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Work Scope and Tools for Wind Farm Interconnection Studies

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Interconnection studies of wind farms are executed for two principal reasons - to make sure that an addition of a wind farm would not have adverse effects on the existing power system, and to find out what system reinforcements are needed to avoid an adverse effect of the wind farm on the power system.

The industry has transformed over the years - in the past, penetration of wind power was so low that utilities and power pools could afford the luxury of tripping wind turbines off under any disturbance condition. During this initial stage, the issue of wind power modeling was not acute at all.

The current, impressively high level of penetration of wind power not only allowed utilities and power pools worldwide to work out the scope of the interconnection study and gain experience, but also to realize that they can and must dictate terms of interconnection to developers. Shortly speaking, these terms encompass compliance with the grid codes and both availability and validity of wind farm models.

Interconnection Study Scope

For the domestic (U.S.) market, the interconnection study process has been historically split into phases that include preliminary and detailed analysis in determining the system upgrades required to maintain system reliability following interconnection. FERC Order 2003 proposed standard generator interconnection procedures and defined three primary study phases:

- Feasibility - power flow and short circuit analysis
- System Impact - power flow, short circuit and stability analysis
- Facility - design of equipment required to implement the conclusions of the System Impact Study

Interconnection requirements for wind farms are not as uniform as the interconnection study procedures. For instance, one transmission provider may require that all generating units remain connected to the system during and following probable disturbances, while a different provider may permit the study wind farm to trip as long as neighboring units are not affected. The specific interconnection requirements affect the design of the wind farm and may also influence turbine selection.

Grid Codes and Connection Requirements Related to Wind Power

Utilities are generally required to maintain security and stability of their systems in addition to facilitating competition in generation. They are also bound to provide a connection offer and associated terms when a developer makes a connection application.

Grid Codes are designed to cover all technical aspects relating to the connection, operation and use of the transmission system. They must also permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity. They also facilitate competition in generation and supply, and promote both security and efficiency of generation, transmission and distribution.

Grid Codes, which have evolved over many years, have generally been based on conventional and well understood synchronous generating plants. The lack of clarity for non-synchronous plants have led to deficiencies in the ability to adequately address requirements of relatively 'new' wind power generating plants that may impact overall system integrity. For instance, the existing grid code requirements may be impossible or irrelevant with respect to the physical aspects and technical capabilities of wind generation. This has led to the concept of derogations (project specific exceptions from particular grid code clauses) being proposed by wind farm developers, and either accepted or rejected by utilities/regulatory bodies (which is becoming a burden on resources, delays projects and may be considered to be non-transparent, discriminatory and create inconsistencies).

Many countries are now expending substantial efforts and resources to update their grid codes (in addition to the standard periodic review and revision process) to incorporate realistic and practical (both technically and economically) provisions for wind generation, thus reducing the need for derogations and providing clear and transparent guidance to wind turbine manufacturers and wind farm developers.

Current versions of grid codes and connection requirement documents contain detailed specifications on aspects including, but not limited to, the following:

- Operational control (start-up, shut-down, power ramp rates)
- Power cap & constraints/curtailment
- Voltage and frequency operating ranges
- Frequency regulation
- Reserve
- Reactive power capability and voltage control
- Fault ride through
- Protection

Work is also ongoing with respect to the requirements and scope of wind-specific connection application documents, provision of data and information, and provision and format of dynamic models.

Collecting Data

The amount of time required to construct a wind farm is much shorter than conventional generation projects, and interconnection studies were occasionally performed without significant input from the developer regarding turbine layouts or electrical designs. Therefore the level of modeling detail can vary greatly from study to study, or even from wind farm to wind farm within the same study. For instance, one wind farm may include a separate model for every individual turbine within the wind farm, while another may be modeled as a single turbine equivalent. The level of modeling detail may not have a significant impact on study results, where the wind farm is relatively small and connected to the strong bulk transmission system. However, the level of modeling detail will affect results when the wind farm is connected to a relatively weak system. Our experience has shown that "turbine cluster" modeling -

detailed modeling of wind turbines located in close proximity as one equivalent wind turbine - is usually an acceptable compromise for both steady-state and stability analysis.

Model Maintenance

As more and more wind farms are incorporated into planning and operating models, maintenance of those models have become an issue that the PSS/E™ user must consider, especially in developing a case that will be utilized for stability analysis. Unlike synchronous machine model parameters, certain wind turbine model parameters are dependent on the terminal voltage and/or MW generation of the turbine. Therefore, in making power flow case changes, such as redispatching generation or applying prior outages, the user must consider the impact of these changes on wind turbines and make corresponding changes to the dynamic model parameters. This underscores the importance of reviewing the PSS/E progress window output to check for correct model initialization after executing activity STRT.

This relationship between terminal conditions and model parameters could be a problem where the proximity of turbines is such, that changes to the parameters of one turbine will then affect the terminal conditions of another.

We are thinking of changing the design of our software in order to have all dynamic simulation models self-initialized with no input from the currently supplied IPLAN/Python based "Model Builder" program.

Wind Turbines

Early interconnection studies were performed using standard induction machine models or synchronous machine models having parameters derived to approximate wind turbine behavior for small speed deviations. However, several turbine-specific models have now been developed and validated against actual turbine performance measurements or EMTP-type simulations performed by turbine manufacturers. Based on the variety of turbine technologies and controls, it is not surprising that turbine response to the same system disturbance may differ between turbine types; these differences are often the most pronounced where the transmission system is relatively weak. A change in the turbine supplier after completion of the system impact study necessitates restudy of critical contingencies to ensure that the new turbine can meet interconnection requirements.

We have been permanently working in close collaboration with PSS/E users. Their feedback supplements our own experience in running interconnection studies for wind farms. This combined experience revealed several problems with existing wind models. Most of these problems have been encountered when studying wind farms interconnected to weak points of the system. The latest version of the model of GE 1.5 and 3.6 MW wind turbines is a good illustration of the model upgrade done in cooperation with the manufacturer. We are currently discussing with Vestas the scope of upgrading models for V80 and V47.

PSS/E Wind Software

From the very beginning, development of the PSS/E software for wind power was oriented on specific wind turbine units. Main concepts of modeling wind turbines/farms in PSS/E were thoroughly discussed in our Newsletter Issue No. 95 of March 2004.

Up to date, the following PSS/E software packages have been developed for wind power applications utilizing the various different types of turbine technology.

PSS/E Wind Model Packages Developed by Siemens PTI				
Induction generator -directly connected	Induction generator – converter connected	Synchronous generator – converter connected	Doubly-fed induction generator with active control	Doubly-fed induction generator with passive control
NEG MICON NM72 (now Vestas) 1.65MW 50Hz/60Hz	Kennetech 33-MVS 400kW 60Hz	Enercon E66 1.8MW 50Hz	Generic model	Vestas V80 1.8MW 60Hz
NEG MICON NM82 (now Vestas V82) 1.65MW 50Hz/60Hz		Enercon E70 2.0MW 50Hz	GE 1.5MW 50Hz/60Hz	Vestas V47 660kW 50Hz/60Hz
BONUS (now Siemens) 1.3MW 50Hz/60Hz			GE 3.6MW 50Hz/60Hz	Gamesa G80 1.8MW 60Hz
BONUS (now Siemens) 2.3MW 50Hz			Gamesa G80 2MW 50Hz	
Mitsubishi MWT100a 1MW 60Hz			NORDEX N80 2.5MW 50Hz	
Suzlon S66 1.25MW 50Hz			REPower MD70 & MD77 1.5MW 50Hz	
Suzlon S88 2.1MW 50Hz			REPower MM70 & MM82 2.0MW 50Hz	

The majority of these software packages have a similar structure and include the following components:

- The IPLAN program (steady-state "Model Builder") to:
  - Aggregate wind farm/equivalent wind turbines to collector buses
  - Dispatch equivalent machines
  - Setup reactive power control
  - Implement control strategies
  - Write out dynamic model data to the dynamic data input file
- Dynamic simulation models:
  - Wind gust and ramp
  - Aerodynamic conversion
  - Mechanical shaft system
  - Pitch control
  - Generator
  - Generator controls (if applicable)
  - Reactive compensation (if applicable)
  - Voltage protection
  - Frequency protection

- Input data files
  - Aerodynamic Cp matrix
  - Machine parameters
- Dynamic models datasheets and block diagrams
- Instructions and other documentation
- Example data files
  - Collector bus data
  - Wind speed data
  - Protection data
  - Compilation and linking

Siemens PTI provides full support for all available wind software to any current PSS/E licensees within the terms and conditions of maintenance and support.

Siemens PTI is aware of several other PSS/E wind model packages NOT developed by Siemens PTI:

- Vestas V52 850kW, V66 1.75MW, V80 2MW, V90 3MW
- DeWind D6 1.25MW and D8 2MW
- Gamesa G5X 850kW and G8X 2MW

Siemens PTI is not providing any support with regard to these programs.

All dynamic simulation models included into PSS/E wind packages are written as user's models. For different reasons, mostly related to proprietary issues, only Vestas and GE WT models can be downloaded by any licensed PSS/E user from the Siemens PTI web site. Other models can be distributed following some procedure which involves Siemens PTI and a manufacturer.

Model Validation

Individual client projects have included model validation in different ways, which are described below. The primary objectives of model validation have been to ensure accurate model response and allow tuning of data parameters as required.

Many PSS/E models developed have been validated by comparison of the response of these models to the response of more detailed, higher-bandwidth models in EMTP-type simulation packages.

A wind model package representing a fixed speed wind turbine (comprising standard squirrel cage induction generator, aerodynamic & mechanical system, dynamic reactive power compensation, limited blade angle pitch control) was developed and tested. Results from the PSS/E model were compared to results from a similar analysis package used in-house by the turbine manufacturer and some mechanical system data parameters tuned to suit. Validation and tuning of the manufacturers model had previously been done by comparing and matching model results against actual turbine performance measurements and certificates of testing.

A different wind model package representing a variable speed wind turbine employing a doubly-fed induction generator with rotor voltage control and fault ride through functionality was developed and tested. Siemens PTI worked closely with the supplier of the DFIG converter who used an EMTP-type package to model in detail the DFIG and rotor side converter. The highly detailed model and incorporated control systems were reduced to a level of detail suitable for a PSS/E model and various simulations were performed to validate each sub-section of the rotor voltage control philosophy (e.g. reference and input signal step tests) and fault ride through functionality (disabling of parts of the control system, reduction/increase in active power generation, reactive power injection from grid-side converter etc.). As above, the validation process allowed tuning of control systems parameters and optimal setting of time constants.

Another wind model package representing a fixed speed wind turbine (comprising standard squirrel cage induction generator, simplified aerodynamic & mechanical system, dynamic reactive power compensation) was developed and tested. Results from the PSS/E model were compared to measured results from the actual response of a windfarm comprising these turbines for a known system disturbance.

The Latest Release of the PSS/E Wind Software

The following PSS/E-Wind Packages for different platforms are available to download from http://www.pti-us.com/pti/software/psse/user_support.cfm.

Model	PSS/E Versions	Base Frequency	Operating Systems
GE 1.5 MW (GE15)	27, 28, 29, 30	60 Hz, 50 Hz	Windows, UNIX
GE 3.6 MW (GE36)	27, 28, 29, 30	60 Hz, 50 Hz	Windows, UNIX
Vestas 0.66 MW (V47)	27, 28, 29, 30	60 Hz, 50 Hz	Windows, UNIX
Vestas 1.8 MW (V80)	27, 28, 29, 30	60 Hz	Windows, UNIX

<table>
<tr><th colspan="2" rowspan="2">Model</th><th colspan="2">Library</th><th rowspan="2">IPLAN</th><th rowspan="2">Machine Parameters</th><th rowspan="2">CP Matrix</th></tr>
<tr><th>Windows</th><th>UNIX</th></tr>
<tr><td rowspan="2">GE15</td><td>60 Hz</td><td rowspan="7">pssewind.lib</td><td rowspan="7">pssewind.a</td><td rowspan="4">gewinda.irf</td><td>ge15f60a.dat</td><td rowspan="4">gecpa.dat</td></tr>
<tr><td>50 Hz</td><td>ge15f50a.dat</td></tr>
<tr><td rowspan="2">GE36</td><td>60 Hz</td><td>ge36f60a.dat</td></tr>
<tr><td>50 Hz</td><td>ge36f50a.dat</td></tr>
<tr><td rowspan="2">V47</td><td>60 Hz</td><td rowspan="3">vswinda.irf</td><td>vs47f60a.dat</td><td rowspan="3">vscpa.dat</td></tr>
<tr><td>50 Hz</td><td>vs47f50a.dat</td></tr>
<tr><td>V80</td><td>60 Hz</td><td>vs80f60a.dat</td></tr>
</table>

Currently, these packages include object files and libraries for IPLAN programs and dynamic simulation models, along with machine parameter and CP matrix files.

The advantageous features of the new structure of the posted PSS/E wind software include:

- Only one file to download (for selected PSS/E version and Computer platform), e.g. pssewind_v30_1.0.1_win32.exe (for PSS/E-30 on windows)
- One IPLAN program per manufacturer (e.g., gewinda.irf models both GE models at both frequencies)
- One pssewind.lib library file for all models. Alternatively, some wind model packages contain a 'linkmodels' batch file which can be run from DOS (which saves lengthy typing). This file can be edited, if required.
- No need to copy Library, IPLAN and Data files in the user's working directory
- "Self-installing" executable on Windows
- "Compressed-tar" file on UNIX

The GE wind turbine modeling package comprises the following dynamic simulation models:

Function	Model
Doubly-Fed Induction Generator	GEDFA
Active Rotor Control (rotor side converter control)	GECNA
Aerodynamic	GEAERA
Pitch Angle Control	GEPCHA
Wind Gust and Ramp	WGUSTA
2-Mass Shaft	W2MSFA
Under / Over Voltage Generator Tripping Relay	VTGTPA
Under / Over Frequency Generator Tripping Relay	FRQTPA

The Vestas wind turbine modeling package comprises the following dynamic simulation models:

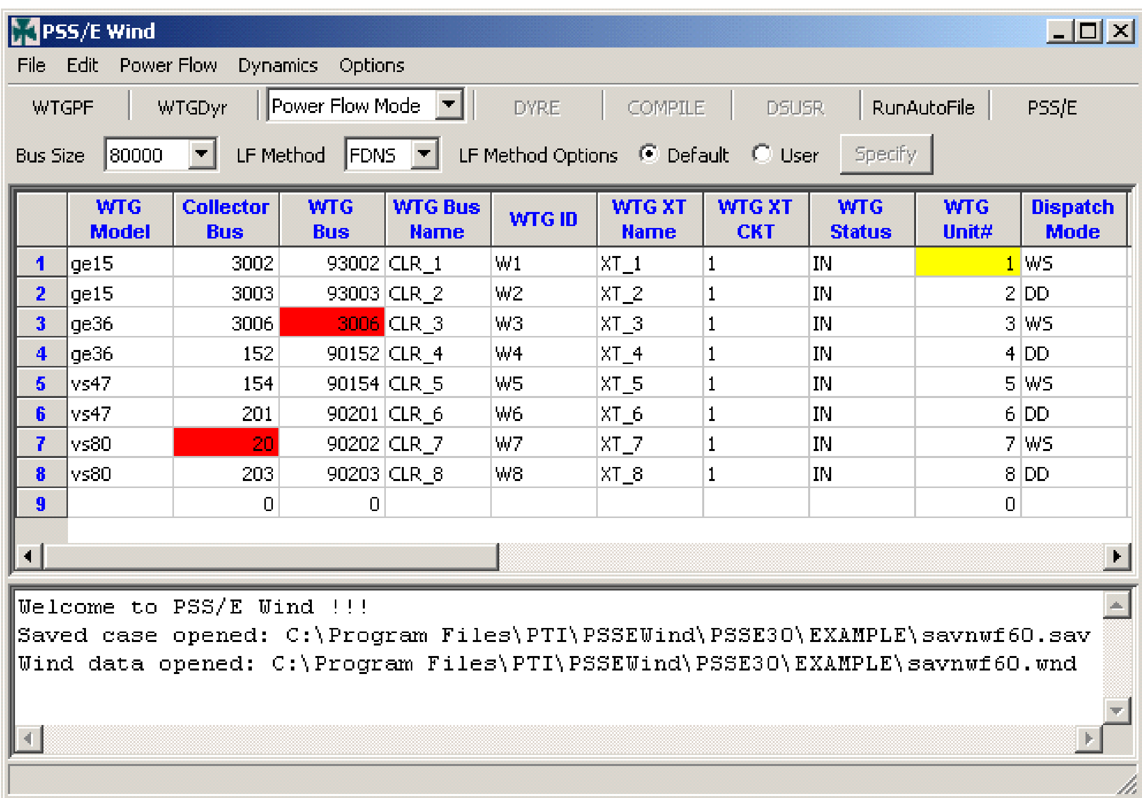
Function	Model
V47 Wound Rotor Induction Generator	VS47A
V80 Wound Rotor Induction Generator	VS80A
Aerodynamic	VSAERA
Pitch Angle Control	VSPCHA
Wind Gust and Ramp	WGUSTA
2-Mass Shaft	W2MSFA
Under / Over Voltage Generator Bus Disconnect Relay	VTGDCA
Under / Over Frequency Generator Bus Disconnect Relay	FRQDCA

All user-written models supplied as OBJect or LIBrary files must be linked to the PSS/E 'dynamic skeleton'. For Wind Models, this is achieved by:

C:\workdir>cload4 pssewind.lib (on Windows)
or
$compile_file pssewind.a (on UNIX)

Future Plans

The PSS/E-Wind Package Issue 2.0.0 and PSS/E-30.2, allow adding these GE and Vestas wind models using the PSS/E Wind Python functions as an alternative to the IPLAN program. The PSS/E Wind Python functions can be accessed from either GUI (shown in figure below) or Python batch scripts. The PSS/E Wind Python functions are written with the objective to simplify the dialogue between PSS/E and a user, especially for the situation when wind farms employing several different types of wind turbines are connected to the system. Using this GUI, the users can interactively add WTGs to the base case, create dyr, conec, and conet files, compile and create dsusr.dll.



As mentioned above, the present wind models being supplied by Siemens PTI are in a user written form, meaning that the use of these models require user compilation of the connection routines and linking to the Siemens PTI supplied library of the wind models. There are plans to make the commonly used wind models an integral part of the PSS/E supplied library of models. An essential aspect of integrating wind models into the PSS/E supplied library of models is that this would inevitably require creation of new dedicated arrays for exclusive use by the wind models, like array WAERO to contain output of aero-dynamic model, array WPITCH to contain the output of pitch control model etc. These new arrays will be made available for PSS/E plotting.

New model categories for wind related models will be created. This will allow wind models to be called in a manner similar to any user written plant related models. We will keep you posted about this proposed development.

Generic Wind Models

Siemens PTI is now at a position that with enough experience of modeling wind turbines around the world we have launched a development program to establish reliable, robust generic (standardized) models. This work will not replace the availability of actual wind turbine models but rather augment them.

Together with two Canadian universities, Siemens PTI has started a comprehensive program to develop and validate a limited number of generic models for different wind turbines available on the wind power market. Research work will be conducted in both EMTP-RV and PSS/E comparing simulation results from both simulation tools – for which there are benchmark data of actual turbine performance available. Our great advantage in this regard is an availability of many turbine type oriented PSS/E models that can be used for validating the generic models. Eventually standard 'table driven' PSS/E wind turbine models will be the result of the generic wind model development program. This work will be coordinated with our efforts to participate in analogous activities of the WECC Wind Generator Modeling Group.

Sizing and Design

Along with wind farm interconnection studies, Siemens Transmission and Distribution is capable now to perform a full scope of the wind farm design including:

- Windfarm layout
- Feeders, cables, bus arrangement, switching equipment
- Platforms for off-shore wind farms
- Off-shore wind farm AC/DC interconnection to the grid
- Compliance with the grid code requirements
- VAR supporting equipment
- Short circuit duties
- Harmonic analysis
- Grounding
- Protection coordination
- Insulations coordination
- Voltage fluctuation
- Lightning protection
- Reliability

The above mentioned studies will result in practical solutions for wind farm developers and transmission owners.

References:

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