

Tutorial on Wind Generator Modeling and Controls

Overview of the Tutorial

This tutorial will provide detailed information on representation of wind power plants in large-scale power flow and dynamic stability studies, as well as short circuit. Wind power plant performance and controls will be covered in detail to frame the requirements and approaches for modeling and simulation. Topics will include overview of the wind industry, steady-state representation, dynamic representation, short circuit representation, and recent experience with interconnection studies.

Summary of Topics

The following general topics will be covered in the tutorial. Please refer to the attached agenda for more information.

- 1. Overview of wind industry*
- 2. Wind Turbine Electrical Technology*
- 3. Representation of Wind Turbine Generators*
 - *Steady state representation*
 - *Dynamic representation*
 - *Short Circuit Representation*
- 4. Model testing and Verification*
- 5. Interconnection Study Experience*

Organization of the Tutorial

The topics listed above will be covered in a daylong session. This would provide an opportunity for discussing specific examples and field questions from the audience.

The Working Group chair will appoint individuals that are experts in the subject matter (topic leaders) to lead presentation of each of the major topics outlined above. These individuals will also serve as the tutorial planning committee. The planning committee will teleconference in early January to determine the scope of each topic and time allocation, and also to identify presenters to cover each topic. Some prospective presenters have already been contacted. A second teleconference will be held in late January to construct a detailed agenda listing individual presentations, and to finalize the list of confirmed presenters.

The Utility Wind Integration Group (UWIG), the WECC Wind Generator Modeling Group (WGMG), the National Renewable Energy Laboratory and other entities have developed relevant presentation material which have been presented in various venues. The Working Group will draw on these existing resources to prepare presentation materials for the tutorial. Supporting

documentation, including reports, guidelines and magazine articles, and brochures will be included in the booklet for reference.

Tutorial Abstract

Wind generation continues to advance at a rapid pace in terms of technology and installed capacity. In some areas of Europe and North America wind power plants already have a major impact on power system performance. This tutorial will provide detailed information on representation of wind power plants in large-scale power flow and dynamic stability studies, as well as short circuit. Wind power plant performance and controls will be covered in detail to frame the requirements and approaches for modeling and simulation. Topics will include overview of the wind industry, steady-state representation, dynamic representation, short circuit representation, and recent experience with interconnection studies. Existing or future interconnection standard such as LVRT, reactive power/power factor control, frequency response, etc, will be discussed to the extent that they affect modeling and simulation. Integration issues such as reserve requirements, integration cost are outside the scope of the tutorial.

Tutorial Planning Committee Members

- Abraham Ellis, Chair, Public Service Company of New Mexico
- Charlie Smith, Utility Wind Integration Group (UWIG)
- Brian Parsons, National Renewable Energy Laboratory (NREL)
- Eduard Muljadi, National Renewable Energy Laboratory (NREL)
- Juan Sanchez-Gasca, General Electric
- Robert Zavadil, EnerNex Corporation
- Hari Singh, American Transmission Company, Midwest Reliability organization
- Ian Hiskens, Professor, University of Wisconsin – Madison

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PROPOSED AGENDA AND PRESENTERS

Welcome.....
(A. Ellis, A. Ceña)

I. Wind Industry Overview
(C. Smith, B. Parsons, Ana Estanqueiro or alternate)

- Installed capacity and trends
- Current technology and trends
- Current technical challenges (interconnection and integration)
- Grid codes
- Discussion

II. Wind Turbine Electrical Technology
(R. Zavadil, K. Clark, G. Bathurst)

- Description of mechanical and electrical systems
- Performance
- Future trends

(Break)

III. Wind Power Plant Modeling

A. Overview
(A. Ellis)

- Levels of modeling versus purpose of the study
- Current industry activities (WECC, IEEE, CIGRE)

B. Steady State Representation.....
(E. Muljadi, H. Singh, A. Ellis)

- Wind power plant topology and components
- Single-machine equivalent representation
- Derivation of single machine equivalent model parameters
- Steady-state reactive power control options and power flow representation
- Reactive limits testing
- Examples
- Discussion

(Lunch).....

C. Positive Sequence Dynamic Models.....
(P. Pouyan, Y. Kazachkov, K. Clark, J. Bech)

- Overview of wind power plant dynamic performance
- Existing manufacturer-specific models

- WECC generic models
- Examples
- Discussion

D. Short Circuit Representation (R. Zavadil)

- Guidelines for short-circuit studies
- Validation
- Examples
- Discussion

(Break)

IV. Testing and Model Verification.....

(C. Smith, J. Fortmann, X. Robe, E. Muljadi, A. Ellis)

- Manufacturer Bench Testing (Repower)
- LVRT Verification (Spain)
- WECC Positive-Sequence Generic Model Verification Efforts (NREL)
- Discussion

V. Interconnection Study Experience

(E. Camm, I. Coughlan, D. McCrank)

- Case Study 1 – Ireland Experience
- Case Study 2 – Alberta Experience
- Case Study 3 – US Experience
- Discussion

Q&A Session.....

Wind Generation Dynamic Performance Working Group
Abraham, Ellis, Chair (aellis@pnm.com)

PRESENTER BIOGRAPHIES

Hari Singh

Hari is a Senior System Planning Engineer at American Transmission Co. located in Pewaukee, Wisconsin. His job responsibilities include performing generator interconnection studies, providing operations-planning support and conducting special studies such as volt-var coordination, special protection system evaluation, wind generation modeling requirements, etc. Before coming to ATC in 2004, Hari worked in Cooper Power Systems for 6 years where he conducted harmonics and switching transient studies and also provided application engineering support to Cooper's protective relaying products. Hari was fortunate to have the opportunity to work on the NERC 2003 Blackout Investigation Team as a principal investigator for Root Cause Analysis of the event. Overall, Hari has approximately 15 years of experience in various aspects of engineering analysis for electric power systems planning, design and operation. He received his undergraduate and graduate EE degrees from Panjab University, Indian Institute of Technology and Texas A&M University respectively.

Ana Estanqueiro

Ana Estanqueiro was born in Coimbra in 1963. She received her electrical engineer degree from the Technical University of Lisbon (TUL) in 1986 where she also did her M.Sc and PhD. in mechanical engineering, respectively in 1991 and 1997.

She works as a research scientist at INETI since 1987, currently as Director of the Wind and Ocean Energy Research Unit as well as associate professor at Universidade Lusitana. Her research interests are broad within wind energy with a focus on dynamic models of wind turbine benefiting from her electrical and mechanical background. She is currently chair of the International Energy Agency - IEA Wind Agreement and President of the PT IEP/IEC CTE 88 Wind Turbines

Pouyan Pourbeik

Pouyan Pourbeik received the degree of BE in Electrical & Electronic Engineering and the PhD in Electrical Engineering from the University of Adelaide, Australia in 1993 and 1997, respectively. From 1997 to 2000 he was with GE Power Systems. In September 2000 he joined ABB Inc., and worked at ABB until 2006. In June 2006 he joined EPRI solutions, which latter became part of EPRI in 2007. He is presently a Technical Executive at EPRI. Throughout his career he has been involved in and led studies related to all aspects of power systems modeling, dynamics and control. Relating to wind generation, he has performed numerous studies for the interconnection of wind

farms to utility grids in North America. He also helped two Canadian provinces in developing their interconnection standards for wind generation. He is presently chairman of CIGRE WG C4.6.01 on Power System Security Assessment and is the Chairman of the Power System Stability Subcommittee of the IEEE PES. He is a senior member of the IEEE and is a registered professional engineer in North Carolina.

Yvonne Coughlan

Yvonne Coughlan is a senior planning engineer working in the Power Systems Planning department in EirGrid, the transmission system operator in the Republic of Ireland. Main activities at present include evaluation of wind turbine dynamic models and investigation of the stability of the Irish system at high wind penetration levels.

Yvonne holds a B.E. degree from the Department of Electrical and Electronic Engineering at University College Cork, Cork, Ireland. She was awarded a postgraduate diploma in Financial Management by the Association of Chartered and Certified Accountants in 2006. She is a member of the Institute of Engineers, Ireland.

Ernst Camm

Ernst Camm received his BSc (Eng) degree in Electrical and Electronic Engineering from the University of Cape Town, South Africa in 1984 and his MSEE degree from the Ohio State University in 1992. He is currently a Principal Engineer in the Power Systems Services Division at S&C Electric Company.

Ernst has been actively involved in power system analysis associated with dynamic stability, wind power plant integration, capacitor-switching transients, and power quality at S&C for 15 years. He is now mostly involved in system analysis associated with the application of hybrid var compensators for improving power system voltage stability and for wind farm power factor control and fault ride-through.

Ernst is the chairman of the IEEE PES Working Group on Wind Plant Collector System Design and secretary of the Dynamic Performance of Wind Power Generation Task Force.

Robert Zavadil

Vice-President and Principal Consultant
EnerNex Corporation

As a co-founder of EnerNex, Mr. Zavadil is responsible for developing and overseeing the company's power system engineering consulting business.

He has worked on electric power system issues for wind generation for over 15 years. Clients include wind turbine designers and manufacturers, project developers and

operators, transmission service providers and ISOs, and research and development organizations including NREL, DOE, and EPRI.

From 1989 until 2003, Mr. Zavadil served in various consulting and product development capacities for Electrotek Concepts and its parent company, WPT.

Mr. Zavadil began his career in the electric power industry in 1982 as a special studies engineer in the Transmission and Distribution Engineering Division of the Nebraska Public Power District.

Mr. Zavadil received a BSEE degree, with highest honors, from South Dakota State University.

He is a member of the IEEE Power Engineering, Power Electronics, and Industrial Applications Societies, and serves as secretary of the IEEE PES Wind Power Coordinating Committee.

Jens Fortmann

Jens Fortmann (1966) received his Dipl.-Ing. degree in electrical engineering from the Technical University Berlin, Germany, in 1996. From 1995 to 2002 he worked on the simulation of the electrical system and the control design of variable speed wind turbines. Since 2002 he is with REpower Systems AG, Germany as project manager for the simulation and implementation of new technologies for improved grid compatibility of wind turbines like voltage control and ride-through of grid faults. He is member of IEEE.

Istvan Erlich

Istvan Erlich (1953) received his Dipl.-Ing. degree in electrical engineering from the University of Dresden/Germany in 1976. After his studies, he worked in Hungary in the field of electrical distribution networks. From 1979 to 1991, he joined the Department of Electrical Power Systems of the University of Dresden again, where he received his PhD degree in 1983. In the period of 1991 to 1998, he worked with the consulting company EAB in Berlin and the Fraunhofer Institute IITB Dresden respectively. During this time, he also had a teaching assignment at the University of Dresden. Since 1998, he is Professor and head of the Institute of Electrical Power Systems at the University of Duisburg-Essen/Germany. His major scientific interest is focused on power system stability and control, modelling and simulation of power system dynamics including intelligent system applications. He is a member of VDE and senior member of IEEE.

Xavier Robe

Xavier Robe is field tests and measurements manager at Energy To Quality SL (Madrid, Spain) since January 2006. He received the MSc in electromechanical engineering from the ULB (University of Brussels, Belgium) in 2001 and a MBA from the Solvay Business

School (Brussels, Belgium) in 2004. Before joining Energy to Quality, he was research assistant in power quality and protective relays at the ULB from 2001 to 2003. In 2003, he moved to Luxembourg to work as supply chain manager at Air Liquide Luxembourg SA, where he stayed until January 2006.

He is now implied in various national and international working groups for wind energy integration in the electrical grid.

J. Charles Smith
Executive Director
Utility Wind Integration Group

Mr. Smith is a Senior Member of the IEEE Power Engineering Society, and a member of CIGRE, the International Council on Large Electric Systems. He received his BSME and MS degrees from MIT in 1970. He currently serves as the Executive Director of the Utility Wind Integration Group (UWIG), and is also the Managing Director of the consulting company Nexgen Energy. Previously, he served as President of Electrotek Concepts, a power engineering consulting firm. He has 37 years of experience in the electric power industry.

John Bech

John Bech presently works for the wind turbine manufacturer Vestas where he is involved in modeling of wind turbines for grid stability simulations. Before the Vestas/NEG Micon merger – he was at NEG Micon, where he was project manager on the electrical system for the first NEG Micon pitch regulated variable speed turbines (NM80/2750, NM92/2750 and NM110/4200). He earned his M.Sc.E.E. from Aalborg University 1997. After graduation he joined DEFU (Danish Electrical Research Institute).

Kara Clark

Kara Clark is a Principal in GE's Energy Consulting group, which provides engineering expertise in the analysis of large-scale power systems. Ms. Clark's current focus is on the control of wind-turbine generators and wind plants, modeling of WTGs for both cycle-by-cycle and fundamental frequency analysis, and analyzing the impact of significant levels of wind generation on power system performance. She is a senior member of IEEE, author of many technical papers, and a registered Professional Engineer in New York.

Alberto Ceña

Aeronautical engineer, it is now technical Director of ASOCIACION EMPRESARIAL EOLICA (Association of promoters, manufacturers and financial entities) which represents the 85% of the total installed power in Spain.

Previously, he served as Commercial Director de ALABE SA, Energy Services Company of the ACCIONA Group that promotes, operates and constructs projects of cogeneration and renewable energy (biomass and wind, second producer in Spain). He was also President of GEDEON S.COOP., wind turbines manufacturers, as well as he hold different positions in the European Commission and the Spanish Ministry for Industry and Energy

Eduard Muljadi

Eduard Muljadi received his Ph. D. (in Electrical Engineering) from the University of Wisconsin, Madison. From 1988 to 1992, he taught at California State University, Fresno, CA. In June 1992, he joined the National Renewable Energy Laboratory in Golden, Colorado. His current research interests are in the fields of electric machines, power electronics, and power systems in general with emphasis on renewable energy applications. He is member of Eta Kappa Nu, Sigma Xi and a Senior Member of IEEE. He is involved in the activities of the IEEE Industry Application Society (IAS) and Power Engineering Society (PES). He is currently a member of Industrial Drives Committee, Electric Machines Committee, and Industrial Power Converter Committee of the IAS, and a member of the Working Group on Renewable Technologies and the Dynamic Performance of Wind Task Force of the PES. He holds two patents in power conversion for renewable energy.

Juan Sanchez-Gasca

Juan Sanchez-Gasca is a Principal Engineer at GE Energy - Energy Applications & Systems Engineering Department in Schenectady, NY. He has worked extensively in the areas of dynamic simulation and control of power systems. He has recently been involved in the development of wind turbine models and associated controls for implementation in transient stability programs. Related work includes stability studies related to the inclusion of wind farms in power grids.

Juan is a Fellow of IEEE. He currently serves as the Secretary of the IEEE Power System Stability Controls Subcommittee. He is a past Editor of the IEEE Transactions on Power Systems. Juan received his Ph.D. in Electrical Engineering from the University of Wisconsin-Madison.

Nicholas W. Miller

Mr. Miller is a Director for GE Energy in Schenectady, NY. He has 27 years of experience in analysis of power systems dynamics. He is currently leading analytical developments for large scale integration of wind generation into power systems. Nick is a Fellow of IEEE, and a member of CIGRÉ. He is the past chairman of the IEEE Task Force on Dynamic Performance of Wind Generation. He was a principal contributor to

the landmark New York State Wind study, and is a principal on the current California Intermittency Analysis Project. He received the 2005 Utility Wind Interest Group Achievement Award 'for Outstanding Contributions to the Advancement of Utility Compatible Wind Turbine Technology' and the 2007 American Wind Energy Association Technical Achievement Award. He is a licensed professional engineer in the State of New York.

Yuriy Kazachkov

Yuriy Kazachkov received the M.S. and Ph.D. in EE from the Polytechnic Institute, St. Petersburg, Russia in 1961 and 1971 respectively. Until 1992, he worked with the HVDC Transmission Research Institute in St. Petersburg and was responsible for the operational modes, equipment and control specifications, and ac/dc compatibility of power converters for HVDC and other applications. Since 1992, Mr. Kazachkov has worked with Power Technology, Inc., Schenectady, NY, in its Consulting Services (now Siemens PTI). He has been involved in numerous system planning projects and studies domestically and worldwide. He has been also responsible for dynamic simulation model development, specifically for HVDC, FACTS, and wind applications. Mr. Kazachkov is a senior member of the IEEE Power Engineering Society.

Darren McCrank

Darren McCrank works in the Transmission Operations Department of the Alberta System Operator (AESO). He has extensive experience with wind generation interconnection and integration studies.

Abraham Ellis

Abraham graduated from New Mexico State University in 2000 with a Ph.D. in Electrical Engineering. In 2001, he joined the Transmission Operations Department at Public Service Company of New Mexico, where he works in the areas of large generator interconnection studies, transmission expansion planning and special projects related to transmission system performance and monitoring. Abraham involved in various activities related to wind energy at the regional and national level. He currently coordinates Western Electricity Coordinating Council's Wind Generator Modeling Group and the IEEE Wind Generator Dynamic Performance Task Force. He also served as Chairman of the Modeling and Validation Work Group until July 2007. Abraham is a Senior Member of IEEE and is a registered Professional Engineer in the State of New Mexico.