EUROSTAG

Newsletter

N°16 January 2005

## Editor’s Note

### *EUROSTAG Release 4.3 : The unique expert tool*

*Release V4.3, is now available. It is mainly electrical modeling oriented. Eurostag is and will remain the reference tool worldwide for dynamic simulation.*

*The new release includes a set of new models, applicable in different “hot” fields of interest such as Distributed Generation and Power Converters. These models are crucial for the power system of tomorrow (as Distributed/Dispersed Generation and Power Electronics will increasingly affect the power systems dynamic behaviour).*

*A new model of machine, the Double Fed Induction Generator, is also introduced in order to allow a detailed modeling of wind farms.*

*A new generic load model is added allowing the representation of the distribution network including a proportion of rotating load (induction motors).*

*New functionalities for load pattern design have been developed in order to make easier the input of a study case.*

*From the Graphical User Interface, the release V4.3 can be seen as a consolidation of V4.2 one, particularly in term of user-friendliness and Windows compliance.*

*I am pretty sure that you will be glad to get this new release.*

**Arnaud Valenti**

## Contents



### Some new Users Club members

*We welcome new members in our Users Club:*

**HEP-Prijenos (Croatia)**
**University of Ljubjana (Slovenia)**
**North China Power Group (China)**
**Universidad de la Rioja (Spain)**
**Université d’Artois (France)**
**Riga Technical University (Latvia)**
**Kunkuk University (S.Korea)**
**Carnegie Mellon University (USA)**
**Jadavpur University (India)**
**Chubu company (Japan)**

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## ZOOM on the Tsinghua University , Beijing, China

**S**ituated on several former royal gardens of the Qing Dynasty, surrounded by a few historical sites in northwest Beijing, is the campus of Tsinghua University.

**T**singhua University was established in 1911 originally as "Tsinghua Xuetang," a preparatory school for students who would be sent by the government to study in universities in the United States. The school was renamed "Tsinghua School" in 1912. The university section was instituted in 1925 and undergraduate students were then enrolled. The name "National Tsinghua University" was adopted in 1928, and in 1929 the Research Institute was set up.

**T**singhua has flourished since 1978, with the re-establishment of the departments in sciences, economics and management, and the humanities. The Tsinghua graduate school has been recognized nationally, ranking first in the National Evaluation of Graduate Schools. The School of Continuing Education makes the best use of modern information technologies, as well as the advanced educational resources at Tsinghua. Currently, the university consists of 44 departments distributed in 11 schools, including the schools of sciences, architecture, civil engineering, mechanical engineering, information science and technology, humanities and social sciences, economics and management, law, arts and design, public policy and management, and applied technology.

**W**ith a splendid legacy accumulated over the past 90 years, Tsinghua has retained its character and charm while promoting rigorous scholarship research, ensuring academic and educational prestige in China and abroad. The university currently has over 7,100 faculty and staff, with over 900 full professors and 1,200 associate professors, including 24 members of the Chinese Academy of Sciences and 24 members of the Chinese Academy of Engineering.

**T**he educational philosophy of Tsinghua is to "train students with integrity." Among the over 100,000 students who have graduated from Tsinghua since its founding are many outstanding scholars, eminent entrepreneurs and great statesmen remembered and respected by their fellow Chinese citizens. Hence, to study at Tsinghua is the dream of many Chinese youth. Presently, Tsinghua has over 20,000 students, including 12,000 undergraduates, 6,200 master's degrees candidates and 2,800 doctoral candidates.

**W**ith strong support from the nation and in the face of unprecedented opportunities, Tsinghua University is poised to become a world-class university in the 21st century.

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## ZOOM on NCPG in China

Before introducing North China Power Grid, let me describe the general configuration of State Power in China. Territory of China is so vast that it is split in several trans-regional grids, named Northeast China, North China, East China, Central China, Northwest China and South China. At present the State Power is striving for wide area connection and some projects are in progress. Up to now NCPG is connected to Northeast China through 500kV AC link. In addition, the connection to Central China has been commissionned. So it is clear that the operation of NCPG have to take into account adjacent regional grids.

North China Power Group, a wholly-funded subsidiary of the State Power Company, is a legal entity, made up of a number of enterprises, including Hebei Provincial Power Company, Shanxi Provincial Power Company, Tianjin Power Company and Beijing Datang Power Generation Company. NCPG is specified in such business as power grid management, power generation, capital construction, equipment manufacturing and scientific research. The service area totals 373,000 square kilometers and population reaches 122 million, covering Beijing and Tianjin municipalities and Hebei and Shanxi provinces.

By the end of 2002, the total installed capacity reached 49,802MW, 93% of which are fossil-fired power and the rest are hydro power. The 500kV and 220kV transmission lines extend to 5,043km and 21,115km respectively. North China Power Grid boasts 16 500kV substations and 233 220kV substations, with a receptive transformation capacity of 18,277 MVA and 58,442 MVA. It is shaped by looped circuits, with 500kV transmission lines as mainstay frames and 220kV transmission lines as basic frames.

For more intensive use of available transmission facilities, NCPG have used SVC at 500kV lines since 2001 and next step in the near future (may be one or two years) will be the use of TCSC. At present, investigation are focused on SVC, TCSC and SSR, HVDC, and etc.

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# EUROSTAG

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# EUROSTAG USER'S CLUB MEETING BUCHAREST, ROMANIA, APRIL 29$^{TH}$, 2004

The 7th meeting of the Eurostag User's Club was hold in Bucharest on April 29th, 2004. It was chaired by Prof. Alain Germond, from EPFL (Lausanne, Switzerland). The Club meeting was hosted by Transelectrica, the TSO of Romania. The 26 participants were welcomed by Mr Octavian Lohan. We spent a great time together and we are very grateful to Transelectrica for that.

## 1 Introductory lecture : "Doctoral School Researches in Power Systems"

presented by Prof. Mircea Eremia, "Politechnica" University of Bucharest

Prof. Eremia introduced the doctoral school structure in Romania and focused especially on the following topics :

- Voltage stability assessment using :
  - Global and Local Indices (Constantin Bulac). These static methods are based on sensitivities analysis (local indices) of nodal voltage or reactive power to the demand or based on "power distances" calculations (global indices)
  - Intelligent informatics systems (Adrian Bulac) are artificial neural networks.
- Dynamics equivalent of power system, (Alexandru Unguroiu). The aim is to define a reliable dynamic equivalent reduction method applicable to large systems using modal analysis
- FACTS device
  - Use in load flow control, (Constantin Bulac). The ability of such device to redispatch the load flow in case of congestion for instance and required model is presented.
  - Oscillation damping, (Daniel Radu).
- Electricity market
  - Role of the Ancillary services (Lucian Toma) in voltage and frequency control, optimisation of losses and black start capability.
  - Short term Load forecast (Silviu Vergoti) based on neural network.

## 2 Applications of Eurostag : the contributions of the users

### 2-1 Interconnecting zones

#### "Outcomes of reconnecting the 2 UCTE synchronous zones for the national power grid system transient steady - state"

presented by Mrs Rodica Balaurescu, Transelectrica

The interconnection zone includes countries of the south eastern of Europe such as Romania, Bulgaria, Yugoslavia, Greece, Macedonia…

The first issue concerned the optimization of PSS settings of specific units (Portile de Fier) for interconnected operation especially for the mitigation of the interarea oscillations. Special attention has been given to the system security (mainly oscillation damping and stability limits) for relevant scenarii of maintenance (equipment outage).

#### "Comparison of real-time experiments on the Siberian Power System with Eurostag simulations"

presented by Prof. Alain Germond, EPFL

The full-scale experiment made in the Siberian Interconnected Power System in November 2002 is a good base for preliminary investigation of the possibility of the East-West interconnection. Indeed, we have to make sure that the program and the models being used for more than 10 years for long-term stability assessment in power systems, simulates dynamics properly.
Initial status is Eastern and western parts of the Siberian disconnected. Then the power system became connected by one 500 kV circuit breaker. During the experiment, the power flow (in both directions) through the circuit breaker was made such that, on its disconnection, a frequency deviation of ± 0.3 Hz in each part of the power grid was reached.
This experimentation has demonstrated the feasibility of the validation of the power system mathematical model at low frequency.

## 2-2 Wind Generation

The importance of wind energy in electric systems is increasing. In Europe in end 2003, there is already 28519 MW installed with an annual growth of 23%. Thus it is important to be able to perform:
- studies to assess the dynamic behavior considering the wind turbines already installed in a given network,
- prospective studies on wind energy grid penetration in order to evaluate the impact and improve the integration of this type of production.

In this context, Eurostag Users and developers have developed several wind turbine models for dynamic simulations. During this User's club, three contributions were presented:

### "Wind turbines modeling approaches for dynamic power system simulation"

presented by Mr Joris Soens, K.U Leuven – ESAT – ELECTA

- a detailed modeling approach for single wind turbines (squirrel cage Wind Turbine Generator and doubly-fed WTG) + comparison of their respective behavior in case of voltage dip in the grid
- a generic dynamic modeling approach for large wind farms based on active power model. This was validated through the example of an off shore wind farm in Belgium.

### "Connection of wind farms to the grid : technical specification of the TSO and associated modeling"

presented by Mr Olivier Bronckart, ELIA & Mr Peter Van Meirhaeghe, Tractebel
The doubly-fed induction generator Eurostag model developed by Tractebel was presented, including prime mover (wind turbine), injection in the grid (electrical equations), control systems (reactive power control, rotor speed, wind speed) and protection system.

### "Grid impact of different technologies of wind turbines generator systems"

presented by Mr Pierre Bousseau, EDF
The contribution concerned the comparison of various WTG technologies with respect to short circuit currents, stability and robustness to disturbances, control capabilities. The contribution focused on the dynamic behavior simulated with Eurostag of squirrel cage induction WTG, induction WTG with dynamic slip control, doubly-fed induction WTG and synchronous WTG with power electronic.
This contribution is detailed in the special focus, page ???

## 2-3 Use of FACTS

### "Impact and sizing of SVCs for mitigation of slow voltage recovery : Application to a large power system"

presented by Mr Karim Karoui, Tractebel

The slow voltage recovery phenomenon coupled to high proportion of rotating load is presented with the related risks for the power system security. To mitigate this problem, preventive and corrective actions need to be implemented. Corrective action corresponds to UVLS (Under Voltage Load Shedding) and preventive actions corresponds to the installation of SVS. These devices improve the primary voltage control and act as a fast auxiliary source of reactive power.
The SVS sizing methodology is described and the mandatory requirement of an adequate and validated load model is underlined.

### Reminder : use of FACTS was also mentioned in the introductory lecture

It was in the field of Load Flow Control and oscillation damping.

## 3 Technical Visit and Schedule of the day

All participants are grateful to Mr O. Lohan for the visit of the National Control Centre of Transelectrica.
It was a very interesting experience to see on screens the whole Romanian power system and to have the explanations about its general operation.

**Location of the meeting** : National Dispatch Center within Transelectrica headquarters

**Sunday 28/03 Lido Hotel**
Participants arrival and accommodation at the Lido hotel
20h : Cocktail kindly offered by EDF - TRACTEBEL at Lido hotel

**Monday 29/3 Transelectrica**

9h00-9h10 : Introduction to Participants, O. Lohan from Transelectrica
9h10-9h40 : Introductory lecture : "Doctoral School Researches in Power Systems" presented by Prof. Mircea Eremia, "Politechnica" University of Bucharest

9h40–12h00 : Contributions of participants

**12h00-14h00: Lunch break, kindly offered by Transelectrica at Intercontinental hotel (10 minutes far from the National Dispatching Center)**

14h00-14h30 : Technical visit of the Control Room within the National Dispatching Center.

14h30-15h00 : “The dynamic simulation : a tool for the training to power system operation” presented by Mr Marc Stubbe, Tractebel

15h00–15h30 : "Presentation of release 4.3" presented by Mr Arnaud Valenti, EDF

15h30-15h50 : Coffee break

15h50-16h40 : Open discussion about the future of Eurostag

16h40-17h00 : Conclusions, summary of the day

# Eurostag : Release 4.3

## Introduction

After the release 4.2, which had brought an important remodeling of the graphical interfaces, the EUROSTAG release 4.3 provides some changes in the modeling of electrical objects.
The growth of the dispersed generation, particularly the wind energy, has been amply taken into account. Now, the doubly fed induction machine is part of the proposed machines. The Standard model library has been completed and proposes new FACTS, wind turbine models, aeroderivative turbines and some types of local generation.
About the loads, a new model representing a distribution network is available.
Some data manipulation will be facilitated by the notion of overall modification. In the present release, will be concerned evolutions of the loads and modifications of machines and models.
Some improvements have been provided in the graphical modules.

## Data format

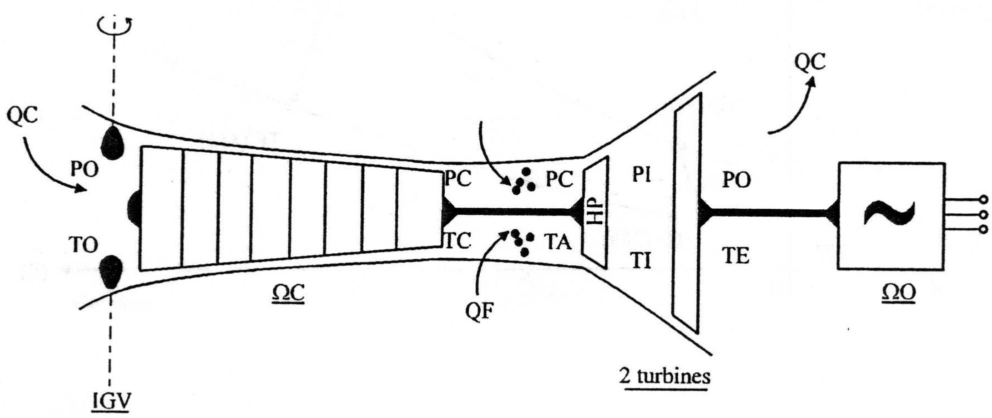
The structure of the dynamic data file (.dta) has been changed. Conversion to the new format is automatically carried out when accessing a release 4.2 file in the data editors or computation modules. Other data files of release 4.2 are used as they are.
Dynamic data file in format 4.1 or earlier must first be converted in the format 4.2. Load flow data files and event data files in format later than or equal to 2.3 are also automatically converted. The conversion will save the initial file with a «_4_2 » extension.

## Modeling aspects

The Standard model library becomes richer in numerous models:

**A. Dispersed generation** : two-shaft aeroderivative turbines, wind turbines, microturbine, photovoltaic, fuel cell.

- **Two-shaft aeroderivative turbines**
  - ⇒ range 40 MW : a validated Rowen model including "Texh(Pel)" modeled by a piecewise function and corrected by Tamb, the governor droop behavior, the fuel control system, and the acceleration limiter activated in case of close located fault.
  - ⇒ range 25 MW : a validated thermodynamic model including one step compression, two step expansion, and the Fuel and IGV control.



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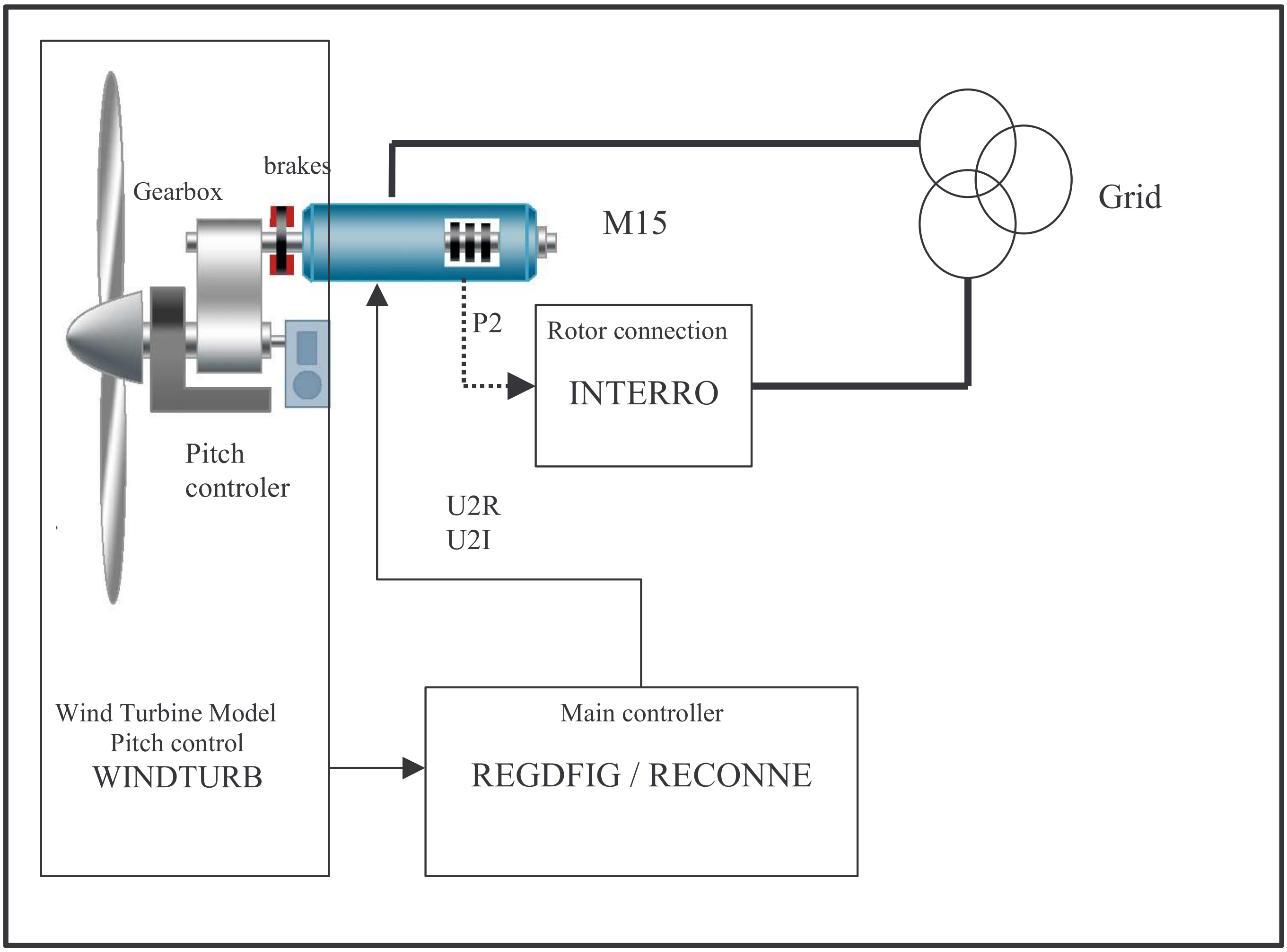
- **Wind turbines**

  Three models are proposed consisting of pitch control, stall control and a DFIG model (doubly fed induction generator). For the DFIG modelling, a new event (connection/disconnection of the stator) and a new automatic device (triggering the connection/disconnection of the stator in case of exceeding a threshold) are available. Further, new measurement elementary blocks specific for this type of machine have been added: the real and imaginary components of the rotor current; the rotor active power; the stator status (connected to the network or disconnected). An advanced example of use in given in the Tutorial.



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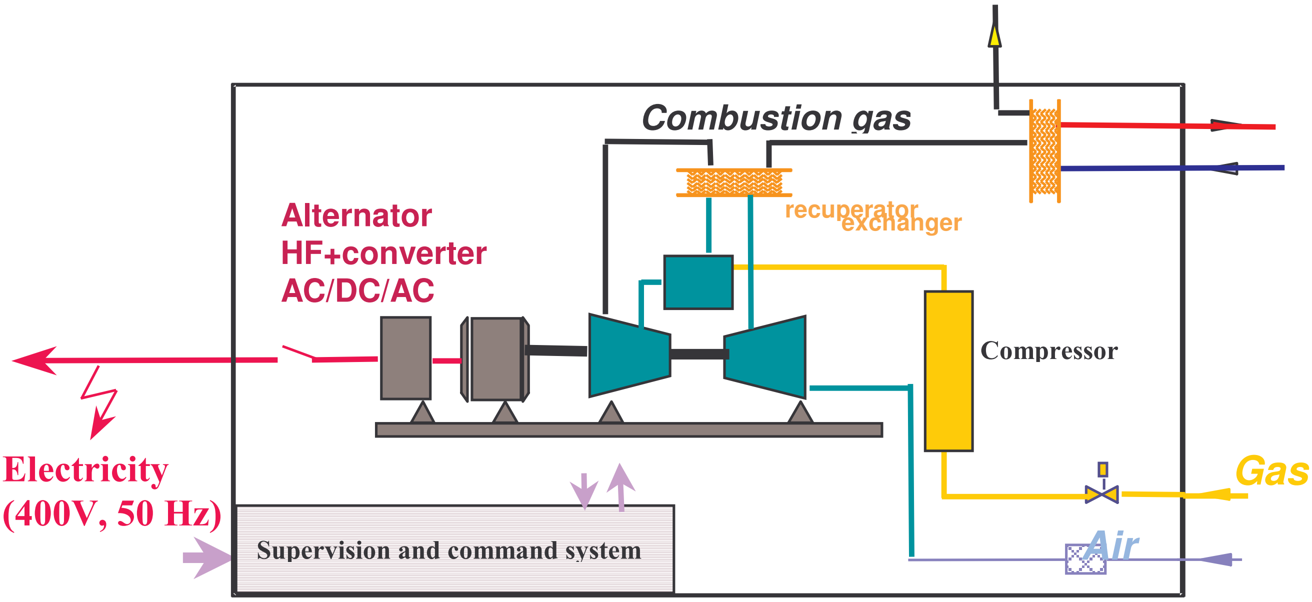
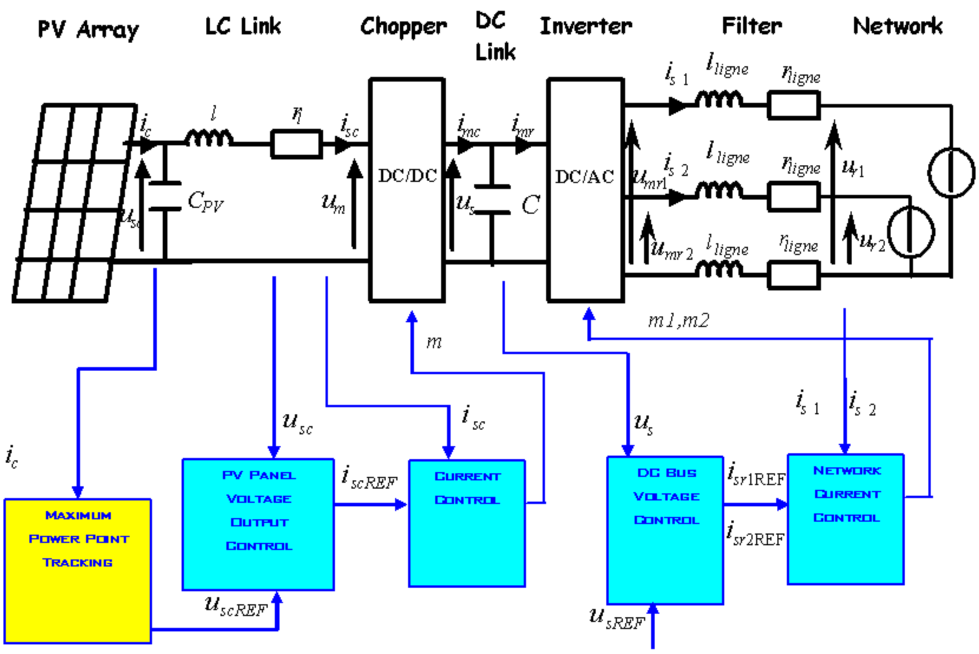
- **Microturbine**

A model including a primary frequency control (⇒ Power reference), a voltage control mode (⇒ Reactive current reference), a speed controller and a DC link interface. The mode of operation is island or grid operation (validated on test recordings)




*Soundproofed unit*

- **Photovoltaic**

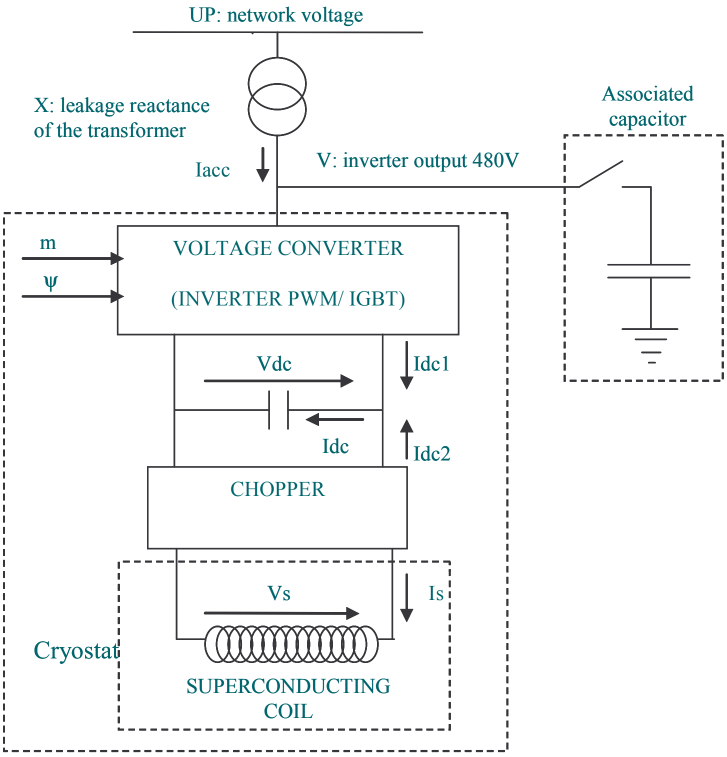


- **Fuel cell**.

A Fuel cell model related to a SOFC system and including a "Power section" (fuel cells) that generates the electrical power (constant DC voltage) and a "Power conditioner" that converts DC power to AC power output (Current control, Voltage control, Frequency control)

**B. FACTS**

A model that simulates the behavior of a D-SMES or a STATCOM.

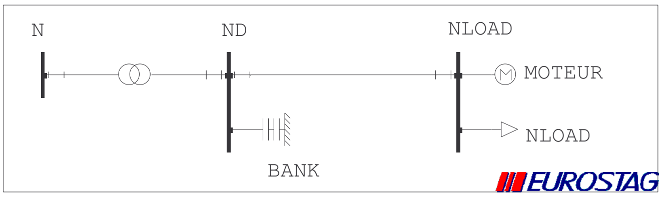



**C. Simplified model of HVDC link**.

It is derived from the full model and is designed to make easier the simulations where the study is not focused on the HVDC elements.

**D. Load model**

A new load model is available. Its aim is to represent loads simulating a distribution network fed by a transformer HV/MV and including a significant proportion of turning loads driven by induction motors.

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## Data conversion program

The PSS/E converter has been adapted to process the PSS/E data files corresponding to releases 24 to 29 (overall modification of the .ech file, overall evolution of the loads, overall modification of the .dta file, overall adding or replacing of machines and/or models).

## Model Editor

- compilation of a group of macroblocks;
- new searches in the diagrams: input variables, output variables, parameters, initial values;
- saving of the parameters array in a .emf file;
- Tool tips help for setting the initial values .

## Computation Module

- In the Load flow calculation: opportunity to block the transformers tap changer position.
- In the Dynamic simulation:
  - processing of the new models indicated chapter 4 here above;
  - modification of the algorithmic parameters during the simulation (numerical precision, final time, …);
  - opportunity to energize an area by starting a generator;
  - connection/disconnection of the stator breaker of the DFIG;
  - message notifying the stop of the frequency load shedding automatic device when the area splits up in two parts.

## Post-Processor

- access to the reference frequency in each node;
- access to the modulus and angle of the composed voltage in each node;
- vertical alignment of the charts;
- definition of the user's observables in the working units;
- exportation of the observables in the working units;
- display of several “time elimination” curves on the same chart;
- opportunity to add markers along the curves in order to differentiate them more easily;
- opportunity to add arrows in order to improve the presentation of the curves in the studies reports.

## Tabular Output program

- access to the reference frequency in each node;
- access to active and reactive losses on the branches;
- access to the rated current of the branches;
- access to the area of the node connected to a generator;
- access to the free attributes;
- saving of the results tables in a .emf file;

## And Fixing some bugs …

Technical paper

# Grid impact of different technologies of wind turbine generator systems (WTGS)


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**Abstract :** Today, the impact of wind farms on the grid is no more negligible [1]. Therefore, with the emergence of wind energy, it is important to assess the impact of the different technologies of wind turbines on the grid in order to anticipate potential problems. This paper compares the dynamic behavior of different Wind Turbine Generator (WTG) technologies for voltage dips, frequency variations, changes of wind power and three phase shorts-circuits. The technologies taken into account are: squirrel cage induction generators, doubly-fed induction generators, synchronous generators connected to the grid through power electronics converters. For the synchronous generators, two models have been used: one detailed model with converter blocking during voltage dips and one generic model implementing a current limitation in the converter. A set of simulations (three phase short-circuits, frequency variation, changes of the wind power, etc.) has been performed with EUROSTAG software on three different types of networks. As expected, results confirm that synchronous WTGs with power electronics show more control capabilities than doubly-fed WTGs, which in turn show more control capabilities than squirrel cage induction WTGs. However, the use of the power electronics converters may make synchronous and doubly fed WTGs very sensitive to voltage dips. Moreover, the dynamic behavior depends on different parameters such as inertia, converter ratings, protection settings, etc., and the results may change depending on WTG specific characteristics.



**Keywords :** grid integration, wind farms, dynamic behavior, synchronous generators, squirrel cage induction generator, doubly-fed induction generator, wind turbine technologies, wind turbine models


## 1 INTRODUCTION

The part of wind energy in the European electric production is significantly increasing. Wind turbine technologies evolve quickly due to:

- the pressure of the producers who want to reduce their production costs,
- the connection conditions to the network that become more and more constraining, because of the limited integration capacity of the electric systems.

Today, the impact of wind farms on the grid is no longer negligible. Therefore, with the growth of wind energy, it is important to assess the impact of the different technologies of wind turbines on the grid in order to anticipate potential problems that could occur.

This paper describes, mainly from the point of view of dynamic behavior, the impact of the grid connection of the following technologies: squirrel cage induction wind turbine generators (WTG), doubly-fed induction WTGs, and synchronous WTGs connected to the grid through power electronics converters. Simulations have been performed with the EUROSTAG software on three distribution networks:

- the distribution network of “Les Saintes” Islands, connected to the power system of “Guadeloupe” Island,
- a typical distribution network with a high short-circuit power, connected to the French interconnected network and hence to the European network,
- a typical distribution network with a low-circuit power, connected to the French interconnected network.

Only part of the simulation results is presented in the paper. To preserve generality, the data and models chosen for the different technologies are not specific to a manufacturer or a given wind turbine. Furthermore, specific devices such as FACTS, storage devices have not been taken into account.

## 2 DESCRIPTION OF THE WIND TURBINE GENERATOR MODELS

The models of the WTG technologies studied below have been implemented in EUROSTAG dynamic simulation software. These models were mainly developed in the framework of the DISPOWER European project.

### 2.1. Squirrel cage induction WTG:

A classical squirrel cage induction generator model is used. A constant mechanical torque is considered during the simulations.

### 2.2. Doubly-fed induction WTG:

The doubly-fed induction WTG 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 or in other words to the network (Figure 1).

The converter controls the rotor speed of the WTG and the reactive power at WTG low voltage (LV) bus. A simplified representation is used to model the power electronics behavior. When the terminal voltage of the WTG becomes lower than 0.8 pu, the control system blocks the converter, the power exchange between the converter and the network is equal to 0 and the rotor of the doubly-fed induction generator is short-circuited. The doubly-fed induction WTG works as a classical squirrel cage induction generator. Once the terminal voltage becomes higher than 0.8 pu, the doubly-fed induction generator then recovers its normal operating mode.

### 2.3. Synchronous WTG connected to the grid through a back to back converter (Figure 2):

This technology has been represented by two WTGs models: one with converter blocking during voltage dips (detailed model) and the other with a current limitation in the converter (generic model).
The WTG corresponding to the detailed model consists of a synchronous generator with permanent magnets and of a power electronics interface for the grid connection. The power electronics system controls the speed of the wind turbine and the reactive power sent to the network. A simplified representation is used to model the power electronics behavior. When the terminal voltage of the wind turbine becomes lower than 0.7 pu, the control system blocks the converters, the power in the converters is set equal to 0. Then, when the terminal voltage becomes again higher than 0.85 pu, the synchronous wind generator model recovers its normal operating mode.
The WTG corresponding to the generic model is a synchronous generator (whatever the technology: with permanent magnets or with controlled excitation) connected to the network through a back to back converter with a current limitation (see Figure 2). The generic model consists of an “impedance” type injector, the electric part of the WTG is simplified, the swing equation is incorporated to model the dynamic behavior of the WTG. The power electronics converter controls the speed of the wind turbine and the reactive power sent to the network. This model includes a current limitation for the power electronics converter. In the operating point chosen for the simulations, the converters control the speed of the wind turbine such that it is equal to 1 pu (50 Hz) at nominal output power and the reactive power is equal to 0 at the wind turbine LV bus.

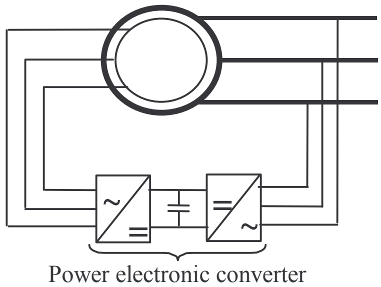


**Figure 1:** The doubly-fed induction WTG

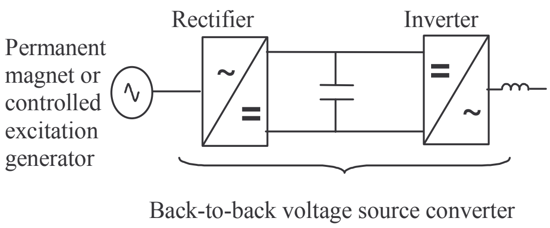


**Figure 2:** Synchronous WTG connected through power electronics converters

## 3. DESCRIPTION OF THE SIMULATIONS

Different types of disturbances have been simulated on the three networks in order to analyze and compare the behavior of the WTG technologies studied. Part of the results for the following simulations will be presented:

- A grid frequency variation corresponding to the reference UCTE event of a loss of 3000 MW on the European network in the case of the interconnected networks and the loss of the largest generator (29 MW) in the case of the network of “Les Saintes”,
- A three phase short-circuit on a neighboring MV feeder close to the feeder where the wind farm is connected. The short-circuit is cleared in 550 ms,
- A three phase short-circuit on a HV line cleared in two steps. In the first step, the HV line is

disconnected in 150 ms on the side which is the nearest to the fault, and in the second step, the HV line is disconnected in 300 ms on the other side.
- A three phase short-circuit on a HV line, cleared in two steps as above but in 150 ms and 600 ms,
- A change in the mechanical power of the wind turbine, from 1 pu to 0.8 pu and then from 0.8 pu to 1 pu.

These simulations don't take into account the action of the rotor over-speed protections.

## 4 SYNTHESIS OF THE RESULTS

### 4.1 Squirrel cage induction wind turbine generator:

Squirrel cage induction WTGs are directly connected to the grid (without power electronics converters). They are fixed speed wind turbines and therefore can't adjust the rotor speed in order to extract the maximum power from the wind. Concerning the grid integration, the following points can be mentioned :

- In case of voltage dips on the grid,
  - The rotor speed may increase a lot and the squirrel cage WTG may lose its stability.
  - However the rotor speed acceleration may be reduced to a certain extent by the possible active power exchange with the grid during the voltage dip, this contributes to reducing the risk of disconnection due to triggering of the overspeed protection
  - When the WTG is not unstable, the voltage at the connection point may take a rather long time before recovering its initial value due to the re-magnetization of the induction generator.
- Wind speed variations are rapidly followed by corresponding variations in the active power provided to the grid. The reaction time depends of course on the inertia constant of the machine.
- Depending on the machine parameters, the short-circuit current contribution of a squirrel cage WTG may easily be higher than 3 times the nominal current,
- Finally, grid frequency variations are immediately followed by rotor speed variations, that can lead to variations in active power provided to the grid.

### 4.2 Doubly-fed induction wind turbine generator:

The doubly-fed induction generator is a variable speed WTG, where the converter connected to the rotor can regulate the rotor speed so as to extract the maximum power from the wind. Moreover it can regulate the reactive power provided to the network. Concerning the grid integration, the following points can be mentioned :

- In case of voltage dips:
  - During the voltage dip, the converter is blocked and the doubly fed WTG behaves as a squirrel cage induction generator. However after the disturbance clearing, the converter restarts its operation and its control functions.
  - The doubly-fed WTG may lose its stability. However, the larger the rated power of the converter is, the more likely the WTG will be able to withstand voltage dips due the reactive power control performed by the converter.
  - Again, the risk of disconnection due to overspeed protection may be slightly reduced by the presence a possible active power exchange with the network during the voltage dip.
  - The voltage recovers quite quickly its initial value after the disturbance clearing : the need for reactive power from the induction generator due to its demagnetization is compensated to a certain extent (depending of the size of the converter) by the reactive power produced by the rotor converter
- Thanks to the converter there is a possibility to smooth the variations of active power due to wind speed variations by adjusting the rotor speed.
- As for the squirrel cage induction WTG, the short circuit current contribution from a doubly fed WTG can be higher than 3 times the nominal current,
- In case of grid frequency variations, depending on the rated power of the converters and on the difference between the grid frequency and the rotor speed set point, the rotor speed may be maintained and if so, the WTG can provide the same active power as initially, except for temporary short time variations.

### 4.3 Synchronous wind turbine generators connected to the grid through power electronics converters

The synchronous WTGs are variable speed generators. The converters connecting the generator to the network can regulate the reactive power provided to the grid and adapt the rotor speed so as to extract the maximum power from the wind.

- In case of voltage dips:

  - The voltage quickly recovers its initial value after the disturbance clearance
  - The converters of the synchronous WTG can control the frequency on the stator of the WTG and the active power provided to the grid. This will help to go through voltage dips without loss of stability.
  - The risk of disconnection due to the triggering of the overspeed protection in case of a voltage dip is reduced if there is a current limitation during voltage dips because in this case there could be an active power exchange during the voltage dip. However, if the converters are blocked during voltage dips, there will be no active power exchange with the network, and the risk of disconnection due to the triggering overspeed protection will be higher.
- Thanks to the converters there is a possibility to smooth the variations of active power due to wind speed variations by adjusting the rotor speed.
- The short circuit current contribution from a synchronous WTG is generally in the order of magnitude of the rated current of the converters.
- In case of grid frequency variation, there will be no change in the active power provided to the network.

In the study presented by this paper, the influence of different parameters such as inertia, settings of overspeed and voltage protections, etc., has not been taken into account to stay as much as possible at a generic level. However for a given WT, these parameters can have an important impact on the dynamic behavior. Therefore to obtain a more detailed assessment of the impact of the different types of WTGs, complementary studies have to be carried out taking into account these parameters and their possible different values depending on the WTGs considered.

**5 CONCLUSION**

The results confirm that synchronous WTGs with power electronics show more control capabilities than doubly-fed WTGs, which in turn show more control capabilities than squirrel cage induction WTGs. These control capabilities enable to improve dynamic behavior and hence the grid integration of the WFs. They can help to withstand grid disturbances (voltage dips, grid frequency variations,… ) without losing stability and with a limited impact on the grid. However, with the present design, the power electronics converters are generally very sensitive to voltage dips : depending of design, disconnection of the power electronics converters often occur to prevent the equipment from over currents.
The objective of the paper is to provide a generic comparison between WTG technologies. The dynamic behavior depends on precise characteristics of WTG system and the performance assessment of a given WTG will require a careful analysis taking into account :

- electric parameters of the machine
- precise value of the inertia constant,
- protection settings,
- rated power of the power electronics, and their control system
- possibly the breaking resistances that could be used to dissipate the power during voltage dips,
- use of a fast pitch control, …

Furthermore, different devices can be used in combination with the WTGs to improve the dynamic behavior of the WFs, such as FACTS or D-FACTS, energy storage systems, short-circuit limitation devices, …
Finally, it should be noted that one of the major difficulties concerning the grid integration of WFs is their limited ability of to withstand voltage dips. This is especially significant for insular networks where a voltage dip on the HV network can generally be seen everywhere on the network [7] and so can lead to the disconnection of all the WFs connected to the network. For interconnected continental networks, the ability to withstand voltage dips is a bit less important because the proportion of WFs affected by a same voltage dip in regard to the whole generating power installed is smaller. But the impact depends on the relative "strength" of the network and on the location of WFs (large "clusters" in some areas or distributed over the network). Nevertheless, on interconnected networks, the high variability of wind power, the difficulties of wind prediction and the need for primary and secondary power reserve may become at least as important and sometimes (for high penetration levels) more important than the capability to withstand voltage dips.