

Utility Wind Integration

**Southeast Regional Offshore Wind Power
Symposium**

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Wind Turbine Generators

- **Conventional fossil fuel generators utilize synchronous generators. Synchronous generators provide significant advantages over induction generators. Synchronous generators allow for easy voltage and reactive power regulation along with improved stability characteristics.**
- **Large utility scale wind turbines utilize induction (asynchronous) generators modified through the use of power electronics to obtain characteristics of synchronous generators. At least one manufacturer of large wind turbines has introduced a unit utilizing a synchronous generator.**
- **Induction style generators provide several advantages in wind generation. Rotor slip of the induction generator provides speed regulation for momentary wind speed excursions. Rotor slip also acts as a shock absorber for the mechanical components of the wind turbine.**

Wind Plant Interconnection

- Although wind turbine generators have different characteristics than conventional fossil generation, wind plants can readily be connected to the electric grid. Existing technology allows wind plants to meet requirements of the utility grid such as reactive power control, voltage regulation, ability to remain connected to the grid during momentary voltage collapse and SCADA control to reduce impacts of generator ramp rate.
- Wind plant sizes have increased from the 50 MW size in the 1990's to 200 MWs and up including the Horse Hollow facility in Texas with a capacity of 700+ MWs. Within several years, wind plant(s) of 1000 MWs or larger concentrated in a localized area will be in existence.
- Interconnecting utility tariff requirements require wind plants to be interconnected to the utility grid in a manner identical to other generation although most tariffs do allow for slightly different treatment of wind generation.

Typical Wind Plant Interconnect Studies

- **Most power pools utilize a three step approach to analyze and determine facilities necessary and operating requirements of the generator interconnect. These steps are as follows:**
 - **Feasibility Study**
 - **System Impact Study**
 - **Facility Study**

Feasibility Study

- **Interconnection Feasibility Study is a preliminary evaluation of the impact the wind generating facility characteristics has on the electric utility system.**
- **Low cost rather quick written analysis of the expected costs to be incurred if wind generating facility is interconnected to the transmission system.**
- **A high level cost analysis of interconnecting the wind generating facility is provided.**
- **Allows the wind generator facility Owner to determine the economics of proceeding with the project.**

System Impact Study

- **Interconnection System Impact Study is an in-depth analysis of impacts on the transmission system that will incur when the wind plant generating facility is interconnected.**
- **Safety and reliability of the transmission system is analyzed.**
- **Adjacent transmission systems and underlying low voltage systems are analyzed for impacts.**
- **Dynamic and stability issues are analyzed.**
- **Short circuit impacts are determined**
- **Adverse system impacts are identified.**
- **Summary of transmission system improvements are provided along with estimated costs.**

Facility Study

- **Facility Study provides detail on transmission system upgrades found to be necessary in the System Impact Study to allow interconnection of the wind plant facility.**
- **Includes Transmission Owner's Interconnection Facilities, System Protection Facilities.**
- **Provides detailed cost analysis of required facilities.**
- **Provides detailed construction schedule necessary to complete required transmission system upgrades.**
- **Determines which transmission system upgrades are classified as network upgrades and those upgrades that are the full responsibility of the wind plant owner.**
- **Provides summary, estimated costs and schedule for improvements necessary on adjacent transmission systems.**

Energy Resource

- **Energy Resource Interconnection Service allows the wind plant generator to interconnect with a less stringent set of requirements. That is, deliverability of the wind plant generation to the transmission load is not a requirement for Energy Resource designation.**
- **Energy Resource allows the wind plant's output to be delivered using existing firm or non-firm capacity of the Transmission System on an "as available" basis.**
- **Energy Resource does not convey any right to deliver generation to any specific customer or Point of Delivery.**
- **Generally results in a lower cost to interconnect the wind plant facility as transmission system upgrades necessary to deliver generation to the transmission load are not necessary.**

Network Resource

- The Transmission Provider must conduct the necessary studies and the Transmission Owner shall cause the construction of the Network Upgrades, System Protection Facilities, Distribution Upgrades or Generator Upgrades, subject to the approval of Governmental Authorities, needed to integrate the Generating Facility in the same manner as for any Large Generating Facility being designated as a Network Resource.
- NR Interconnection Service allows the Generating Facility to be designated as a Network Resource, up to the Generating Facility's full output on the same basis as other Network Resources that are interconnected to the Transmission or Distribution System as applicable, and to be studied as a Network Resource on the assumption that such a designation will occur.

Capacity Accreditation

- Important as capacity accreditation of the wind plant will allow the load serving entity or local utility claiming the wind plant output to apply a percentage of the wind plant rating to its resource adequacy requirement. That is, there is economic value in obtaining capacity accreditation.
- To obtain capacity accreditation, the wind plant must be studied as a network resource.
- Typically, ten to twenty percent of the wind plant rating is eligible for capacity accreditation. Therefore, a 100 MW wind plant will provide 10 MWs to 20 MWs of resource capability.

Typical Data for Interconnect Study

Substation Step-Up Transformer Data

RATINGS

Capacity

101,000 / 134,000 / 167,000 KVA (OA/FA/FA)

Voltage Ratio

(Generator side/System side/Tertiary)

34.5 / 161 KV

Winding Connections (Low V/High V/Tertiary V (Delta or Wye))

Grounded Wye / Grounded Wye / Delta

Fixed Taps Available 153, 157, 161, 165, 169 KV

Present Tap Setting: 161 KV

IMPEDANCE

Positive Z1 (on self-cooled kVA rating) 8.0 % 33 X/R

Zero Z0 (on self-cooled kVA rating) 6.9 % 33 X/R

Typical Data for Interconnect Study

Turbine Generator Step-Up Transformer Data

Capacity Self-cooled/maximum nameplate
1750 / 1750 kVA

Voltage Ratio Generator side/System side
575 v / 34.5 kV

Winding Connections Low V/High V (Delta or Wye)
Grounded Wye / Delta

Fixed Taps Available 32.8, 33.6, 34.5, 35.4, 36.2 KV Present Tap Setting 34.5 kV

IMPEDANCE

Positive Z1 (on self-cooled kVA rating) 5.8 % 10.0 X/R
Zero Z0 (on self-cooled kVA rating) 5.2 % 10.0 X/R

Typical Data for Interconnect Study Induction Generator

- (*) Field Volts: Rated voltage (rotor) = 1715 V, Rated voltage (stator) = 575 V
- (*) Field Amperes: Rated current (stator) = 1509 A, Rated Field current 624 A
- (*) Motoring Power (kW): 1,545 kW
- (*) Neutral Grounding Resistor (If Applicable): N/A
- (*) I22t or K (Heating Time Constant): N/A
- (*) Rotor Resistance: 0.00127 ohms
- (*) Stator Resistance: 0.0018 ohms
- (*) Stator Reactance: 0.034 ohms
- (*) Rotor Reactance: 0.031 ohms
- (*) Magnetizing Reactance: 0.618 ohms
- (*) Short Circuit Reactance: 0.065 ohms
- (*) Exciting Current: 615 Amps
- (*) Temperature Rise: Insulation Class F/B
- (*) Frame Size: N/A
- (*) Design Letter: Generator DAS AB 5025-6U
- (*) Reactive Power Required In Vars (No Load): 0 (can supply or absorb Vars)
- (*) Reactive Power Required In Vars (Full Load): 0 (can supply or absorb Vars)
- (*) Total Rotating Inertia, H: 4.44 Per Unit on KVA Base

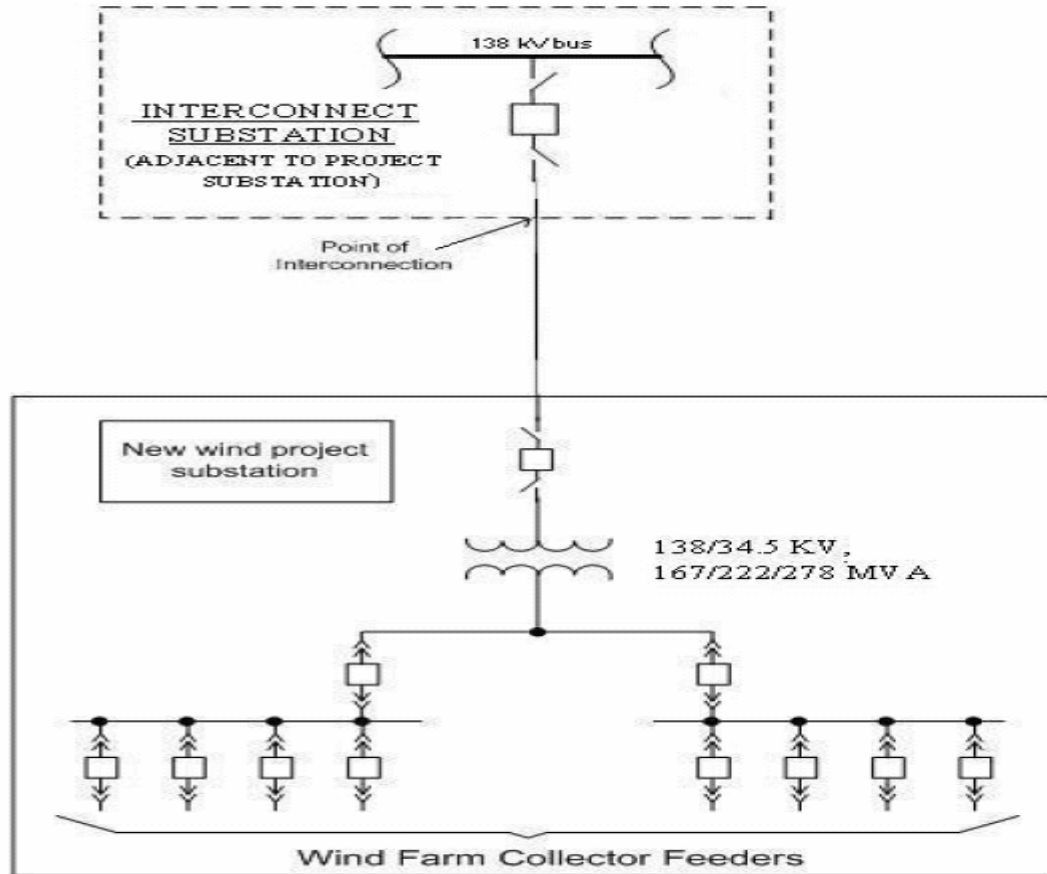
Typical Data for Interconnect Study

Armature Winding Data

- **ARMATURE WINDING RESISTANCE DATA (PER UNIT)**
- Positive R1 0.0043 pu
- Negative R2 0.0043 pu
- Zero R0 0.0043 pu
- Rotor Short Time Thermal Capacity I²t = N/A
- Field Current at Rated kVA, Armature Voltage and PF = 624 amps
- Field Current at Rated kVA and Armature Voltage, 0 PF = N/A amps
- Three Phase Armature Winding Capacitance = N/A microfarad
- Field Winding Resistance = 0.0202 ohms 20 °C
- Armature Winding Resistance (/Phase) = 0.0182 ohms 20 °C

Typical Data for Interconnect Study

One-line of Interconnect Facilities



Low Voltage Ride Through

- **“Low voltage ride through” (LVRT) requirement stipulates the wind turbine will remain connected to the transmission grid under a specified set of conditions.**
- **FERC requirement.**
- **Local transmission interconnecting utility can set these requirements, but must be on a non-discriminatory basis.**
- **First LVRT system installed about five years ago. Has become an industry standard.**
- **Can be achieved by ordering LVRT package with the wind turbine or utilizing SVC, STATCOM, etc. systems.**

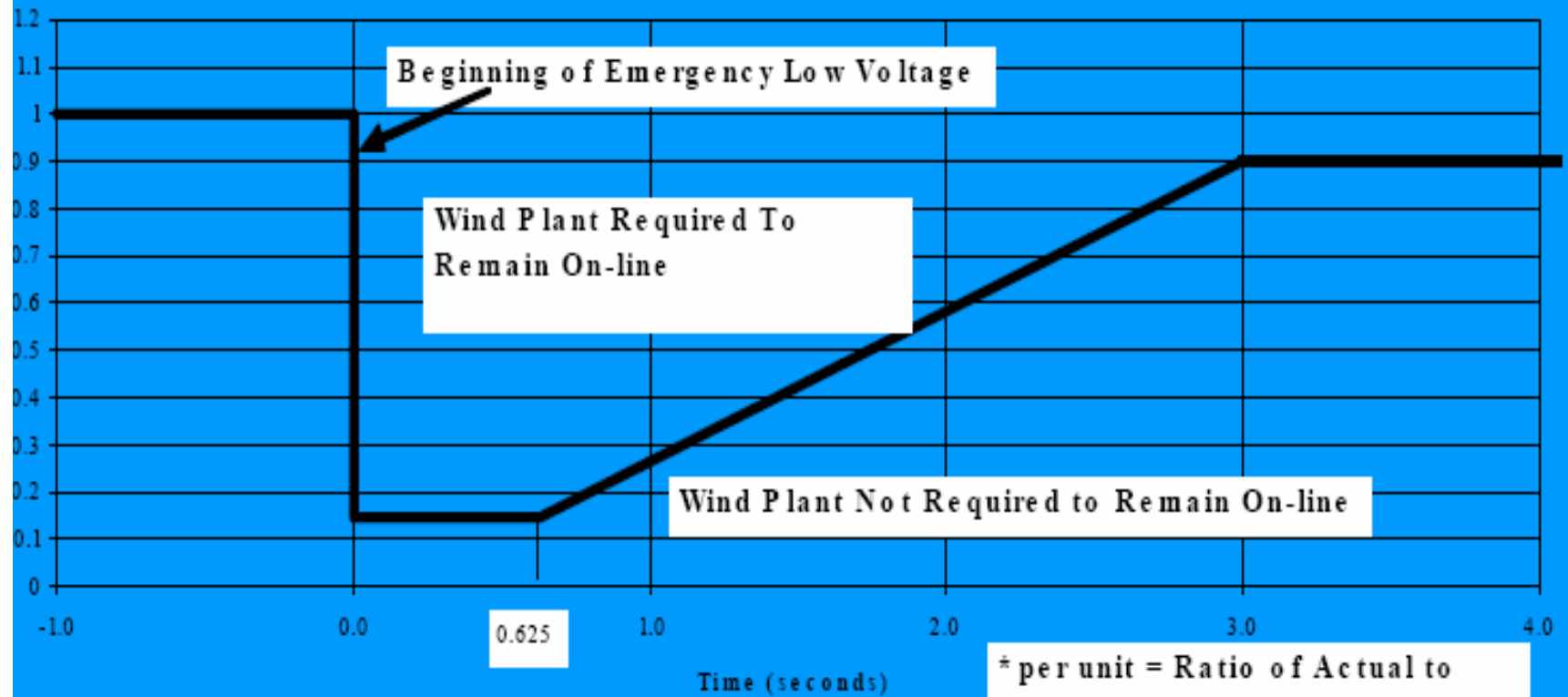
Low Voltage Ride Through (cont)

- Wind plant must remain connected to the transmission grid during and after a three-phase fault on the transmission system. Four to nine cycle clearing time on the transmission system fault.
- Wind plant must remain connected to the transmission grid during and after a single line-to-ground fault on the transmission system with delayed clearing.
- Wind plants being installed through year-end 2007 will be required to meet the above two stipulations down to a per unit voltage of 0.15.
- After 2007, requirement will be down to a per unit voltage of 0.00.

Low Voltage Ride Through (cont)

- Synchronous generators are able to stay on-line due to excitation of the generator from an alternate source.
- Induction generators used on wind turbines require the transmission system as a source of excitation. Momentary loss of the transmission system due to a fault will cause immediate loss of the excitation source for the turbine generator. Loss of the excitation source will cause the wind turbine generator to go off-line. LVRT provides an alternate source of excitation to ride-through these momentary loss of excitation from the transmission system.
- With wind generation adding upto hundreds of MWs in particular areas, LVRT is necessary to meet stability requirements.

Minimum Required Wind Plant Response to Emergency Low Voltage



Beginning of Emergency Low Voltage

Wind Plant Required To Remain On-line

Wind Plant Not Required to Remain On-line

* per unit = Ratio of Actual to Nominal Voltage

Wind Plant Communication

- **The wind plant must arrange for dedicated communication links between the wind plant control system and interconnecting utility. Necessary to protect system reliability.**
- **Typically, dedicated voice lines through the local telephone system are utilized. Data regarding critical operating components of the wind plant is transferred on a continuous basis back to the interconnecting utility system dispatch center. Dedicated data circuits are preferred. Data circuits must be high speed.**
- **Larger wind plants will require dedicated data circuits.**

Wind Plant Communication (cont)

Typical wind plant information that is transferred between the wind plant and interconnecting utility system dispatch center is as follows:

- **Wind speed.**
- **Wind plant generation scheduling data.**
- **Wind turbine operational status.**
- **Wind plant MW and MVAR output.**
- **Wind turbine(s) down for maintenance.**
- **Wind plant substation status alarms.**
- **Wind plant interconnecting breaker control.**
- **Voltage schedules.**
- **Redispatch schedules.**

Wind Plant SCADA System

- **FERC requires a wind plant to have a SCADA system that can transmit data and receive data to ensure transmission system reliability is met.**
- **Current wind plant SCADA systems allow for an extensive means of remote operation of individual turbines and collection of operating data. High speed SCADA links to each turbine and other critical devices provide a continuous flow of data to the wind plant operator.**
- **Interfaces to utility central dispatch operations are being implemented, allowing automated implementation of control area operational requirements.**

Wind Plant SCADA System (cont)

- **Future wind plants will be subjected to automatic curtailment, required meet voltage schedules, meet improved ramp rates, etc. all of which will require enhanced SCADA systems with remote capabilities.**
- **In the near future, participation in automatic generator control (AGC) will likely be accomplished by the control area EMS interacting with the wind plant control center, rather than from EMS to individual wind turbines. Participation in the AGC will allow for improved power system security and reliability and provide for automatic curtailment of the wind plant generation under system contingencies.**

Imbalance Issues

- **Wind plants are classified as an intermittent (dynamic) resource. That is delivery of the wind plant output varies (can be significant) over time.**
- **Generally, pro forma tariffs contain requirements to deliver a set amount of capacity and energy over a specific time interval. This commitment by the generator is called a schedule. Schedules work very well with fossil and to a certain extent with hydro as energy and capacity output can readily be controlled.**
- **Imbalance charges were developed in order to ensure that a generator's actual hourly output matched the scheduled amounts. These imbalance charges work to enhance reliability, encourage accurate scheduling and discourage other conduct detrimental to the ethical and reliable operation of the generator.**

Imbalance Issues (cont)

- **Wind plants have great difficulty in predicting actual hourly output on a day ahead basis. Thus, imbalance charges based on an hourly scheduled output tend to be very punitive to wind plants.**
- **Re-dispatching the wind plant to meet avoid imbalance charges is difficult. Reducing wind plant output to avoid over scheduling is a significant economic impact as operating costs are extremely low and the fuel is free. Increasing wind plant output to avoid under scheduling is impossible as there is no control over fuel delivery (wind).**
- **The control area operator (or balancing authority) has responsibility to maintain load, generation and net interchange balance within the control area and ensure system frequency requirements are met.**

Imbalance Issues (cont)

- **Tariffs are being developed to accommodate imbalance issues with intermittent resources. These tariffs are market based under which the independent system operator establishes a mechanism to market based costs associated with balancing. The intermittent resource owner then purchases energy/capacity to meet balancing requirements. Market based costs are significantly closer to the true cost of operating an intermittent resource outside a delivered schedule.**
- **Further refinement of this market and tariffs allows net scheduling at the end of the month. This concept in effect by California Independent System Operator (CAISO) exempts the wind plant owner from hourly imbalance penalties and allows net scheduling.**

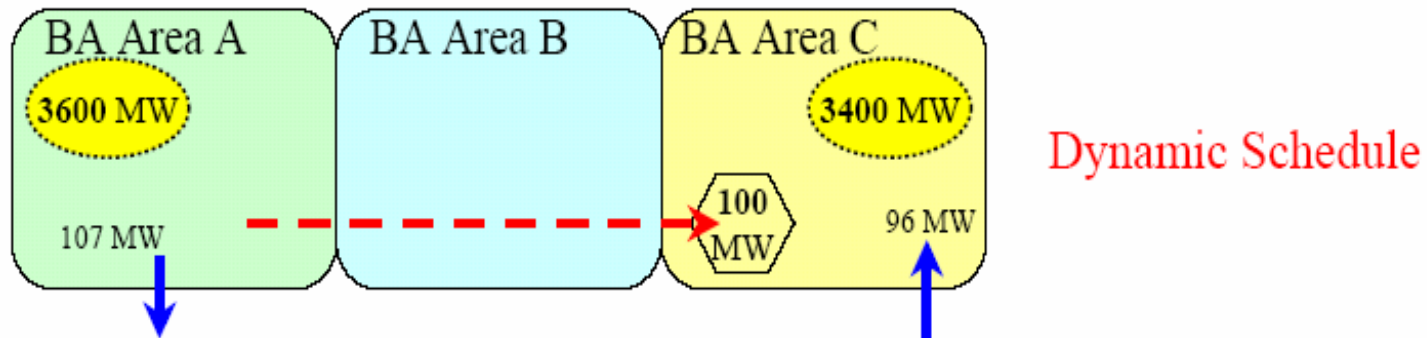
Imbalance Issues (cont)

- **Typical tariffs establishes penalties for energy imbalances exceeding plus or minus 1.5 percent of the schedule. There is precedent to allow greater deviation of upto a plus or minus 10 percent bandwidth on the schedule before imbalance penalties kick in.**
- **CAISO is allowing monthly netting of imbalances. However, the wind plant owner must participate in a centralized wind plant output forecasting program operated by CAISO. Under this arrangement, imbalance penalties due to the intermittent nature of wind are generally negated. CAISO provides all forecasting and scheduling for the wind plants participating in this program and nets any imbalances over the course of a month.**

Dynamic Scheduling Example

(Courtesy of Cinergy)

Load Following and Regulation service through a Dynamic Schedule



The dynamic schedule has a source BA of “A” and a sink BA of “C”, and the load is reported in the system served by Balancing Authority C. Reserve requirements for each BA Area are dependent upon the Ancillary Services provided: the load in “C” could receive Schedule 3 services from generation within “A” for example while procuring Schedule 5 & 6 from Balancing Authority C.

Dynamic Scheduling Example (cont)

(Courtesy of Cinergy)

Balancing Authority Area A

Generation = 3600 MW

Net Actual Interchange = 107 MW

BA Load = 3600 - (107) = 3493 MW

Net Scheduled Interchange = 100 MW

$ACE = (107 - 100) - 10B(F_A - F_S) - I_{ME}$

Balancing Authority Area C

Generation = 3400 MW

Net Actual Interchange = -96 MW

BA Load = 3400 - (-96) = 3496 MW

Net Scheduled Interchange = -100 MW

$ACE = (-96 + 100) - 10B(F_A - F_S) - I_{ME2}$

Scheduling

- **Operating rules require generators to schedule generator output ahead of schedule to meet expected load. Most generator scheduling is on a day-ahead basis. Accurate schedules are critical to the economic and reliable operation of the transmission system.**
- **Once the generator provides a schedule, the generator is obligated to meet the schedule or to reimburse the control area for costs incurred with such reimbursements known as imbalance penalties.**
- **Typically, wind plant operators contract with an outside firm to provide wind plant output forecasts to the wind plant operator. The wind plant operator then submits this information to the control area operator in the form of a schedule.**

Scheduling (cont)

- **Tremendous advancement has been made in regards to accurately forecasting wind plant output. However, significant unpredictability exists especially in regards to actual hourly output when scheduling on a day ahead basis.**
- **Wind is not completely unpredictable on a day-ahead basis, it is practical for some wind capacity to be scheduled.**
- **Prior day's wind or the prior hour's wind can be used to estimate the wind speed, and hence the capacity available for the next period. Wind plant operators ability to predict their plant's output increases significantly in the hour ahead of delivery.**
- **Data is gathered from wind plant site anemometers and submitted continuously to outside wind forecasting firms who then provide wind plant output on a day ahead basis.**

Scheduling (cont)

- **As previously discussed, there will be a gradual evolution to centralized forecasting and scheduling of wind plant output with such forecasting and scheduling being completed by the transmission owners or independent system operators (ISOs).**

Voltage Schedules

- **There is an increasing need to have wind plants meet voltage schedules to maintain transmission system integrity and reliability. Voltage schedules are significantly easier to meet when using synchronous generators as one only has to adjust the excitation. Since it is not possible to adjust excitation with induction machines, other means are required.**
- **Typically, wind turbines will be provided with reactive compensation capabilities that allow reactive power to be absorbed from the transmission system or injected into the transmission system.**
- **There are limitations as a wind plant's ability to absorb reactive power is directly proportional to the wind turbine output.**

Voltage Schedules (cont)

- **At zero output, the wind plant will only absorb reactive power sufficient to meet the excitation requirements of the transformers and machine. Thus there is little ability to absorb reactive power.**
- **At zero output, the wind plant can provide reactive power as all available reactive compensation can be provided to the transmission system. As the wind turbine increases its MW output, there is a decrease in available reactive compensation as some of this reactive power has to be utilized by the machine to ensure KVA ratings are not exceeded.**
- **Voltage schedules are generally delivered to the wind plant operator on a day ahead basis. However, transmission system contingencies may result in much shorter notification.**

Voltage Schedules (cont)

- **Wind plants are not penalized for failure to meet voltage schedules if a good faith effort has been made and the wind plant is operating within the power factor requirements of the interconnection agreement.**
- **The wind plant operator must notify the control area operator of its inability to meet the voltage schedule.**
- **SVC and STATCOM equipment is available and is currently being used to enhance the reactive capability of wind plants. In turn, the wind plants ability to meet voltage schedules is improved.**

Power Factor Requirements

- **Wind Plants are required to operate within a specified power factor range as determined by the Transmission Owner.**
- **Typically, this power factor range is 0.95 leading to 0.95 lagging and the wind plant is required to operate at any point within this range. That is, the wind plant cannot “float” over this range as it wishes, but must operate at a value within this range as dictated by the transmission owner. However, power factor requirements with bandwidths of 0.88 leading to 0.90 lagging do exist.**
- **As previously noted, wind turbines are provided with reactive compensation capabilities that allow reactive power to be absorbed from the transmission system or injected into the transmission system.**

Power Factor Requirements (cont)

- **Each wind turbine on the market today has various packages to meet power factor requirements. Some wind turbines have significant advantages over others in this regards and the wind plant owner must be conscious of power factor and voltage schedule requirements when selecting a wind turbine and/or the reactive compensation package.**
- **Several wind turbine manufacturers have the capability of providing reactive compensation on a dynamic basic which has inherent advantages.**
- **SVC and STATCOM equipment is available and is currently being used to meet wider power factor bandwidths.**

Wind Turbine Transformers

- **Utility scale wind turbines utilize generators rated less than 1000 volts. The generator voltage is stepped-up to a higher voltage (15 KV, 25 KV or 35 KV) through the use of a transformer at each turbine. These transformers are generally located at the base of the turbine. However, one major manufacturer of wind turbines locates these transformers in the turbine nacelle adjacent to the generator.**
- **The low voltage windings of these transformers are generally wye-connected and provide ancillary power needs of the turbine (heaters, pumps, braking, lights, etc.). The medium-voltage side of the transformer is generally delta connected.**

Wind Turbine Transformers (cont)

- **With the advent of low voltage ride-through capabilities on wind turbines, it is necessary to provide a ground source for the medium voltage side of the wind turbine transformer. Without the ground source, large, equipment damaging overvoltages can occur when a fault occurs on the medium voltage system.**
- **This ground source can consist of either a neutral reactor or a grounding transformer. Ground source equipment is generally located at the utility source end of the medium voltage circuit.**
- **Important to include safety interlocks to ensure ground source equipment is not disconnected from the energized system it is providing the ground source for.**

Typical Wind Plant Electrical Layout

