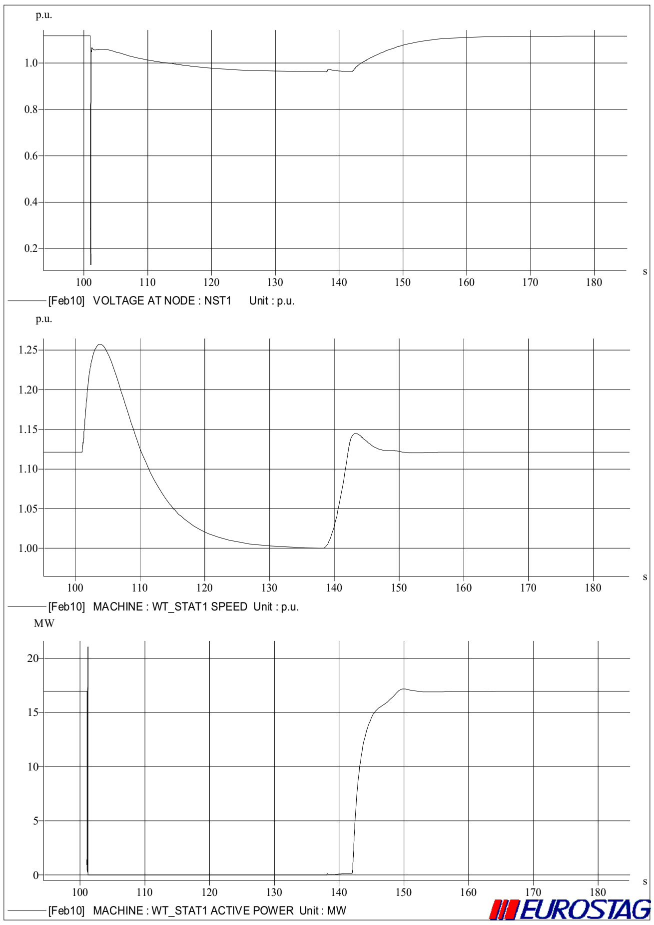

Figure 5. The evolution of the voltage at node NST1, the speed of the machine WT_STAT1 and the active power produced by the WT_STAT1.

Case 3: DFIG stator protection device responded to this fault after 80 ms and power plant made fast reconnection. The monitored variable was voltage at the stator connection node. This mode authorized the stator reconnection as soon as the voltage reached threshold 0.9 p.u. (Fig. 6).

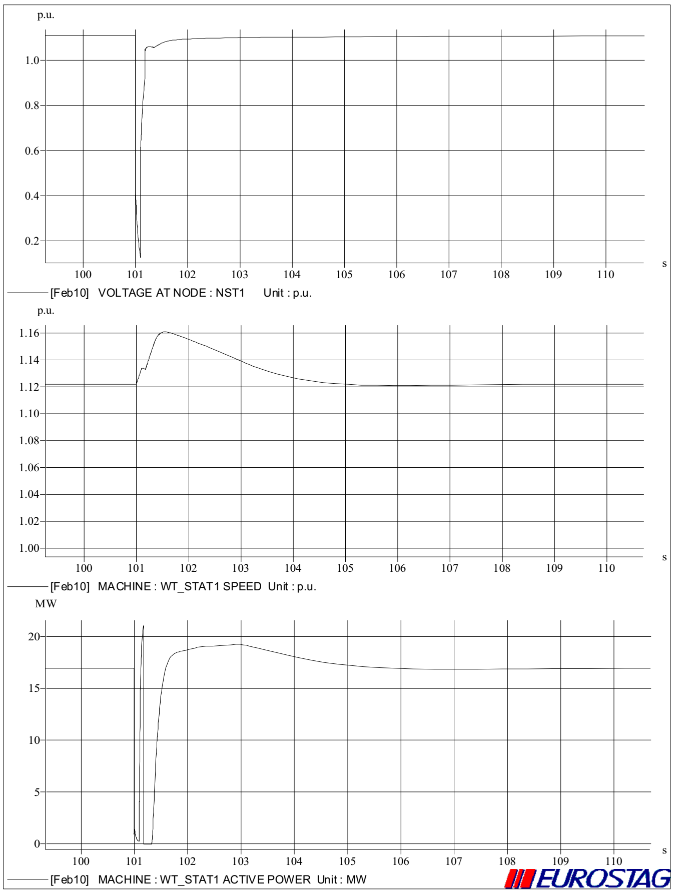

Figure 6. The evolution of the voltage at node NST1, the speed of the machine WT_STAT1 and the active power produced by the WT_STAT1.

IV. CONCLUSION

Nowadays, renewable energy sources utilisation is very actual task. Wind power plants are one of the renewable electricity sources which have significant contribution in world energy production. Interest of investors in wind power plants installing is very intensive also in Slovakia (some GW), but centralized configuration of electrical network in not able to accept it.

Therefore it is necessary to exam impact of all distributed sources on system before their connection to the network to preserve reliability of EPS and quality of electricity [7], [8].

For this purposes it is very suitable to use EUROSTAG software which enables various studies, e.g.:

- Checking the keeping up of synchronism after various disturbances.
- Behaviour of the power system in emergency or in extreme conditions (voltage collapse, loss of synchronism, resynchronisation, etc...).
- Dynamic stability of the machines, regulations, transmission system around an operating point of the power system.
- Design, co-ordination and adjustment of protection systems for power plants and transmission networks.

Moreover, all those possibilities are available for balanced or unbalanced network conditions.

Results of modelling presented in this article correspond with theoretical knowledge and showed suitability of computer modelling of wind power plants operation in EUROSTAG software.

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