2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin

PEGASE Pan-European Test-beds for Testing of Algorithms on Very Large Scale Power Systems

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***Abstract*— This paper presents the methodology proposed and implemented to obtain a very large scale test model for demonstration purpose in FP7 PEGASE project. The model is meant to be representative of the European interconnected transmission network main characteristics. It will be available for public use in benchmarking and testing of power systems simulation tools, from static to dynamic simulation applications. Some simulation results from PEGASE demonstration scenarios are presented for illustration purpose.**

***Index Terms*—Power System, State estimation, Optimal Power Flow, Time-Domain Simulation, Dynamic Models, Dispatcher Training Simulator, Pan-European, Large-scale, Test Case**

I. INTRODUCTION

TODAY the paradigm of the European power system has changed: new interconnections are planned (Turkey) or contemplated (for instance the Mediterranean ring or the Russian system) leading to the most extended interconnected system in the world, penetration of renewable generation is growing at a fast pace, new Extra High Voltage transmission lines face social acceptance challenges, electricity highways to transfer bulk power over long distances across the continent are investigated. All this makes the national grids more interdependent and increase the need for an integrated operation of the European Transmission Network (ETN) as we move from the historically national operation of the power system to a European approach.

New tools capable of simulating the whole ETN to support the daily operation have thus to be developed. The four-year R&D PEGASE project aimed at developing grid management tools to achieve an integrated security analysis and control of the European Transmission Network (ETN) [1]. It was funded by the 7th Framework Program of the European Union and implemented by a consortium composed of 21 Partners which includes Transmission System Operators, expert companies and leading research centres.

The heart of the PEGASE project involved developing advanced algorithms, building prototype software and demonstrating feasibility of real-time state estimation, constrained multi-objective optimization and detailed time domain simulation of a very large model representative of the ETN, taking into account its operation by multiple TSOs [6]-[15].

Several test cases are available to the public use for network of middle size [3] and [10] (with a range of 14 to 300 nodes for the static part and 50 generators for the dynamic part) but the size of these models is largely below the PEGASE specification and its target.

A specific work package has been set-up to implement several test cases for the validation of the algorithms, following the specifications for which regards the size (number of buses, branches and injections) and the expected behavior of the pan-European power system.

The test cases developed have been used to test the different prototypes developed during the project: distributed state estimator [7], OPF and Iterative Security Constrained Optimal Power Flow [8], Dynamical Simulation, Dynamical Security Assessment and Dispatcher Training Simulator (DTS) [9].

In the first part, the base load flow data upon which the test cases have been built is presented. It retains the characteristics of the EHV UCTE network without disclosing sensitive information about geographical locations. In the second part, it is presented how the base load flow has been enriched to fit the PEGASE needs: lower voltage levels representation, measurements (State Estimation), production costs and flow limits (OPF), dynamical behavior of generators, HVDC links or wind farms, detailed topology (Dynamical Simulation and DTS)… Finally the main features of the obtained models are summarized and some simulation results presented.

II. INITIAL LOAD FLOW MODEL

The different models are based on a research static model received by UCTE in the UCTE-DEF format. The load flow represents 26 different areas and includes only the HV/EHV levels of the European power system down to 150kV. No geographical information is included, except for country names, since the nodes have anonymous labels (i.e. random numbers).

It is important to note that this model is not an exact snapshot of the European system but contains slightly noised data, and is not homogeneous: it contains not up-to-date descriptions of some parts of the network, or future equipments in some other parts. It also contains equivalent

Research partly funded by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 211407, PEGASE project http://www.fp7-pegase.com .

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978-1-4673-2597-4/12/$31.00 ©2012 IEEE

lines representing underlying lower voltage levels loops in some countries. Therefore it can be considered as a "realistic" representation of the European grid, though not an exact one.

Additionally, PEGASE consortium was provided a model of the Turkish grid by the partner TEIAS (system operator of the Turkish grid). It consists in real data, anonymized for the purpose of publication.

Those 2 models have been merged, through an AC interconnection, to obtain the full initial model.

The initial static model was not completely complying with the needs of the project since the number of nodes was too limited, the power injections too large and no information on the primary energy source were included. For example the primary energy source is needed to correctly represent the cost of production for the OPF and a correct dynamical behavior of the system.

III. Enriching the model

The most important steps performed to enrich the initial model for the needs of PEGASE are briefly presented.

A. Distributing the primary energy type

The first of the objectives has been to split the aggregated generation of the initial load flow data into smaller, typical-size generation units reproducing the energy mix of each of the 26 countries, based on official statistics for the year 2008.

The following MILP problem, minimizes the difference between the statistical distribution of primary energy source (for each country), and the technology associated to the given power injections, splitting the large injections into typical generators size (Eq.1 -2).

$$
\begin{aligned}
&\min_{x_{i,j}} \sum_{i=1}^{NB} \left\{ \sum_{j=1}^{NT} \left((z_{i,j} \cdot typsize_j) - tgen_j \right) \right\}^2 \\
&s.t. \\
&\sum_{j=1}^{NT} \left(z_{i,j} \cdot typsize_j \right) = cap_i \qquad \forall i \in I \\
&\sum_{j=1}^{NT} x_{i,j} = 1 \qquad \forall i \in I \\
&z_{i,j} - x_{i,j} MAXSPLIT \geq 0 \qquad \forall i \in I, \forall j \in J \\
&\sum_{j=1}^{NT} z_{i,j} \geq 1 \qquad \forall i \in I \\
&x_{i,j} \geq 0 \qquad \forall i \in I, \forall j \in J \\
&x_{i,j} \leq 1 \qquad \forall i \in I, \forall j \in J
\end{aligned} \tag{1}
$$

With

$I = \{1,2,\cdots,NB\}$ the set defining the indexes of buses with power generation

$J = \{1,2,\cdots,NT\}$ the set defining the indexes of the different technologies

$cap_i \in R^{NB}$ the active power capability of each generator I

$tgen_j \in R^{NT}$ the target of generation of technology j in the country

$typsize_j \in R^{NT}$ the typical size of a generator of technology j

$MAXSPLIT \in R$ the maximum number of equivalent generators connected to a bus

And the following respectively binary and continuous variables

$$x_{i,j} = \begin{cases} 1 & \text{if node } i \text{ is associated with tech. } j \\ 0 & \text{otherwise} \end{cases}$$

And

$z_{i,j}$ number of units of type j connected to node i.

The problem defined above is a Mixed Integer Linear Problem complex to be solved. To obtain a solution, the problem, implemented using GAMS has been solved using several on-line solvers. These allowed obtaining a solution only on smaller areas of the European power systems (e.g. Luxemburg, Belgium, Greece…). The problem defined for larger countries has resulted too difficult to be solved, the number of integer variables being too large.

An alternative formulation in terms of Particle Swarm Optimization has been developed and tested, this latter giving very variable results depending on the initialization particle states. The problem has been solved using a heuristic giving acceptable error results for the different technologies, the comparison has been done for small countries.

Several formulations and solvers were tested [12]-[13], and eventually the problem has been solved using a heuristic giving acceptable error results for the different technologies.

B. Enriching the network structure

To be able to simulate accurately a broad range of phenomena (contribution of tap changers to local voltage collapse, etc.), while increasing the size of the model to meet the specifications, it has been decided to add lower voltage levels (70kV, 20kV) to connect the generators and the loads through step-up and step-down transformers. Compensation banks of typical sizes were also added on lower voltages load buses. The power injections and loads have been adapted to keep the load flow state unchanged on the HV level, as shown in Fig. 1.

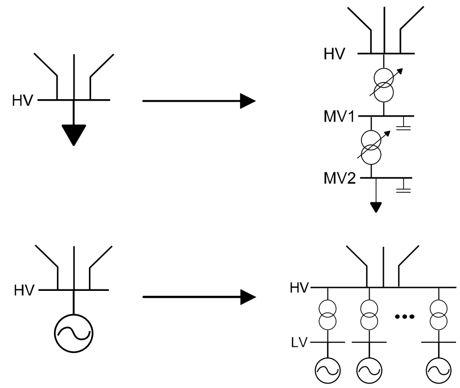

Figure 1 : Extension of the load flow. Initial and final situation respectively for loads and generators.

C. Primary Reserve Adaptation

In order to ensure a credible power reserve on the system, some machine sizes have been increased or decreased and some machines have been stopped.

The generation units connected to the same EHV node have been considered as being part of the same generation plant. For each plant the total generated real power was known from the base load flow file. That total generation was then distributed among units in the plant, and nominal powers marginally adapted, to ensure that:

- machines started at full power have a reserve of a few percents (0.5%, 1%, 1,5% or 2%) of rated power
- none or at most one machine by plant is started not at full power.

D. Creating realistic but constraining current limits

In order to build difficult yet representative optimization problems, and extreme time domain scenarios, line current limits were redefined so that loading of the lines match the following distribution, extracted from RTE EHV network on a peak load day shown on Fig. 2 below.

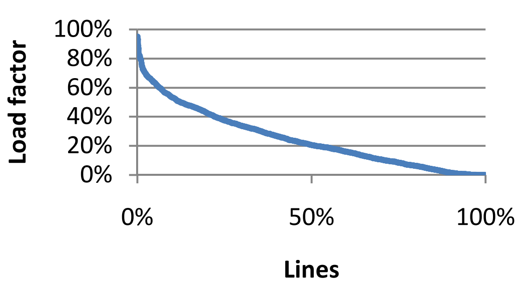

Figure 2: line loading distribution on RTE 225-400kV grid on a peak load day

E. Integrating dynamical Models

Initial data did not include any information on the dynamic behavior of the system components, thus we had to create them from zero. In addition of "standard" models, specific simplified models of HVDC VSC links and wind farms developed in the frame of PEGASE are used.

1) Synchronous generators

For synchronous machines, a classical 4-windings rotor representation has been used. For each type of generation units (nuclear, hydro, oil, gas…) typical values of the model parameters: inertia, direct/quadratic resistance, reactance, transient and sub-transient reactance and associated time constants have been used …[5]

All machines are equipped with:

- Typical speed governor according to the type of primary energy source
- Standard models of exciter + voltage regulator + power system stabilizer for most machines
- More complex "4 loops" PSS models, using 4 different inputs, for some nuclear power plants
- Secondary voltage regulation for some machines: several machines regulating the same voltage through a common level indicator regulating their reactive power output
- Under and over voltage and frequency relays

2) Simplified HVDC VSC model

HVDC VSC (High Voltage Direct Current, Voltage Source Converter) based transmission system comprises of two voltage source converters, one operating as a rectifier and the other as an inverter with the HVDC line linking both. The control functions of the converters include voltage (both AC and DC), active and reactive power controls. The embedded current control together with output limitations completes the set of control tasks. The commonly adopted strategy for a two-terminal HVDC VSC system is that one of the converters controls the DC transmission voltage while the other is used for active power control. Additionally, each of the converters can optionally be set in either AC voltage or reactive power control mode.

The voltage and active power control functions usually aim to fulfill system-wide objectives such as acceptable voltage profile or congestion management. As a result, during normal operation the power and voltage settings are determined by the system operator, and the reference values of the lower level control functions are attuned to these higher level prescriptions. A schematic representation of the HVDC VSC model is shown in Fig. 3.

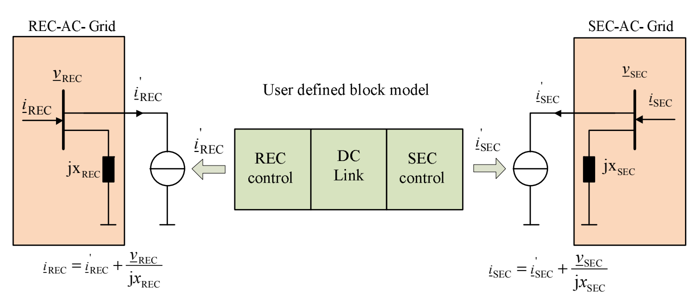

Figure 3 : Overview of HVDC VSC model

3) Receiving-end converter (REC) control

The control structure for the REC is shown in Fig. 4, which performs the following core functions:

– The PI-controller maintaining the DC transmission voltage with the active current as a control variable

- The AC voltage control block (or alternatively the power factor control) maintaining the terminal voltage at the prescribed value
- Current magnitude limitation with active current priority during normal operation.

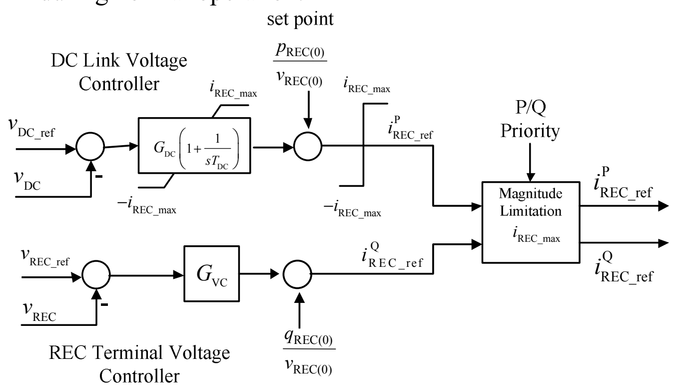

Figure 4 : REC control

The voltage controller is a fast-acting proportional controller that can include a dead band so that the control action is only then activated when the voltage error is larger than a pre-specified value (e.g. 0.1 p.u). This block is also responsible for grid voltage support during faults. The voltage controller can alternatively be implemented as a power factor control block.

4) Embedded current controller

The converter control is based on a vector control approach in rotating coordinates aligned with the system reference or the voltage at the point of connection. With the terminal voltage as the reference, active and reactive powers, respectively, are proportional to the d- and q- axis component of the converter current.

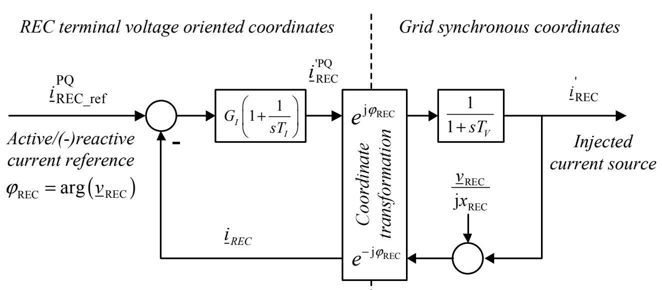

Figure 5 : Simplified current controller model

The current control structure is shown in Fig. 5. As the real and imaginary parts of the converter currents are determined with respect to the terminal voltage at the connection point, the controller output current should be multiplied with a phase shifter to obtain the corresponding value of the current with respect to the system reference frame. The use of PWM makes the fast control of the active and reactive power possible. This capability is useful when support of the AC network, particularly during disturbances, is needed, since the control can be optimized to obtain a fast and stable performance during the fault recovery phase. The model shown in Fig. 5 above is implemented for current source (Norton model) which is more suitable in RMS grid representation.

5) Model of the DC link

The DC circuit consists of the capacitors and the chopper together with its braking resistors. For simplified simulations the DC voltage is assumed constant and the losses along the DC link are neglected. As a result, the model only needs to determine whether the chopper is switched-on, and if so to account for the power dissipated on the chopper resistance. This is summarized in the following equations:

$$p_{\mathrm{CH}} = \begin{cases} 0 & \text{, if chopper off} \\ \dfrac{v_{\mathrm{DC}}^2}{r_{\mathrm{CH}}} & \text{, if chopper on} \end{cases} \tag{2}$$

The chopper block becomes active only when the DC voltage increases beyond a pre-specified threshold.

6) Sending-end converter (SEC) model

The SEC is responsible for the control of the active power injected into the transmission system at its sending-end by at the same time maintaining AC voltage at its set value. The embedded current controller is identical to the one at the receiving-end. Active current reference is calculated from the desired active power to be transmitted through the HVDC line. The reactive current control loop can be used alternatively to control the SEC terminal voltage on the AC side or to guarantee a constant power factor injection to the AC grid. Again, this is similar to the REC side controller.

F. Simplified wind turbine (WT), wind farm (WF) modeling

Wind turbines are generally classified as fixed and variable speed turbines. Fixed speed wind turbines using squirrel cage induction generators are - due to their limited energy efficiency and controllability - no longer state-of-the-art. The doubly-fed induction generator (DFIG) and fully-rated converter synchronous or induction machine based wind turbines belong to the variable speed category.

For purposes of deriving models for use in simulation studies, the following general classification of wind turbine generators is adopted:

- Type 1 – Conventional directly connected induction generator
- Type 2 – Wound rotor induction generator with variable rotor resistance
- Type 3 – Doubly-fed induction generator (DFIG)
- Type 4 – Full converter machine

1) Generic model of a variable speed WT

The most significant advantage of the generic model is that it keeps the modeling of wind turbine as simple as possible, yet the accompanying loss in accuracy for preliminary system studies or estimating grid code compliance remains within acceptable limits. The generic model will unavoidably involve simplifying assumptions, and the results obtained using this model will be less accurate compared to those of the detailed model. But as long as the simplifications do not stunt the physical phenomena to be simulated fundamentally, it represents acceptable compromise, given the difficulty of obtaining manufacturer-specific wind turbine models.

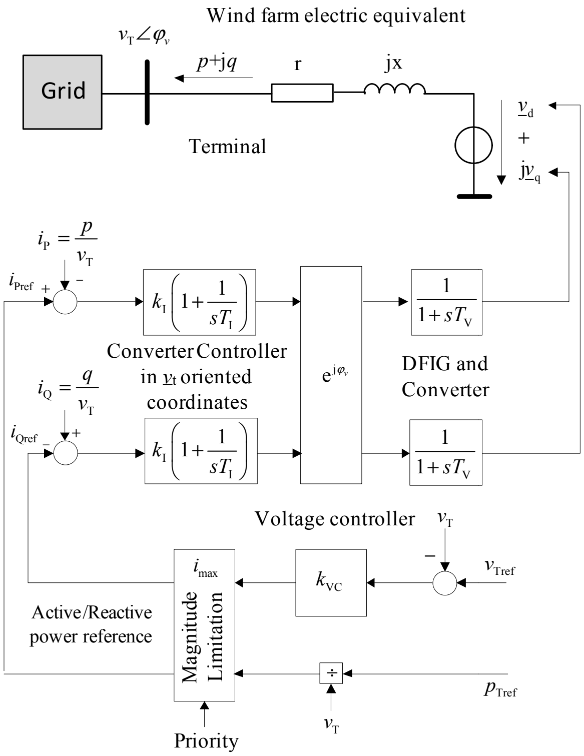

Figure 6 : Generic Wind Turbine/Wind Farm model

Fig. 6 above represents the generic model of a variable speed WT, i.e. Type 3 and Type 4, (which also can be used to represent WF with appropriate parameterization). It shows some similarities to the HVDC current controller model.

The voltage source is supplied by two delay blocks (one each for the d, and q components) representing the electrical machine and/or the converter delay. This part of the model is in grid synchronous coordinates. The controllers represented by PI blocks operate in terminal voltage oriented coordinates in which the real component of the current corresponds with the active current and the imaginary component with the negative of the reactive current. Consequently, both controllers perform active and reactive current (power) control independently one from another.

For simplicity the reference for reactive current is taken from the terminal voltage controller and the active current reference is calculated from the active power which is assumed constant. The last assumption is applicable for 1-2 seconds following a disturbance. For longer simulation durations modeling of the speed controller including the equation of motion may be necessary. The magnitude of the current reference is limited by maximum allowable converter current. As can be seen from the model there is no separate representation of MSC and LSC. Also the parameters do not correspond with any of the real controller parameters, rather characterize the aggregated values.

The model suggested (Fig. 6) is not limited to single wind turbines. It can be used to model entire wind farms or even the entire system by shifting the terminal node to the point of common coupling (PCC). In the latter case the model also considers the collector grid including the internal power consumption.

2) *Parameter identification*

Since the WT/WF model resulted from simplifications, parameters identification techniques have to be used for determining the parameters of the model. One method for identification is using techniques in the time domain based on measurements or detailed simulation results. Due to the nonlinearities (magnitude limitation, coordinate transformation) and the required time domain simulation in each iteration step, application of heuristic optimization methods can be preferable [16].

Of the alternative heuristic optimization methods, Mean Variance Mapping Optimization (MVMO) provides good performance in terms of the accuracy of the generic model parameters obtained and the convergence behavior. The fitness evaluation is performed using time domain simulation in each iteration step. MVMO shows better convergence behavior compared with other heuristic methods.

The model used for the test case use typical parameters obtained using the aforementioned methods.

G. *Improvement of the Eigen properties of the System*

A modal analysis was performed on a first version of the model for dynamic simulation. Interestingly, it showed that the modes is able to reproduce weakly damped slow inter-area (east-west) oscillation modes similar to well known real life modes of the European power system shown in Fig. 7 and Fig. 8.

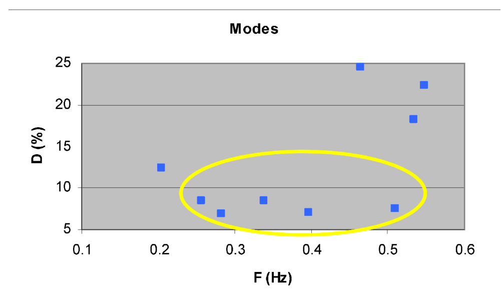

Figure 7: oscillation modes damping

In order to improve damping of these oscillations, the time constants and gains of 16 PSS have been tuned. In Fig. 9 a comparison of machine speed after mode excitation, before (blue) and after (red) tuning:

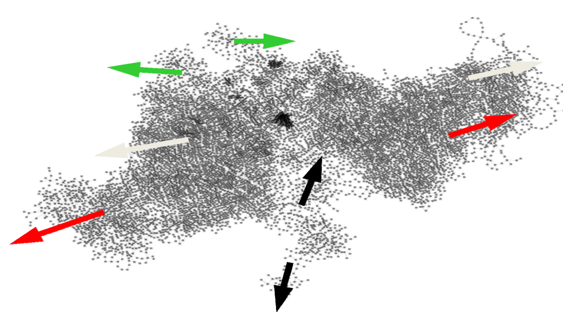

Figure 8: Visual representation of inter-area modes. With the same colors the modes in phase opposition.

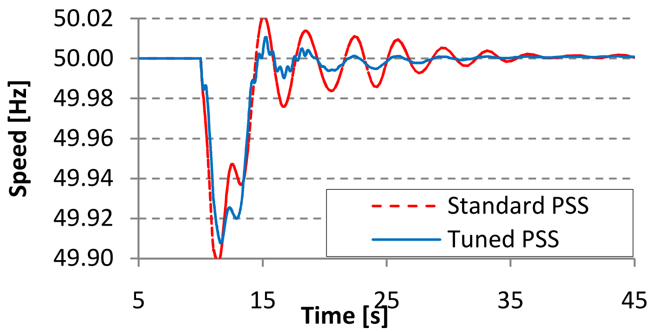

Figure 9: inter-area oscillation damping through PSS tuning, speed of a machine after a short circuit, in blue before the tuning and in red after the tuning.

IV. Description of the test-beds and simulation results

From the work presented above, 2 models have been derived, one for static computations and one for dynamic simulation. Hereafter the main features of these models are reminded, and some simulation results are presented.

A. Static model

For state estimation and optimization application, a simpler version of the model has been generated, not including the description of step-up transformers and the 2 levels of step-down transformers of loads (see III. B.). The following table summarizes the main characteristics of the model.

TABLE I. Static Model features

Buses	9241
Lines	14044
Transformers	2234
Phase shifters	80
Loads	5274
Compensation banks	289
Generation Regulating Buses	1445
Areas	27 (+X nodes)
Total load	400 GW

B. Dynamic model

For dynamic simulations, the most detailed version of the model is used; this has been obtained applying all the methods described in III.

The models for the generating units explicitly model a large number of synchronous generators that are fully represented and no dynamical equivalents have been used. This approach has been chosen because of the specifications within the project that asked for a very large test model.

The following table summarizes the main characteristics of the model.

TABLE II. Dynamic Model features

Buses	16578
Lines	14044
Transformers	9654
Loads	5308
Compensation banks	1954
Synchronous Generators	3240
Secondary voltage control pilot bus	248
Wind farms	707
HVDC Links	3
Different User-Defined Models	19
Algebraic Equations	63182
Differential Equations	63422
Areas	27 (+X nodes)
Total load	400 GW

C. Simulation Results and Tests

In this section two scenarios are presented: the first reproducing a splitting of the pan-European system into three asynchronous areas, very similar to the one of November 2006, and the second showing the influence of a centralized PSS on the inter-area oscillations in the European system.

1) Splitting of the EUROPEAN system

This scenario reproduces the behavior of the test case subject to a cascade of events (line tripping due to thermal overloads) with the consequence of splitting of the system in four different islands running at different frequencies. The results hereby presented aims at showing the capability of the model to reproduce a scenario similar to the instabilities of November 2006 [11] in the UCTE interconnected network but does not endeavor to reproduce correctly the events happening in the reality. These differences are due to the fact that the modeling is not realistic enough due to an anonymous network and to the lack of detailed information on the pre- and post incident load flow. In addition the Turkish power system is synchronously interconnected to the European Power system in the test case, while this was not the case in 2006. Finally the sequence of events leading to the splitting and to the reconnections here simulated does not strictly follow the real incident.

At time t=10s, a first cascade of line openings splits the European system in three parts, respectively the south-eastern part (incl. Romania) and Turkey (that was importing a limited amount of active power) with a deficit of production and an under-frequency around 49.9Hz, and the western part (incl. Germany, Czech Republic…) with an excess of production and slight over- frequency of around 50.1Hz (cf. Fig. 11). One may notice that in the real incident, the western part of Europe was in a state of under-frequency, which is due to a different load flow in the initial safe state.

The effect of the secondary power frequency control has not been modeled in the test case; for this reason only the primary frequency response of the system is represented.

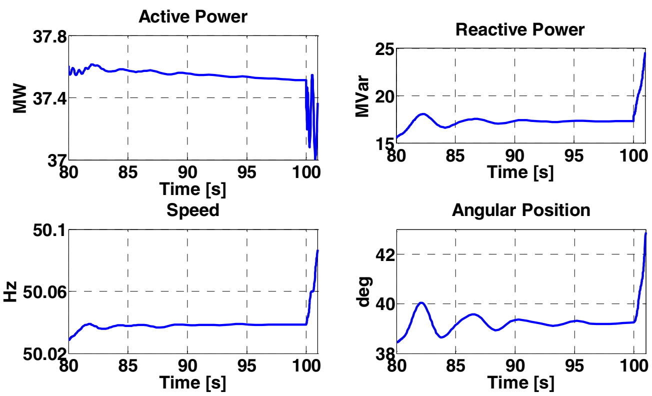

Figure 10 : Effect of the splitting on the stability of a generator in Germany.

The first cascade of line trips causes other overloads in rest of the ETN with the consequence of several successive line disconnections. The dynamical phenomena simulated during these slow tripping are various and span from local voltage collapse to loss of synchronism of machines, under-voltage load shedding and consequent machine disconnections (i.e. 15 generators) as shown in Fig. 10.

The last line tripping is caused by a wrong operation of a dispatcher (here simulated only with its consequences: a line opening), this line opening causes at time t=560s, a second split of the western ETN into 2 sub islands, shown in the figure below.

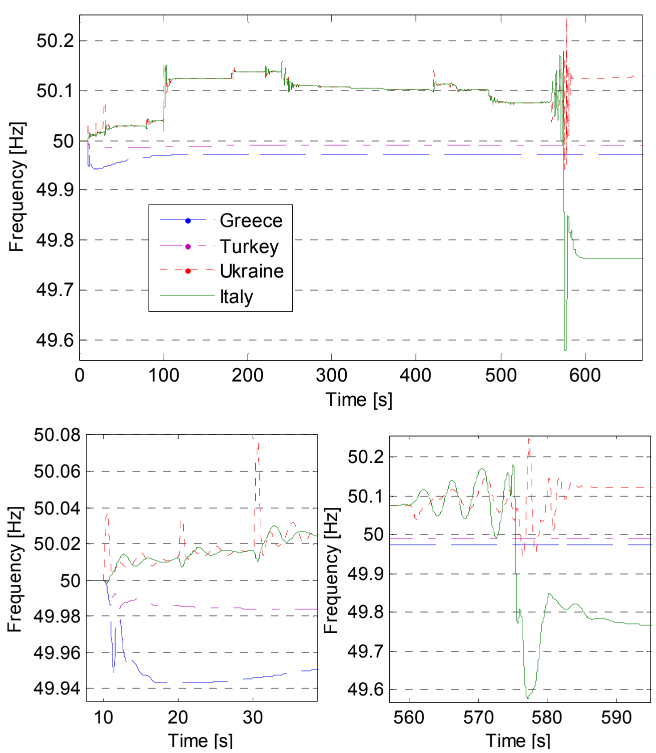

Figure 11: Splitting of the European system - frequencies of the islands (above) and zoom around the times of first (below left) and second splitting (below right).

2) Interarea oscillations and centralized PSS

The scenario includes the tripping of 3000MW of generation in Spain (nuclear generators ESNU857, ESNU858, and ESNU859) in conditions of weakened interconnected network (8 tie-lines disconnected).

The trip generates inter-area oscillations with a frequency of about 0.28Hz; but the oscillations remaining small and damped when using the original country balances.

Modifications were made in the dynamic data, including reduction of amplifying constants of some PSSs with speed input, and the increase by 700MW of East to West power flow (from Turkey to Spain and outside the continental network) leading to undamped oscillations with larger amplitude at the same frequency of 0.28Hz. These oscillations are illustrated in Fig. 12.

The scenario was completed with the simulation of the effect of a centralized PSS, using frequencies from nodes in 9 areas (representing PMU measurements) to generate for each area a centralized frequency deviation type signal as input for PSSs of generators.

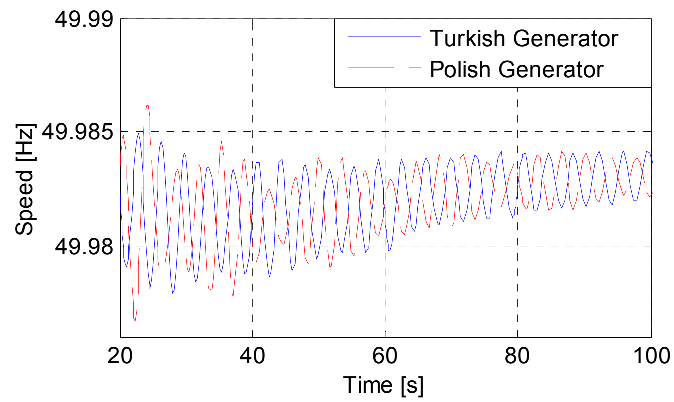

Figure 12: North-South inter-area speed oscillations after 3000MW loss in Spain.

The PSSs with speed deviation input were replaced with a modified version, adding the possibility to switch from local speed deviation to centralized frequency deviation signal and back triggered through manually in the definition of the scenario (this could be automated).

The use of Centralized PSS induced an effective damping of the small undamped oscillations obtained using the initial dynamic data (see Fig. 13), and a decrease of amplitude but with insufficient damping in the case of reduced PSS amplifying constants.

Once oscillations are damped, the steady state corresponding to the “standard” behavior of the exciter is correctly reached again by switching back to the local signal input, as also illustrated in Fig. 14 below.

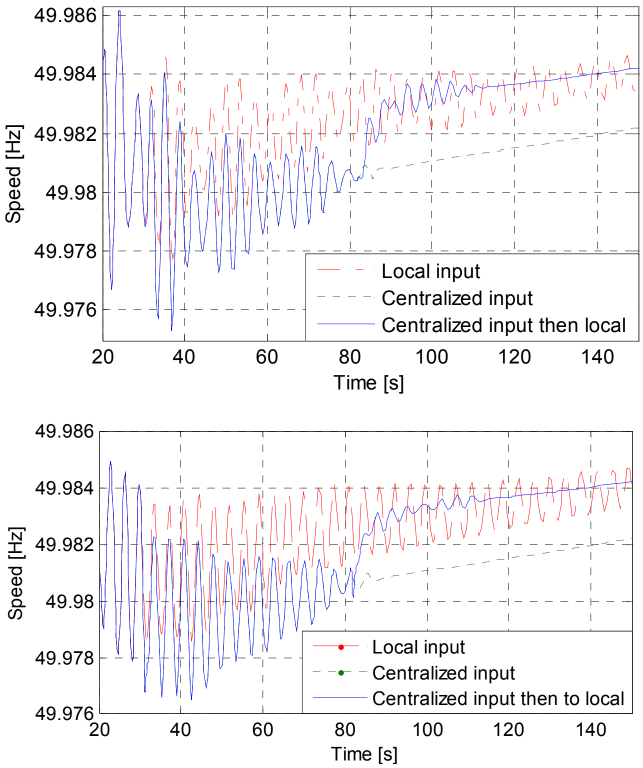

Figure 15: Comparison of the effect of different PSS inputs on the oscillation of a Turkish (above) and a Polish generator (below).

V. Conclusions

This paper presents the methodology proposed and implemented to obtain a very large scale test model developed for demonstration purpose in FP7 PEGASE project.

The test case has been built from a steady state snapshot of the EHV UCTE network provided for research purposes with no information on the location of the buses or on the type of primary energy source of the generators.

A complex methodology has been used to refine the test case and include the characteristics needed for the correct testing of the prototypes developed in the frame of the PEGASE test case (e.g. large scale, typical generators sizes, tap changer transformers, branch limits …).

The developed test case is meant to be representative of the European interconnected transmission network main characteristics but it is not suited for operational studies as it is not based on the real data of the system. The simulation results are realistic as they reproduce the type of phenomena characteristic of the European interconnected system. These behaviors cannot be directly compared to the real ones due to the anonymity of the bus names and difference in the load flow. The simulations are presented here to illustrate the complexity of the model and the ability of the model to reproduce realistic scenarios.

The results will be made available to the research community for public use to benchmark and test of power systems tools, for static and dynamic simulation applications.

VI. Acknowledgments

The authors would like to thank all the partners who participated in the development of the test cases and of the scenarios, in particular Rodica Balaurescu from Transelectrica (Romania) for the development of the scenario on inter-area oscillations.

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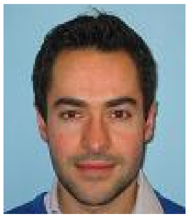
VIII. Biographies

Fortunato Villella (S' 2005) graduated summa cum laude in 2005 from the University of Calabria (Italy) with a thesis on fault tolerant control of hybrid systems developed in the Automatic Control department of Aalborg University (Denmark). From 2006 and 2008 he was with University of Gent (Belgium). From 2008 he is with Tractebel Engineering in the Power System Consulting section where he is currently expert and project manager. His main interests are modeling and identification of electrical power systems dynamics, simulation, operation and control. He is involved in several FP7 –founded R&D projects and he is responsible and trainer for the DTS of ELIA, the Belgian TSO.



Sylvain Leclerc graduated from Ecole Centrale Paris with a specialization in applied mathematics. He joined RTE in 2008 in the System Expertise Department. He has been working since then on RTE simulation tools for security studies from real time to long-term planning, as developer, teacher, and support to operators. He is also expert at RTE on state estimation and is involved in the management of data quality. He has been responsible for testing and demonstration activities in the PEGASE FP7 R&D project.

Prof.Dr. Istvan Erlich graduated from University of Technology, Dresden, Germany with Dipl.-Ing in 1976, PhD in Electrical Engineering in 1983 and Habilitation (post-doc degree) in Electrical Engineering in 1996. He served as a project manager for planning and operation of MV networks of the power system utility TITASZ in the city of Nyiregyhaza, Hungary, senior engineer of the company EAB Energie-Anlagen Berlin, Germany and research group leader at the Fraunhofer Institute for Information and Data Processing, Dresden. In 1998 he was appointed full professor and director of the Institute of Electrical Power Systems, University of Duisburg-Essen, Germany. He is actively involved in joint research projects with the German Transmission Utilities RWE, Vattenfall and several German DSOs. His research interests include power system small signal stability, power system (parameter) identification and optimization, development of power system simulation software, high voltage and medium voltage network planning, transmission cost calculation, distributed power generation and computational intelligence.

Stéphane Rapoport graduated summa cum laude as an electromechanical engineer at the ULB (University of Brussels). Participating in an exchange program, he also studied at McGill University, Montréal. He joined Tractebel Engineering in 2004. He is now Expert and Project Manager within Power System Consulting of the Power & Gas department. He is currently project coordinator of the PEGASE FP7 R&D project, a large-scale collaborative project of 13m€ stretching over 4 years, involving more than 20 Partners and funded by the European Commission. He is also involved as power system expert in Smart Grid R&D activities of the GDF-SUEZ Group and in the Pegase FP7 project.