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Developing a Dynamic Smart Grid Model

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Abstract. The aim of the research was to create a computer simulation model of the future smart grid systems, suitable to examine their operation and optimal control. The model is able to simulate events in arbitrary system cases and the answers of the system. The flexibility of the simulation is foreseen by the modular structure of the software. The generation and consumption data are based on real measured values. Different size and number of smart grids were examined by using this model.
The actual result of the research was that the system's behavior, as simulated by the model, was similar to the everyday operation of a real grid. Furthermore, the model is a tool to investigate the trends of future network development (regarding the change of smart grid criteria).
There is a need to work out new application behaviors, procedures, and operational routines regarding the research areas represented by certain modules.
The computer simulation model is already ready to use in the education, and as it is extensible, it is suitable to follow the changes of smart systems in the future.

Key words

smart grid, dynamic model, regulation, modular structure

1. Introduction

In the traditional electric power systems there is practically a direct link between producers (power stations) and consumers. The fundamental architecture of these networks has been designed to meet the needs of large, mostly carbon-based generation technologies. The power stations are located usually away from consumption centers, but near to coal fields. This world of electricity will be changed dramatically in the near future. Drive for lower carbon generation technologies and greatly improved efficiency of the demand side will enable customers to become much more interactive with the grid. The consumer friendly network of the future is out of reach now. However, these fundamental changes will determine the design and control of future networks.
The EU has recognized the task and has set up the European Technology Platform of Smart Grids in 2005, which aimed to create a shared vision for European grids of 2020 and beyond. The platform incorporates representatives from industry, transmission and distribution system operators, research groups and regulators. The strategy, developed by this group, was one of the first in Europe that has set the criteria for Smart Grids. It includes the following criteria:

- Flexibility: the network has to fulfill the needs of customers, while it has to respond to the different challenges
- Accessibility: all network users have to be granted with connection access, especially renewable power sources and low CO_2 emission, high efficiency (combined heat and power) units
- Security: the network has to assure and improve the quality of service, consistent with the demands of the 21st century with resilience to network events and uncertainties
- Economy: the network has to provide its best value through innovation, efficient energy management and regulations

Key elements of this vision include:

- Establishing a toolbox of proven technical solutions that can be deployed rapidly and cost-effectively, enabling the existing grid to accept power injections from all sources
- Harmonization of regulatory and commercial frameworks, to facilitate international trading of both power and grid services
- Establishing shared technical standards and protocols that will ensure open access, enabling the deployment of equipment from any chosen manufacturer

- Development of information, computing and telecommunication systems that enable businesses to utilize innovative services to improve their efficiency and services
- Ensuring the interfacing of old and new devices, to ensure interoperability of automation and control.

Research is continuous both in Europe and all over the world, based on vision like the one mentioned.

2. The Simulation Environment

The calculation program DIgSILENT PowerFactory is a computer aided engineering tool for the analysis of industrial, utility, and commercial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation simulation.
The name DIgSILENT stands for „Digital SImuLation and Electrical NeTwork calculation program". DIgSILENT Version 7 was the world's first power system analysis software with an integrated graphical one-line interface. That interactive one-line diagram included drawing functions, editing capabilities and all relevant static and dynamic calculation features.
The PowerFactory package was designed and developed by qualified engineers and programmers with many years of experience in both electrical power system analysis and programming fields. The accuracy and validity of the results obtained with this package has been confirmed in a large number of implementations, by organizations involved in planning and operation of power systems.
In order to meet today's power system analysis requirements, the DIgSILENT power system calculation package was designed as an integrated engineering tool which provides a complete 'walk-around' technique through all available functions, rather than a collection of different software modules. The following key-features are provided within one single executable program.
PowerFactory core functions: definition, modification and organization of cases; core numerical routines; output and documentation functions.

- Integrated interactive single line graphic and data case handling
- Power system element and base case database
- Integrated calculation functions (e.g. line and machine parameter calculation based on geometrical or nameplate information)
- Power system network configuration with interactive or on-line access to the SCADA system
- Generic interface for computer-based mapping systems

By using just a single database, containing all the required data for all equipment within a power system (e.g. line data, generator data, protection data, harmonic data, controller data), PowerFactory can easily execute any or all available functions, all within the same program environment. Some of these functions are load-flow, short-circuit calculation, harmonic analysis, protection coordination, stability calculation and modal analysis.

The authors' opinion is quite similar. PowerFactory is a very powerful simulation tool. It is capable of performing different calculations at high level. There are a number of variable features concerning for example a load-flow, so an exact task can be examined arbitrarily. The software is able to calculate distribution networks or micro grids. There is a high amount of built-in models available, but in case this does not satisfy us, we are able to create our own models which give us a free hand in design. Another powerful feature of the software is its built-in programming language, DPL (DIgSILENT Programming Language). With the use of DPL, not only various calculations may be performed, but it also makes it possible to create own routines. The syntax of DPL language is similar to C and it is easy to learn or use. The disadvantage in connection with PowerFactory is the same thing as its advantage; the complexity of the program requires a practiced user to handle it well. Though basic calculations are easy to perform, it takes a little time to get used to the software, and exploit its potential.

3. The Model Network

The network model, shown on Fig. 1., consists of:

- high- and middle voltage overhead lines
- high- and middle voltage buses
- transformers
- generators and loads.

The generators of the model possess both primary controllers and voltage regulators. The following generators are implemented in the model:

- two wind farms connected to MO1S and MSZ20 buses,
- three 5 MW gas turbines (connected to the MO1G bus)
- and a large spinning machine (connected to the G4 bus) as a system slack.

The program is able to handle two synchronous systems operating with different frequencies. During island operation the gas turbines are the reference machine. In the two wind farms there are 25 x 2 MW wind turbines in operation. The loads in the system are frequency and voltage dependent.

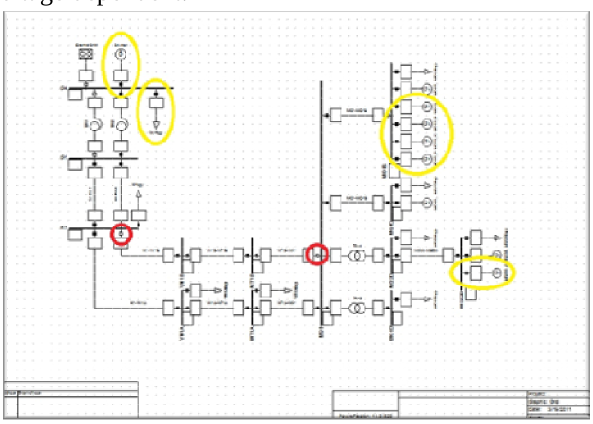

Fig. 1. Topology of the model network

The model is complete in the aspect of control. A primary controller and an exciter were modeled. A new turbine controller had to be created and one of the built-in exciters had to be re-parameterized.

For further examination it was necessary to implement frequency relays and to perform UFLS (Under Frequency Load Shedding) simulations. A 6 step, 50 Hz nominal frequency relay was chosen for these simulations. The first step operates at 49 Hz after a wake time of 300 ms, and the other steps are activated after every 200 mHz decrease until 48 Hz. Every step induces a 5% proportional load shedding. This dependency and the UFLS relays can be switched on or off independently.

The two wind farms contain more wind power plants (MO1S consist of 20 turbines, MSZ20 consist of 5 turbines). The earlier model has perceived these wind power farms like parallel machines which all are operated in the same way. Now more units were separated to be able to be switched on/off during the simulations (in MO1S 4 x 2 pieces and in MSZ20 1 x 2 pieces).

4. Creating the Controller Units

The primary aim of the authors is to create a simulation environment that is able to simulate power system transients. PowerFactory supports different time-domain simulation. The following three calculation methods are used: Balanced RMS Simulation, Three-Phase RMS Simulation and Three-Phase EMT Simulation. The model, described above is a balanced model; all loads are balanced as well. Since our calculations relate to the field of transient or mid-term stability analysis, Three-Phase RMS Simulations were performed. Such stability analysis assumes that our grid possesses the ability to control its frequency and voltage values. On one hand this approach is used when determining the types for general loads. By selecting dynamic loads, frequency and voltage dependence of active and reactive power may be determined, so all loads are able to react, and compensate frequency or voltage deviations. However dynamic loads alone are not sufficient. All or at least some generating units of our grid need to possess the ability to take care of the P-f and U-Q regulation of the power system. To achieve this, different control mechanisms have to be prepared for the generators. PowerFactory offers several different built-in types for controllers; voltage controllers (VCO), power system stabilizers (PSS), primary controllers (PCO) and prime mover units (PMU). To create a typical controller system for a synchronous generator, the following steps are needed:

- Transient models for each required controller type have to be defined, this is called Model or Block Definitions in the program
- For each generator, the transient models of the individual controller must be customized by setting the parameters to the correct values. This can be done using the Common Model of the controller
- A diagram has to be made defining the connections between the inputs and the outputs of the various models, this will serve as the Composite Frame
- For each generator, the diagram and the customized transient models are to be grouped together to define an unique composite generator model, the so-called Composite Model

From our point of view, the most important is the Composite Frame, since it defines all units and controllers, we have used. The general power plant model of PowerFactory utilizes all four, previously mentioned controllers. However it would be easy to use this structure, the authors decided to follow another path, because of two reasons. On one hand, the part of the grid, that is examined in present work, includes several small generating units, like wind generators or small CHP units. None of them has a PSS, which is unnecessary in the default model. On the other hand, the authors aim is to compare the results of the transient simulations to results prepared with other simulation tools. One of these software is the HTSW simulator, developed by the Department of Electric Power Engineering, Budapest University of Technology and Economics, back in the 1980s, and updated even today. The possibilities of this software are detailed in [1]. The power plant controller model of HTSW uses a single primary controller unit (PCO) instead of a primary controller and a prime mover unit. To reach as exact likeness to this model as possible, a new primary controller unit was created by the authors for this model.

The Composite Frame of our model consists of three blocks: the synchronous machine itself, the voltage controller and the primary controller unit. There are three signal connections between them. The voltage controller uses the terminal voltage (ut) [p.u.] of the synchronous machine as input, and sends an excitation voltage (ve) [p.u.] sign as output. The primary controller unit uses the speed (xspeed) [p.u.] of the synchronous machine as input, and generates input sign for turbine power (pt) [p.u.].

A. Voltage Controller Unit

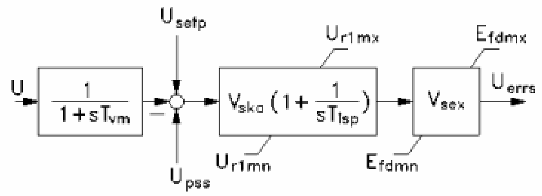

Fig. 2. Model of the Voltage Controller Unit

One of the built-in models of PowerFactory was chosen as the voltage controller. VCO type 16 is an excitation control system with simplified exciter. T_{vm} is the regulator input filter time constant, v_{ska} is the regulator time constant, t_{isp} is the regulator integration time constant, v_{sex} is the exciter constant, while the rest of the parameters are signal limitations. The parameters of the unit were determined based on own experience, as seen on Fig. 3.

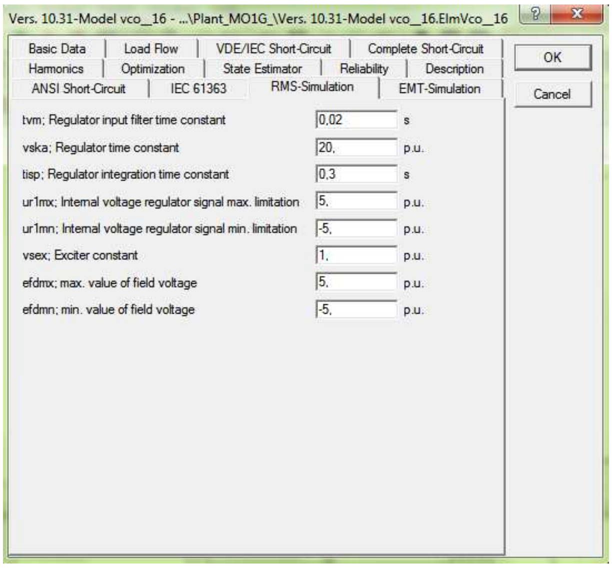

Fig. 3. Parameters of the VCO

B. *Primary Controller*

The primary controller was constructed in a way, to best suit end-user application. Since PowerFactory built-in models sometimes have too many adjustable parameters, it was also our aim, to make the controller as simple as possible. The composite model has two constant values. One is the reference of frequency, which is set as constant 50 [Hz]. The other reference is a power reference signal, set as constant 1. The composite model receives the speed [p.u.] of the synchronous machine as input signal. It is multiplied by the F=50 constant, which results a signal with Hz dimensions. This signal is extracted from the reference to create the frequency deviation. Next it has to be converted to power. It is achieved by using the following equations:

$$R = 100 \cdot \frac{\Delta f}{f_0} \cdot \frac{P_0}{\Delta P} \, [\%] \tag{1}$$

If we rearrange (1) we get

$$R' = \frac{\Delta f}{\Delta P} = \frac{R}{100} \cdot \frac{f_0}{P_0} \, [\text{Hz/MW}] \tag{2}$$

And then we may determine the transfer function:

$$\Delta P = -\Delta f \cdot \frac{1}{R'} \cdot \frac{1}{P_{\max}} \, [\text{p.u.}] \tag{3}$$

Based on (3), two block definitions are used in series. The frequency deviation is divided by the statism R' [Hz/MW] of the generator, and the maximal power of the generator P_{max}. The next group is an arbitrary delay. Time constant and proportion of the delayed and non-delayed branch may be set to implement different turbine technologies. For example, a wind generator has almost no delay, when transforming the torque created by the wind to the generator, while a bigger CHP unit reacts quite slowly. The sum of the two branches provides the power deviation signal. The other part of the controller uses a constant power reference, which is multiplied by the maximal power of the generator P_{max}, and the reciprocal of the target power of the generator P_{hat} to generate a reference value in [p.u.] dimension. The sum of the two branches are calculated and sent through a limiter, which preserves the generator from reaching over-speed. The block diagram of the primary controller is shown on Fig. 4.. As it was mentioned before, our aim was to create a user-friendly model, which is achieved by using well-known parameters for the controller. For parameterization, the common model may also be equipped with the necessary data and information, for example constant values and dimensions are indicated in the data table.

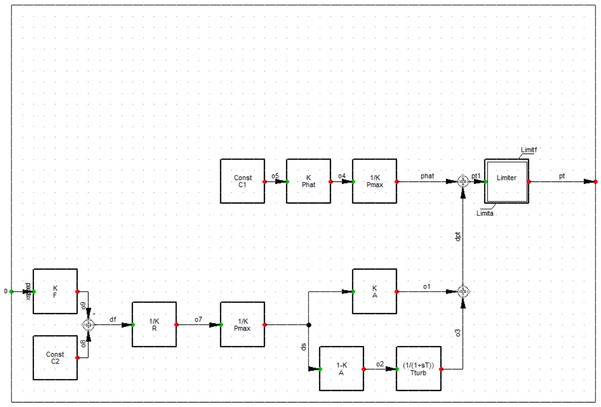

Fig. 4. Model of the Primary Controller

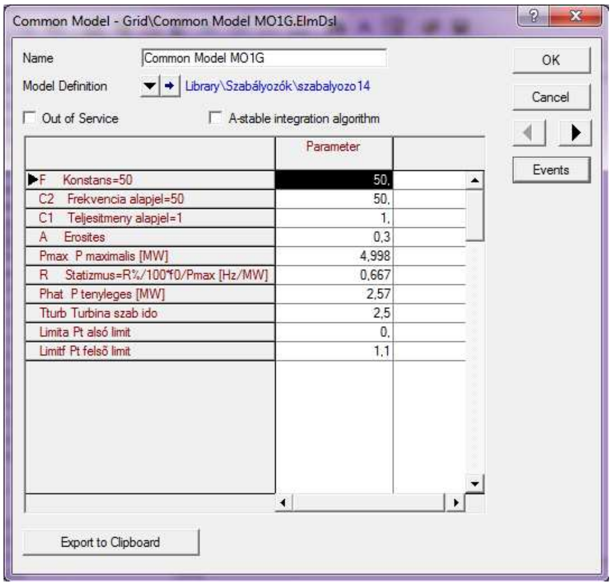

Fig. 5. Parameters of the Primary Controller

5. Parameterization

The most complex part of the research was the parameterization. Although this process may not seem to be most spectacular part of the work, all results might be useless without its proper execution. The lack of available information on electrical parameters hindered the work. Since dynamic simulations were also performed, appropriate parameters had to be assigned to the entire network.

Despite of these difficulties the task has been completed and also strongly supported by the supervisors' experience. With the help of possessed data, gathered information and intuitive engineering approach, the model was revived. The process is shown on Fig. 6..

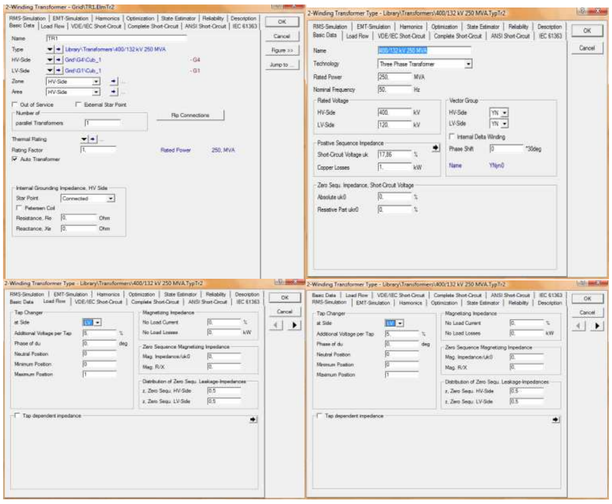

Fig. 6. Parameterization of a 400/120kV transformer

6. Preliminary Simulations

After completion of the model, the next step was the process of verification. The system was tested through load-flow simulations, load increment and decrement; and power and frequency behavior examination. The results of these simulations were compared to previously verified results, to ensure proper behavior. For example, the effects of a simple 1 MW change of active power can be calculated easily.

The simulations had proper results both quantitatively and qualitatively.

7. Summary, Future Work

Several outstanding simulation software packages are available on the market nowadays. It is difficult to choose the most appropriate one for the specific examinations. The DigSilent PowerFactory seems to be useful to our investigations. The next question after choosing the appropriate software is, to get to know exactly how the simulator works; how to create a network, run load-flow simulations, and calculate short circuits or RMS examinations.

There is a long way from choosing the simulation software to the useful examinations. Creating the network topology, re-calculating the parameters, setting up the controllers, running preliminary simulations to compare the results with other numerical calculations, etc..

The model is suitable for the educational introduction of the operation, events and maintenance of next generation power systems. It serves as an addition for theoretical studies, or serves as an independent base for practical curriculum or laboratory education. Interactivity and the introduction of innovative technologies will play a key role in the regular education of future generations, all of which are fulfilled by the model.

We aim to implement different research areas as independent modules, therefore enabling future development and modification of the model. The research fields that arise from each model are up-to-date and perspective from both scientific and industrial view.

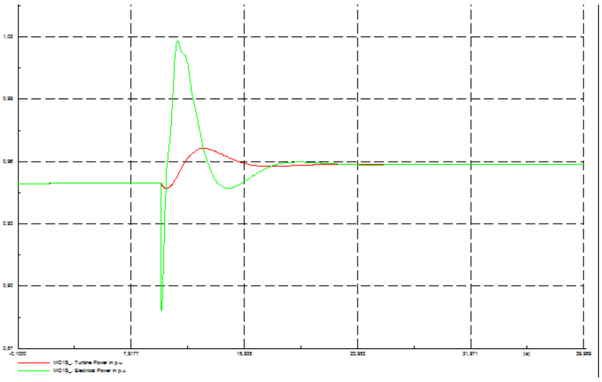

Fig. 7. The MO1S machine’s mechanical and electrical power during a switch

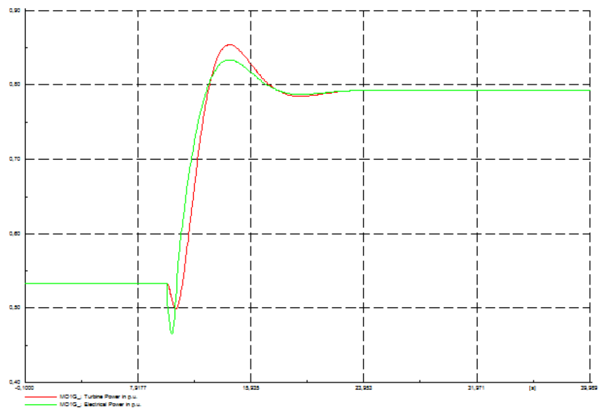

Fig. 8. The MO1G machine’s mechanical and electrical power during a switch

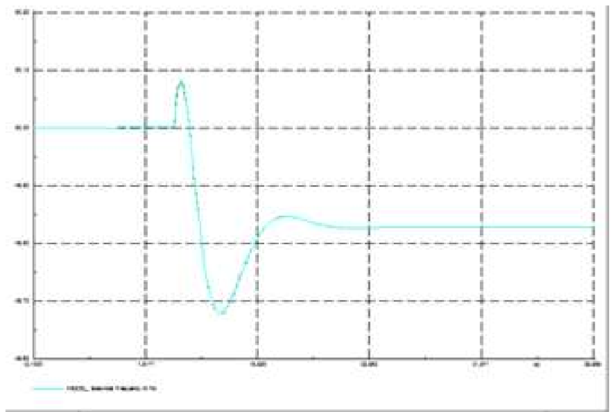

Fig. 9. The system frequency during a switch

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