CRESP Phase II Preparation: Integration Study Task Descriptions

Final Report

Prepared for the World Bank

Prepared by:

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BACKGROUND

The China Renewable Energy Scale-up Program (CRESP) has been developed by the Government of China (GoC) in cooperation with the World Bank (WB) and the Global Environment Facility (GEF) to provide assistance with the implementation of a renewable energy policy development and investment program. CRESP Phase I closed in September 2011, and Phase II is scheduled to begin in late 2012. CRESP I contributed greatly to the scale up of China's renewable energy sector. China passed the Renewable Energy Law in 2005, one of the first in the developing world. The government adopted a feed-in tariff for wind and biomass power, and allowed the incremental cost difference between renewable energy and fossil fuels to be passed on to domestic consumers. In 2010, China was ranked first in the world in total renewable energy and small hydro capacity installed, and highly ranked in biomass installed capacity as well. Chinese manufacturers produce about a quarter of both wind turbines and solar PV systems worldwide.

The objective of CRESP Phase II is to support the Chinese government's 12th Five Year Plan (FYP) to enable continued and sustainable scale-up of commercial renewable energy development through cost reduction, efficiency improvement, and smooth integration to the grids, thereby contributing to the government's target of reduction in carbon intensity. CRESP Phase II has four components: (1) policy and implementation support; (2) development strategy and technology improvement; (3) capacity building; and (4) RE investment.

The second component, development strategy and technology improvement, will consist of targeted studies to ensure strategic and optimal deployment of key RE technologies and cost sharing demonstration and deployment and technology improvement activities to enhance quality and reduce RE incremental costs. The studies includes: (1) improving site layout design to decrease wake effects for GW-scale on-shore Wind Power Bases and off-shore wind to maximize outputs of wind, and developing wind farm development standard and implementation methodology; (2) developing strategies and policies for biomass technology and promotion of biomass manufacturing industry; and (3) improving grid integration and planning. The cost-sharing grants include: (4) improving off-shore wind technology and domestic manufacturing capacity through cost-shared demonstration and deployment and turbine specifications; (5) developing grid integration technologies such as smart grids, grid friendly wind turbines, and energy storage technologies in areas with a large share of wind in the power grids; (6) improving biomass technologies; and (7) pilot demonstration of RE distributed generation districts in urban areas and green counties.

One of the major barriers to RE development in China now is that a large share of wind power cannot get connected to the grids due to policy, institutional, and technological barriers. CRESP II plans to address this barrier through recommending (1) systematic grid access policies, financial incentives and mandatory policies to grid companies, and Grid Code recommendations; (2) institutional arrangements for power system operation; (3) better coordinated planning between generation and transmission; and (4) supporting advanced technologies such as smart grids and grid-friendly turbines to ensure smooth integration of RE into the grids.

The objective of the assignment reported here is to design detailed activities for improving renewable energy grid integration and planning, and examining the policy, institutional, and technology perspectives under CRESP Phase II. The work is also intended to identify approaches for developing grid technologies to be implemented under CRESP Phase II. The following provides a more detailed description of the specific project objectives, recognizing the unique characteristics of renewable energy grid integration.

1. Design the detail activities regarding policies on:
    a. incentives and transmission pricing policies for the grid companies to invest in additional transmission facilities and to cover costs of dispatch activities required to accommodate more intermittent renewable resources;
    b. necessary grid code characteristics to ensure system reliability; and
    c. grid access policies for distributed generation, priority dispatch for distributed generation; and institutional set-up for the power sector system; including scheduling and dispatch policies

2. Design the detail activities regarding technical studies on:
    a. complementarity of the pump storage, hydro resources, and other storage technology with intermittent wind resources;
    b. review international experience particularly in Demark and Spain on how to handle the dispatch when wind power accounts for up to 80% of the power system in one day;
    c. design, development and eventual demonstration and deployment of grid friendly turbines with better power factor control and grid fault management capability to reduce disturbances to the grid based on China's grid code(s) and grid connection technologies;
    d. grid integration technologies, such as smart grids and energy storage technologies, in order to ease the deployment of renewable energy;
    e. comprehensive connection studies involving all the stakeholders with a focus on the optimum connection size and connection circuit size and connection circuit layout for the large-scale wind power bases;
    f. simulation of large-scale grid integration of wind and solar PV, including transmission planning and wind integration studies, and examination of sources of system flexibility.

Grid integration has become a major bottleneck for wind development in China, which the above activities are meant to address in a comprehensive fashion. China already has the largest amount of wind generation capacity in the word and is continuing to expand with 250-300 GW of wind generation planned for 2020. Integrating that much wind generation into the power system presents significant challenges for the transmission system, the conventional generators, and system operators. Existing wind generation already has difficulty getting connected to the grid and delivering energy to load centers. These problems will only get worse. A coordinated effort is required to optimize the design, operation, cost and reliability of the future power system. The objective of the assignment reported here is to design detailed activities for improving renewable energy grid integration and planning, and examining the policy, institutional, and technology perspectives under CRESP Phase II. This effort is critical if wind generation is to expand as called for in the 12th five year plan.

The CRESP Phase II Preparation: Integration Study Task Descriptions report proposes a set of integrated tasks that are designed to improve renewable energy grid integration and planning, identify approaches for developing grid technologies, and examine the policy, institutional, and technology perspectives under CRESP Phase II. Individual tasks are interrelated and grouped into tracks for a complete and coordinated approach, as shown in Figure 1.

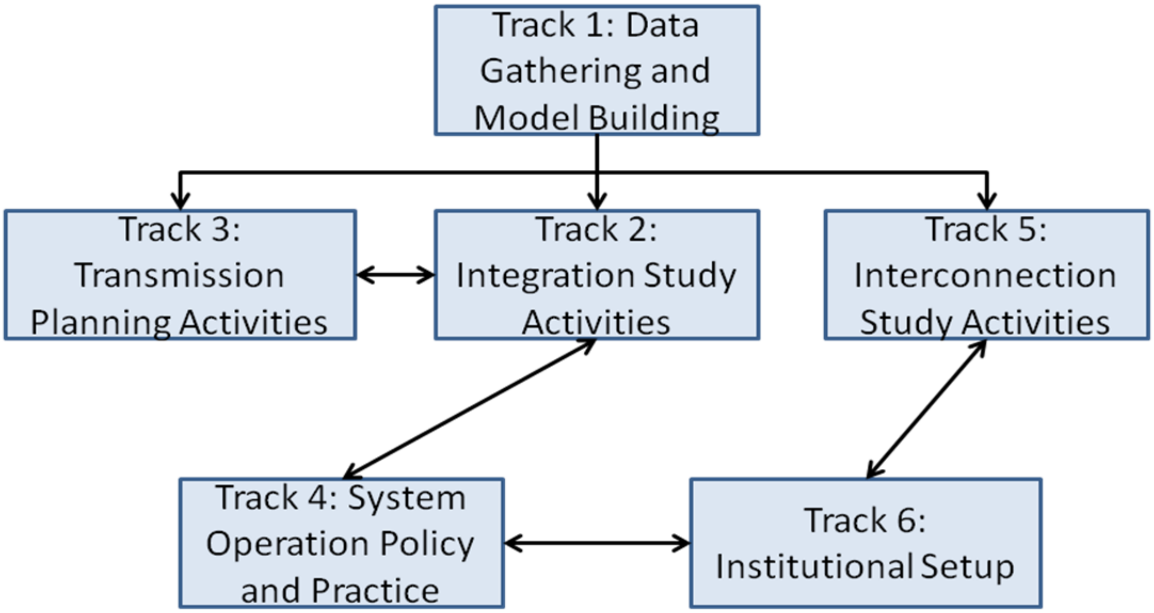


Figure 1 Interrelationship between Tracks within the overall project.

Track 1 consists of five tasks which gather data, develop models, and define the scenarios to be modeled in the rest of the program. Separate but parallel meso scale wind modeling and load modeling tasks are identified for Inner Mongolia and for the multi-province power system. The meso scale wind modeling tasks must be closely coordinated with the time synchronized load modeling task. Both of these efforts are required for developing the scenarios. The results from Track 1 are required for all of the subsequent analysis. Track 1 utilizes transmission system design input from Track 3 for both the model and scenario development.

Track 2 consists of four tasks to perform the comprehensive wind integration studies identified in Track 1, review international experience and identify solutions that are applicable for China, and identify opportunities to increase reliability, reduce costs, and increase the amount of wind that can be reliably integrated into the power system. Track 2 requires input from Track 1 and provides results that are used by Tracks 3 and 4. Track 2 utilizes transmission system design inputs from Task 3 for transmission system design and Task 4 to correctly model wind forecasting and account for wind generation impacts on ancillary service requirements.

Track 3 consists of four tasks that develop transmission and generation expansion plans for both Inner Mongolia and the multi-province power system. It develops a comprehensive connections studies process to determine optimum plant configurations and sizes. It also develops transmission pricing policies and incentives. Load and wind data is required from Track 1 and integration study results are required from Track 2. Track 3 results are also used by Track 2 for transmission system design.

Track 4 consists of two tasks that incorporate wind plant output forecasting into system operations and that identify the ancillary services required to reliably and economically integrate wind generation. Wind integration study results are required from Track 2. Changes in institutional, regulatory, and business practices are required from Track 6. Track 4 supplies input to both Track 2 so that ancillary services can be appropriately included in the wind integration studies and Track 6 so that regulatory and business practices can be designed to obtain the required ancillary services.

Track 5 consists of three tasks that specify interconnection requirements, define grid friendly wind turbine and plant designs, and recommend grid access policies for wind generators. Wind generation data is required from Track 1 and regulatory and business practice input is required from Track 6. Track 5 results will be used by Track 6 to refine business practices and regulatory policies.

Track 6 has a single task to refine business practices and regulatory policies. Input is required from Track 4 concerning ancillary service requirements and forecasting needs. Input is required from Track 5 on grid friendly wind plant interconnection requirements. Track 6 results are in turn used by both Track 4 and Track 5 to refine ancillary service definitions and grid friendly wind generator and plant definitions.

Individual tasks are defined in each Track to facilitate efficiently organizing and conducting the required work. The overall project is organized into individual Tracks of related tasks. Each Track builds on the results of other Tracks and in turn provides results for use in the rest of the analysis. Together the six Tracks and their constituent tasks collectively form a program that will improve renewable energy grid integration and planning as well as the regulatory and business institutions that support the electric power system.

TRACK 1: DATA GATHERING, MODEL BUILDING AND ESTABLISHING WHAT TO MODEL

Task 1: Meso Scale Wind Modeling

a. Conduct back-casting numerical weather modeling to create a multi-year time-series data set of wind speed at hub height and wind power output with a ten minute resolution on a 2 km grid spacing.
b. Synchronize selected modeling years with Task 2.
c. Verify wind modeling with actual wind plant output from selected wind plants.

Task 2: Load Modeling

a. Build a multi-year time-series load data set that is based on the same historic years as the synthesized wind data in Task 1.
b. Include the appropriate minute-to-minute variability, and appropriately scale to the model years specified in Task 3.

Task 3: Scenario Definition

a. Define the base case and sensitivities
    - Select the future modeling year or years
    - Determine how much wind generation to model based on the latest 5 year plan
    - Define the conventional generation expansion plan
        - Include future generation expansion alternatives with added flexibility
b. Define the industry structure to be modeled
    - Establish transmission design assumptions
    - Establish generation and transmission scheduling assumptions (balancing criteria)

        - At a minimum, include both the current province-by-province balancing method and system-wide security constrained unit commitment and economic dispatch as sensitivities.
    - Define reliability criteria
    - Define required ancillary services criteria
c. Select the modeling tools
d. Build system models and populate them with plant data for current and expected future generators
    - Characterize the conventional generation plants response flexibility and costs.
    - Characterizing any/all demand response capability and cost.

TRACK 2: INTEGRATION STUDY ACTIVITIES

Task 1: Perform Comprehensive Wind Integration Study Based on Track 1 Input

a. Use latest methodologies from previous studies including the Midwest Independent System Operator Multi Value Projects iterative methodology (see attachment 1)
    - Include capacity adequacy and stability studies
b. Perform Sensitivity Studies Including:
    - Pumped storage, hydro resources and other storage technologies
    - Effects of aggregation of wind plant output over large geographic regions
    - Participation of demand side management for energy response and ancillary service supply

Task 2: Review International Experience

a. Include Denmark, Spain, Ireland, Portugal, and Xcel/PSCO in USA on how to handle the dispatch when instantaneous wind power accounts for up to 80% of the power system generation
    - Recommend additions or deletions and justify
b. Specifically look at modifications to CHP plants to increase flexibility

Task 3: Expanding Flexibility Options

a. Investigate various methods for increasing power system flexibility to assist with wind integration including:
    i. Advanced smart grid technologies
    ii. Electric vehicles
    iii. Large-scale thermal storage opportunities with electric boilers or heat pumps to compensate for inflexible fossil systems with CHP plants in winter
    iv. Design of new fossil plants and CHP plants for increased flexibility
    v. Retrofitting older fossil plants for increased flexibility
    vi. Alternative generation expansion plans with increased renewables, including plans with reciprocating engine plants, gas turbines and combined cycle gas turbines

TRACK 3: TRANSMISSION PLANNING ACTIVITIES

Task 1: Develop a Transmission and Generation Expansion Plan for Immediate Use in Track 1 and Track 2 Modeling

a. Consider simplified renewable energy zones

Task 2: Develop a Comprehensive Connection Studies Process

a. Involve all stakeholders
b. Focus on the optimum connection size, connection circuit size, and connection circuit layout for the large-scale wind power bases (10 GW) in designated areas

Task 3: Develop Transmission Pricing Policies and Incentives

a. Include incentives to grid companies to invest in additional transmission facilities required to accommodate more intermittent renewable resources

TRACK 4: SYSTEM OPERATION STUDY ACTIVITIES

Task 1: Incorporating Wind Plant Forecasting Into System Operations

a. Recommend best practices in wind power forecasting for power system operations
b. Determine how to incorporate wind plant output forecasting into operations planning on all timescales
    - Compare benefits of centralized vs decentralized forecasting
c. Recommend best practices for security constrained unit commitment and economic dispatch with high penetrations of variable generation
    - Considering Priority Dispatch for variable generation vs Dispatchable Intermittent Resource as part of economic dispatch
d. Recommend best practices for managing the power system with excess energy

Task 2: System Balancing and Ancillary Services

a. Develop sub-hourly dispatch practices and energy imbalance markets rules, ancillary services definitions, and day-ahead hourly ancillary service scheduling practices
    - Include compensation criteria for resources providing ancillary services including compensation for lost opportunities
    - Consider ancillary service markets with uniform clearing prices
b. Recommend incentives to the grid companies to cover costs of dispatch activities required to accommodate more intermittent renewable resources

TRACK 5: INTERCONNECTION STUDY ACTIVITIES

Task 1: Specify Interconnection Requirements

a. Establish/design a process to determine what interconnection requirements are needed
b. Specify Grid Code Requirements including dynamic models, testing and certification

Task 2: Define Grid Friendly Wind Turbine and Wind Plant Designs Including:

a. Fault ride through
b. Dynamic voltage support
c. Frequency response
d. Synthetic inertia

Task 3: Recommend Grid Access Policies for Variable Generation

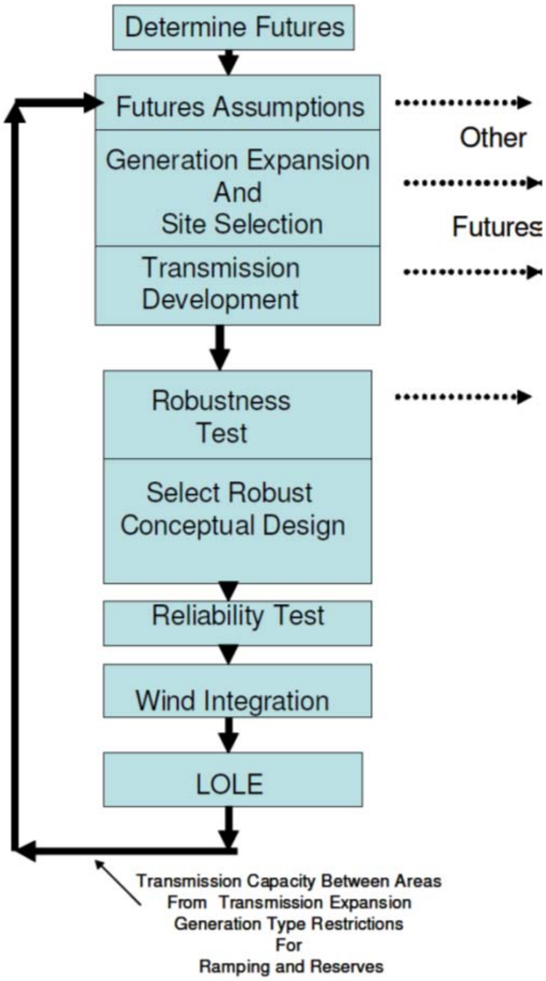
a. At a minimum compare priority access vs a process similar to that adopted in FERC Order 2003

TRACK 6: INSTITUTIONAL SETUP

Task 1: Institutional Process and Policies

a. Design an institutional process to assure that grid access policies and recommended operating practices work.
b. Determine what additional policies are required to facilitate integration of large amounts of wind generation.

Attachment 1: MISO MVP Iterative Methodology



Transmission Capacity Between Areas
From Transmission Expansion
Generation Type Restrictions
For
Ramping and Reserves

Figure 2
Long Range Planning Process Diagram

D. Osborn and J. Lawhorn, Midwest ISO Transmission Planning Process. IEEE P&E Annual Meeting, Calgary, Alberta, Canada, July 2009.

TRACK 1: DATA GATHERING, MODEL BUILDING AND ESTABLISHING WHAT TO MODEL

Track 1, Task 1: Meso Scale Wind Modeling – Inner Mongolia

Background

The CRESP Phase II wind integration study will analyze the Inner Mongolian power system with the 35 GW of wind generation planned for in the near term and the 100 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual provincial transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. It will be necessary to model a sufficient amount of the inter-provincial power system to accurately represent the full expected export capabilities for both wind energy and variability mitigation. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value.

Though the production cost modeling will be run with hourly time steps, synchronized wind and load data are required with a ten minute resolution in order to determine the variability of the net system load and the resulting hourly regulation, spinning and non-spinning reserve requirements. Three years of time-synchronized wind and load data are required. Wind data is required for each simulated wind plant. Load and wind data must be physically correlated because meteorology influences load patterns and is a critical factor for wind energy production.

It is not possible to forecast future wind and load as precisely as is required by the modeling technique. Instead, numerical weather modeling techniques must be used to recreate the atmospheric conditions that existed during a period in the past so that wind speed at hub height and the resulting wind power output can be calculated at potential wind plant locations throughout the provinces. Calculating wind speed every 10 minute and for every potential wind plant location over a three year period preserves the short-term synchronization between load and wind and enables sub-hourly effects to be take into account. The wind data will be matched with three years of historically accurate time series load data to be generated in Track 1, Task 2.

Objective

Build a three year time-series wind dataset that is synchronized to the historic load data set being developed in Track 1, Task 2. The dataset will have a 10 minute time resolution and a spatial resolution that is appropriate for the topography.

Approach

Mesoscale wind modeling tools will be used to generate a multi-year data set of historic wind speed and wind power output for potential wind plants throughout the provinces. The wind power data will be time synchronized with the historic load data developed in Track 1, Task 2. The mesoscale wind modeling will use known meteorological measurement data for the historical years to reproduce what the wind speeds and air density would have been at many points, both on the ground and at wind turbine hub height. Those wind speeds will then be used, along with local geographic information (e.g., mountains, lakes, and ridgelines), to calculate the wind power output from potential wind plants at each location. For each plant, the data will span 3 years of 10-minute power production data. For each site, three hourly resolution forecast vectors will be calculated, including a day-ahead horizon (18 to 42 hours), a 6-hour-ahead forecast, and a 4-hour-ahead forecast. A limited amount of 1 second wind data will be required to characterize the regulation requirements.

Using numerical weather prediction models, also known as mesoscale models, is an accepted method for producing a time series of wind plant output data. Essentially, physics-based, numerical simulations on supercomputers, integrated with observational data sets, re-create the weather of historical years and generate a four-dimensional gridded wind-speed data set. A wind speed time series data set can be extracted and converted to wind power output. This approach produces a temporally, spatially, and physically consistent wind data set. This must be done for thousands of potential wind plant locations.

Model results will be verified by comparing with selected historic wind plant time-series output data collected from existing wind plants as well as comparing with anemometer data.

Deliverables

Three years of 10 minute time-series wind speed at hub height and wind power output data, synchronized to the load data being developed in Track 1, Task 2, for each location with a spatial resolution that is appropriate for the topography covering the province. Three wind power output forecasts will also be developed for each location: a day-ahead forecast (18 to 42 hours), a 6-hour-ahead forecast, and a 4-hour-ahead forecast. The data must be based on historic wind data and preserve the correlation with the load data. Sample wind power output data must be verified with historic wind output data from existing wind plants.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a high quality wind time series data set will enable more accurate modeling of reserve requirements, expected wind curtailments, required operating practices, transmission needs, and conventional generation flexibility requirements. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity. Without accurate time series expected wind data synchronized to time series expected load data it will be necessary to plan for 100% reserves for the future wind fleet. With accurate load data the reserve requirements can be reduced to XX%.

Track 1, Task 1: Meso Scale Wind Modeling - National

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual inter-province transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value.

Though the production cost modeling will be run with hourly time steps, synchronized wind and load data are required with a ten minute resolution in order to determine the variability of the net system load and the resulting hourly regulation, spinning and non-spinning reserve requirements. Three years of time-synchronized wind and load data are required. Wind data is required for each simulated wind plant. Load and wind data must be physically correlated because meteorology influences load patterns and is a critical factor for wind energy production.

It is not possible to forecast future wind and load as precisely as is required by the modeling technique. Instead, numerical weather modeling techniques must be used to recreate the atmospheric conditions that existed during a period in the past so that wind speed at hub height and the resulting wind power output can be calculated at potential wind plant locations throughout the provinces. Calculating wind speed every 10 minute and for every potential wind plant location over a three year period preserves the short-term synchronization between load and wind and enables sub-hourly effects to be take into account. The wind data will be matched with three years of historically accurate time series load data to be generated in Track 1, Task 2.

Objective

Build a three year time-series wind dataset that is synchronized to the historic load data set being developed in Track 1, Task 2. The dataset will have a 10 minute time resolution and a spatial resolution that is appropriate for the topography.

Approach

Mesoscale wind modeling tools will be used to generate a multi-year data set of historic wind speed and wind power output for potential wind plants throughout the provinces. The wind power data will be time synchronized with the historic load data developed in Track 1, Task 2. The mesoscale wind modeling will use known meteorological measurement data for the historical years to reproduce what the wind speeds and air density would have been at many points, both on the ground and at wind turbine hub height. Those wind speeds will then be used, along with local geographic information (e.g., mountains, lakes, and ridgelines), to calculate the wind power output from potential wind plants at each location. For each plant, the data will span 3 years of 10-minute power production data. For each site, three hourly resolution forecast vectors will be calculated, including a day-ahead horizon (18 to 42 hours), a 6-hour-ahead forecast, and a 4-hour-ahead forecast. A limited amount of 1 second wind data will be required to characterize the regulation requirements.

Using numerical weather prediction models, also known as mesoscale models, is an accepted method for producing a time series of wind plant output data. Essentially, physics-based, numerical simulations on supercomputers, integrated with observational data sets, re-create the weather of historical years and generate a four-dimensional gridded wind-speed data set. A wind speed time series data set can be extracted and converted to wind power output. This approach produces a temporally, spatially, and physically consistent wind data set. This must be done for thousands of potential wind plant locations.

Model results will be verified by comparing with selected historic wind plant time-series output data collected from existing wind plants as well as comparing with anemometer data.

Deliverables

Three years of 10 minute time-series wind speed at hub height and wind power output data, synchronized to the load data being developed in Track 1, Task 2, for each location with a spatial resolution that is appropriate for the topography covering the provinces. Three wind power output forecasts will also be developed for each location: a day-ahead forecast (18 to 42 hours), a 6-hour-ahead forecast, and a 4-hour-ahead forecast. The data must be based on historic wind data and preserve the correlation with the load data. Sample wind power output data must be verified with historic wind output data from existing wind plants.

Schedule

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Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a high quality wind time series data set will enable more accurate modeling of reserve requirements, expected wind curtailments, required operating practices, transmission needs, and conventional generation flexibility requirements. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity. Without accurate time series expected wind data synchronized to time series expected load data it will be necessary to plan for 100% reserves for the future wind fleet. With accurate load data the reserve requirements can be reduced to XX%.

Track 1, Task 2: Load Modeling – Inner Mongolia

Background

The CRESP Phase II wind integration study will analyze the Inner Mongolian power system with the 35 GW of wind generation planned for in the near term and the 100 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual provincial transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. It will be necessary to model a sufficient amount of the inter-provincial power system to accurately represent the full expected export capabilities for both wind energy and variability mitigation. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value.

Though the production cost modeling will be run with hourly time steps, synchronized wind and load data are required with a ten minute resolution in order to determine the variability of the net system load and the resulting hourly regulation, spinning and non-spinning reserve requirements. Three years of time-synchronized wind and load data are required. Load data is required for each bus in the load flow model.

It is not possible to forecast future wind and load as precisely as is required by the modeling technique. Instead, historic data must be used and escalated to the future expected conditions. This preserves the short-term synchronization between load and wind. Three years of historically accurate time series wind power data will be generated in Track 1, Task 1. This Task 2 will generate load data for the same three years. The load data must be based on the actual load data, in order to capture the appropriate short term fluctuations, but it must be escalated to the expected future conditions based on economic growth and any other factors.

Objective

Build a three year time-series load dataset that is synchronized to the wind data set being developed in Track 1, Task 1 and scaled to the conditions expected in the Track 1, Task 3 model year. The dataset will have a 10 minute time resolution. Separate data series are required for each bus in the power flow model. A limited amount of 1 sec data will be required for calculation of regulation requirements.

Approach

Historic utility supervisory control and data acquisition (SCADA) load data will be collected from each utility in the footprint matching the time frame of the wind data being modeled in Track 1, Task 1. Load data will be scrubbed to remove bad data. Load data will be aggregated from the SCADA rate to a 10 minute time resolution. A limited amount of 1 second load data will be required to characterize the regulation requirements. Load data will be mapped from the SCADA dataset to the appropriate busses in the power flow model. Historic load data will be scaled to match the conditions expected in the modeling year. Both overall system load growth and location specific load growth will be considered. This will require determining what types of loads are expected to be added at each location and using data from similar historic loads as the basis for the projected loads in order to retain appropriate characteristics of the current and projected load shapes such as load factor and annual peak to off-peak load ratio except where they are explicitly expected to change.

Deliverables

Three years of 1 minute time-series load data, synchronized to the wind data being developed in Track 1, Task 1, for each bus location in the study footprint. The data must be based on historic data and preserve the historic minute-to-minute variability. The data must be scaled to the conditions expected in Track 1, Task 3.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a high quality load time series data set will enable more accurate modeling of reserve requirements, expected wind curtailments, required operating practices, transmission needs, and conventional generation flexibility requirements. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity. Without accurate time series expected load data synchronized to time series expected wind data it will be necessary to plan for 100% reserves for the future wind fleet. With accurate load data the reserve requirements can be reduced to XX%.

Track 1, Task 2: Load Modeling - National

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual inter-province transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value.

Though the production cost modeling will be run with hourly time steps, synchronized wind and load data are required with a ten minute resolution in order to determine the variability of the net system load and the resulting hourly regulation, spinning and non-spinning reserve requirements. Three years of time-synchronized wind and load data are required. Load data is required for each bus in the load flow model.

It is not possible to forecast future wind and load as precisely as is required by the modeling technique. Instead, historic data must be used and escalated to the future expected conditions. This preserves the short-term synchronization between load and wind. Three years of historically accurate time series wind power data will be generated in Track 1, Task 1. This Task 2 will generate load data for the same three years. The load data must be based on the actual load data, in order to capture the appropriate short term fluctuations, but it must be escalated to the expected future conditions based on economic growth and any other factors.

Objective

Build a three year time-series load dataset that is synchronized to the wind data set being developed in Track 1, Task 1 and scaled to the conditions expected in the Track 1, Task 3 model year. The dataset will have a 10 minute time resolution. Separate data series are required for each bus in the power flow model. A limited amount of 1 sec data will be required for calculation of regulation requirements.

Approach

Historic utility supervisory control and data acquisition (SCADA) load data will be collected from each utility in the footprint matching the time frame of the wind data being modeled in Track 1, Task 1. Load data will be scrubbed to remove bad data. Load data will be aggregated from the SCADA rate to a 10 minute time resolution. A limited amount of 1 second load data will be required to characterize the regulation requirements. Load data will be mapped from the SCADA dataset to the appropriate busses in the power flow model. Historic load data will be scaled to match the conditions expected in the modeling year. Both overall system load growth and location specific load growth will be considered. This will require determining what types of loads are expected to be added at each location and using data from similar historic loads as the basis for the projected loads in order to retain appropriate characteristics of the current and projected load shapes such as load factor and annual peak to off-peak load ratio except where they are explicitly expected to change.

Deliverables

Three years of 1 minute time-series load data, synchronized to the wind data being developed in Track 1, Task 1, for each bus location in the study footprint. The data must be based on historic data and preserve the historic minute-to-minute variability. The data must be scaled to the conditions expected in Track 1, Task 3.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a high quality load time series data set will enable more accurate modeling of reserve requirements, expected wind curtailments, required operating practices, transmission needs, and conventional generation flexibility requirements. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity. Without accurate time series expected load data synchronized to time series expected wind data it will be necessary to plan for 100% reserves for the future wind fleet. With accurate load data the reserve requirements can be reduced to XX%.

Track 1, Task 3: Scenario Definitions - General

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual inter-province transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value.

It is necessary to characterize the industry structure as well as the capabilities and limitations of the generators and loads before wind integration modeling can be performed. Both a base case and various scenarios must be defined. All data, including the synthesized wind and load data developed in Task 1, Tracks 1 and 2 as well as the conventional generation data and industry structure developed in this Task, must be based on the same future year.

Objective

Establish the base case and scenario assumptions for the wind integration modeling. Define the industry structure to be modeled. Select the modeling tools and build the models based on the generator, load, and transmission system characteristics.

Approach

This Task will specify the conditions to be modeled in the wind integration analysis. Analysis will be conducted of 2020 or of an alternative year, if justified. The amount of wind generation will be based on the 12th five year plan (200 GW of wind generation). The conventional generation mix will also be based on the 12th five year plan. Future generation plans with added flexibility will be included as alternative scenarios.

Transmission design assumptions will be established based on maximum desirable wind curtailment or based on an economic criteria that balances wind curtailment and transmission cost.

The industry structure will be defined based on security constrained least-cost unit commitment and economic dispatch optimized over a wide area with free-flowing ties between utilities and provinces. The current province-by-province balancing will also be included as an alternative scenario. Ancillary services will be defined in technology neutral terms. Reliability criteria and a methodology for establishing reserve requirements and ancillary service amounts based on the reliability criteria will be developed. Reserve requirements will depend, at a minimum, upon current wind and load conditions.

Modeling tools will be selected including production cost modeling tools as well as compatible power flow and stability analysis tools. Hourly production cost modeling capability covering a year or more with security constrained unit commitment and economic dispatch will be required.

Computer based power system models will be built and populate with plant data for current and expected future generators. Conventional generators’ flexibility and costs will be included. Any and all current and planned demand response, both for energy response (efficiency, peak reduction, price response, non-firm load, etc.) and ancillary services (regulation, spinning and non-spinning reserve) will be included.

Deliverables

A base case and set of scenarios that define the modeled conditions including the expected conventional generation as well as the amounts of wind generation will be provided. A description of the expected industry structure, with alternatives, including the reliability requirements and the ancillary services that will assure reliability will be developed. Modeling tools will be selected and models will be developed and populated with generation data.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Developing the industry structure and modeling framework is one of several steps that are necessary to perform the analysis that will assure the reliable and economic integration of large amounts of wind generation. Establishing a structure based on reliability constrained unit commitment and economic dispatch with strong free-flowing transmission ties will be especially beneficial. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity.

TRACK 2: INTEGRATION STUDY ACTIVITIES

Track 2, Task 1: Perform Comprehensive Wind Integration Study based on Track 1 Input – Inner Mongolia

Background

In this task of the CRESP Phase II study, impacts of wind generation on the operation of the Inner Mongolia grid will be analyzed and quantified.

To understand how wind power can be added to the power grid, it is important to recognize how system operators balance supply and demand. The demand for electricity (referred to as "load") can vary widely based on weather—heating and cooling loads dominate utility peak demand. The time of day also influences load, since energy use tends to peak during the daytime when business and industrial needs are highest. Load also fluctuates with the time of year as seasonal changes influence heating, cooling and lighting needs. Although load forecasting is good, loads are somewhat unpredictable. Production also can be unpredictable since power plants and transmission lines can fail unexpectedly or must be taken out of service for maintenance. Wind plants create additional variability and uncertainty because they generate electricity based on wind speed, which changes over time. System operators are responsible for balancing varying demand and supply. They can treat a reduction in wind energy the same as they would an increase in energy demand

Wind generation cannot be controlled or precisely predicted. While these attributes are not unique to wind generation, variability of the fuel supply and its associated uncertainty over short time frames are more pronounced than with conventional generation technologies. Energy from wind generating facilities must be taken "as delivered", which necessitates the use of other controllable resources to keep the demand and supply of electric energy in balance.

Integrating wind energy involves the use of supply side resources to serve load not served by wind generation and to maintain the security of the bulk power supply system. Conventional resources must then be used to follow the net of wind energy delivery and electric demand and to provide essential services such as regulation and contingency reserves that ensure power system reliability. To the extent that wind generation increases the required quantity of these generating services, additional costs are incurred. Too much wind generation at times of low system demand may result in severe operational constraints for conventional generating units. And, large changes in wind generation may tax the ability of conventional generation to respond, potentially jeopardizing system reliability.

Objectives

To conduct operational simulations for the purpose of assessing, in detail, the impact of the wind generation levels defined in an earlier task on the Inner Mongolian power system. These impacts will include:

- The additional amounts of operating reserve required to manage the power system in light of the increased variability and uncertainty introduced by the defined wind generation levels;
- Assess significant operating constraints, such as minimum load/excess wind generation periods, severe net load ramps (where wind generation and load are simultaneously changing in opposite directions);
- Impacts of forecast error and uncertainty on the costs of serving load in the province.
- The value of increased forecast accuracy over all operational time scales (minutes-ahead to day or days ahead);
- The contribution of wind generation in the defined scenarios to resource adequacy through a rigorous ELCC (effective load carrying capability) methodology which considers wind generation and load profiles along with unit performance and maintenance data;
- Impacts of wind generation delivery on the bulk transmission network through power flow, contingency, and dynamic analysis
- The ability to supply all of the required balancing with Inner Mongolian resources while exporting wind generation through hourly energy schedules vs. obtaining some of the sub-hourly balancing reserves from resources in the load provinces

Approach

With the hourly data sets developed in a previous task as the starting point, assessment of wind integration issues will be accomplished through a "simulation" of operational activities. For most utilities, this involves a forward-looking process where resources are committed for operation based on forecasts of load and wind. The selected resources are then dispatched against the "actual" load and wind generation to simulate real-time operations. Using planning tools that operate on time steps of one hour, an entire annual set of wind and load data can be processed.

A variety of production simulation tools have been employed over the last decade in wind integration studies around the globe. The most appropriate tools have a common set of features, which include:

- They are chronological simulation tools, which allow the actual or assumed operational practices to be mimicked with some degree of fidelity at an hour-by-hour time resolution.
- They allow some representation of the transmission network, at either a bus level (nodal model) or an area model with a transportation model of inter-area transactions.
- They facilitate simulation of short-term power system planning and real-time operation over a substantial time period, usually one calendar year or more;
- They utilize algorithms for security constrained unit commitment (SCUC) and security-constrained economic dispatch (SCED);
- They allow wind generation to be defined each hour from records or previous numerical weather simulation studies.
- They offer flexibility for representing and enforcing time-varying constraints and requirements, on individual generating resources as well as the modeled system or sub-areas.

Chronological, and correlated, hourly profiles of load and wind generation developed in previous tasks are the primary input to the production modeling tool to be used for the study. With substantial amounts of wind generation relative to the amount of load in the Inner Mongolia power system, assumptions must be made regarding the ability to export energy to other areas in times of excess. In the absence of detailed data, this will be done by representing each external area by a single large generator and single large load.

The unit characteristics and fuel price along with the load profile can be adjusted to mimic conditions in those external areas. Limitations on transfer/export capability can also be adjusted in the model. Transmission expansion analysis performed in a previous task will inform this modeling.

Because most production simulation tools are based on an hourly time step, direct representation of real-time operation in not possible. Short-term balancing of generation and load, therefore, must be accounted for by applying constraints on the hourly commitment and dispatch of generating units, along with other spinning and non-spinning reserves held to cover contingencies.

A variety of mathematical and statistical techniques have been developed over the past decade to estimate the additional operating reserve requirements due to large amounts of wind generation. As a precursor to the production simulations in this task, the most appropriate technique will be selected and applied to the load and wind generation profiles for each scenario.

Additional analysis of the load and wind generation profiles will be performed to identify operationally challenging periods, such as times of large wind or net load ramps or minimum loads. This analysis will assist with interpretation of the production simulations. Effects of geographic diversity in reduction of the aggregate variability of wind generation over a large region will also be quantified.

The case list for the production simulations will be specifically designed to provide the quantitative data necessary for characterizing wind integration impacts. These impacts include, but are not limited to the major issues identified as study objectives. Sensitivity cases will also be designed to ascertain relationships between various integration impacts and assumptions. These will include, but are not necessarily limited to, the effects of obtaining balancing reserves exclusively from Inner Mongolia vs. also from the load provinces, pumped storage, hydro resources, or other storage technologies, along with demand side options for energy response and supply of ancillary services.

The contribution of wind generation to resource adequacy will be assessed using statistical techniques to determine the loss-of-load probability (LOLP). The effect of wind generation can be isolated by comparing two cases – one with the hourly wind generation included in the net load, and one without. The ELCC is generally taken as the difference in system load carrying capability from the cases above at the target system reliability level.

Finally, a sampling of the system states as defined by the hourly production simulations will be evaluated through ac power flow and dynamic analysis for bulk system security impacts. Reactive power control and dispatch, stability effects, and influence on system primary frequency response will be quantified.

Deliverables

A comprehensive assessment of wind integration impacts in the Inner Mongolia grid for the defined wind generation scenarios and assumptions.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Successful execution of this task in the CRESP Phase II study will quantify the operational challenges and impacts of substantial amounts of wind generation on the Inner Mongolia power system. Major barriers will have been clearly identified, whether they be physical or institutional. Operational costs for integrating the defined quantities of wind generation will be calculated.

Track 2, Task 1: Perform Comprehensive Wind Integration Study based on Track 1 Input - National

Background

In this task of the CRESP Phase II study, impacts of wind generation on the operation of the China national grids will be analyzed and quantified.

To understand how wind power can be added to the power grid, it is important to recognize how system operators balance supply and demand. The demand for electricity (referred to as “load”) can vary widely based on weather—heating and cooling loads dominate utility peak demand. The time of day also influences load, since energy use tends to peak during the daytime when business and industrial needs are highest. Load also fluctuates with the time of year as seasonal changes influence heating, cooling and lighting needs. Although load forecasting is good, loads are somewhat unpredictable. Production also can be unpredictable since power plants and transmission lines can fail unexpectedly or must be taken out of service for maintenance. Wind plants create additional variability and uncertainty because they generate electricity based on wind speed, which changes over time. System operators are responsible for balancing varying demand and supply. They can treat a reduction in wind energy the same as they would an increase in energy demand

Wind generation cannot be controlled or precisely predicted. While these attributes are not unique to wind generation, variability of the fuel supply and its associated uncertainty over short time frames are more pronounced than with conventional generation technologies. Energy from wind generating facilities must be taken “as delivered”, which necessitates the use of other controllable resources to keep the demand and supply of electric energy in balance.

Integrating wind energy involves the use of supply side resources to serve load not served by wind generation and to maintain the security of the bulk power supply system. Conventional resources must then be used to follow the net of wind energy delivery and electric demand and to provide essential services such as regulation and contingency reserves that ensure power system reliability. To the extent that wind generation increases the required quantity of these generating services, additional costs are incurred. Too much wind generation at times of low system demand may result in severe operational constraints for conventional generating units. And, large changes in wind generation may tax the ability of conventional generation to respond, potentially jeopardizing system reliability.

Objectives

To conduct operational simulations for the purpose of assessing in detail the impact of the wind generation levels defined in an earlier task on the China national grids. These impacts will include:

- The additional amounts of operating reserve required to manage the power system in light of the increased variability and uncertainty introduced by the defined wind generation levels;
- Assess significant operating constraints, such as minimum load/excess wind generation periods, severe net load ramps (where wind generation and load are simultaneously changing in opposite directions);
- Impacts of forecast error and uncertainty on the costs of serving load in the province.
- The value of increased forecast accuracy over all operational time scales (minutes-ahead to day or days ahead);
- The contribution of wind generation in the defined scenarios to resource adequacy through a rigorous ELCC (effective load carrying capability) methodology which considers wind generation and load profiles along with unit performance and maintenance data;
- Impacts of wind generation delivery on the bulk transmission network through power flow, contingency, and dynamic analysis

Approach

With the hourly data sets developed in a previous task as the starting point, assessment of wind integration issues will be accomplished through a “simulation” of operational activities. For most utilities, this involves a forward-looking process where resources are committed for operation based on forecasts of load and wind. The selected resources are then dispatched against the “actual” load and wind generation to simulate real-time operations. Using planning tools that operate on time steps of one hour, an entire annual set of wind and load data can be processed.

A variety of production simulation tools have been employed over the last decade in wind integration studies around the globe. The most appropriate tools have a common set of features, which include:

- They are chronological simulation tools, which allow the actual or assumed operational practices to be mimicked with some degree of fidelity at an hour-by-hour time resolution.
- They allow some representation of the transmission network, at either a bus level (nodal model) or an area model with a transportation model of inter-area transactions.
- They facilitate simulation of short-term power system planning and real-time operation over a substantial time period, usually one calendar year or more;
- They utilize algorithms for security constrained unit commitment (SCUC) and security-constrained economic dispatch (SCED);
- They allow wind generation to be defined each hour from records or previous numerical weather simulation studies.
- They offer flexibility for representing and enforcing time-varying constraints and requirements, on individual generating resources as well as the modeled system or sub-areas.

Chronological, and correlated, hourly profiles of load and wind generation developed in previous tasks are the primary input to the production modeling tool to be used for the study. With substantial amounts of wind generation relative to the amount of load in some of the regional Chinese grids, long-distance energy exports and exchanges will be a key for integration. Transmission expansion analysis performed in a previous task will inform this modeling.

Because most production simulation tools are based on an hourly time step, direct representation of real-time operation in not possible. Short-term balancing of generation and load, therefore, must be accounted for by applying constraints on the hourly commitment and dispatch of generating units, along with other spinning and non-spinning reserves held to cover contingencies.

A variety of mathematical and statistical techniques have been developed over the past decade to estimate the additional operating reserve requirements due to large amounts of wind generation. As a precursor to the production simulations in this task, the most appropriate technique will be selected and applied to the load and wind generation profiles for each scenario. Each of the China grid systems will be analyzed independently at first to understand their native requirements.

Additional analysis of the load and wind generation profiles will be performed to identify operationally challenging periods, such as times of large wind or net load ramps or minimum loads. This analysis will assist with interpretation of the production simulations. Effects of geographic diversity in reduction of the aggregate variability of wind generation over a large region will also be quantified.

The case list for the production simulations will be specifically designed to provide the quantitative data necessary for characterizing wind integration impacts. These impacts include, but are not limited to the major issues identified as study objectives. Sensitivity cases will also be designed to ascertain relationships between various integration impacts and assumptions. These will include, but are not necessarily limited to, the effects of pumped storage, hydro resources, or other storage technologies, along with demand side options for energy response and supply of ancillary services.

The contribution of wind generation to resource adequacy will be assessed using statistical techniques to determine the loss-of-load probability (LOLP). The effect of wind generation can be isolated by comparing two cases – one with the hourly wind generation included in the net load, and one without. The ELCC is generally taken as the difference in system load carrying capability from the cases above at the target system reliability level.

Finally, a sampling of the system states as defined by the hourly production simulations will be evaluated through ac power flow and dynamic analysis for bulk system security impacts. Reactive power control and dispatch, stability effects, and influence on system primary frequency response will be quantified.

Deliverables

A comprehensive assessment of wind integration impacts across the China national grids for the defined wind generation scenarios and assumptions.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Successful execution of this task in the CRESP Phase II study will quantify the operational challenges and impacts of substantial amounts of wind generation in China. Major barriers will have been clearly identified, whether they be physical or institutional. Operational costs for integrating the defined quantities of wind generation will be calculated.

Track 2, Task 2: Review International Experience

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. Due to the location of the 10 GW wind power bases, the north and north-east regions of the country will experience very high instantaneous penetrations of wind power capacity on the system, especially during the winter months. This is when the wind plant output is highest, and the CHP plants are running near maximum output because of the heat demand.

It is of interest to examine how other power systems in different parts of the world have managed the generation dispatch during such high penetration conditions on their systems. Hourly penetrations in excess of 50% have been achieved in a number of large balancing areas, including West Denmark (120%), Portugal (93%), Public Service of Colorado (55%), Spain (54%), and Ireland (52%). It will be useful to understand the flexibility sources that were available in these systems during these situations, the concerns that were present, and the approaches used by the system operators to manage the system dispatch.

The situation in Denmark with the CHP plant infrastructure will be particularly useful, as they have made significant strides in improving the flexibility of the CHP plants to accommodate increased levels of wind power, improving the control of the boilers and generators, including thermal storage, and utilizing electric boilers powered with excess wind. They have plans to achieve 50% of their electricity from primarily wind power by 2020, up from approximately 20% today. The evolution of this situation in Denmark is an important example of the role that CHP can and must play to achieve truly high penetrations of wind power. By understanding the similarities and differences between these situations and the corresponding situation in China, it is likely that some useful insights can be gained that will be helpful to the Chinese system operators.

Objective

The objective of this task is to review some selected international experience (Denmark, Portugal, Public Service of Colorado, Spain, Ireland) with system dispatch when wind power accounts for up to 80% of the instantaneous generation, identify its applicability to the Chinese situation, and pay particular attention to the experience with CHP plants in Denmark because of a very similar situation in the north of China.

Approach

A two-step approach will be followed for this task, consisting of both a literature review, and site visits with system operators in control centers. There is some published information on the challenges which have been faced with regards to high penetration operating conditions, as well as the challenges which are expected. Some of this information has been presented in papers and presentations at technical conferences and workshops sponsored by organizations such as EWEA, AWEA, IEEE, and the EU. Another excellent source of information is the series of workshops on wind integration sponsored by Energynautics during the past 10 years, the most recent of which was the "*10th International Workshop on Large-scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants*", held in Aarhus, DK, in October of 2011. The annual wind forecasting workshop conducted by UWIG also contains several sessions dedicated to the most recent experience with wind forecasting methods, tools and experience in high penetration scenarios in the referenced systems (e.g. "*WORKSHOP ON VARIABLE GENERATION FORECASTING APPLICATIIONS TO UTILITY PLANNING AND OPERATIONS, February 23-24, 2011, Albany, NY*"). As complete an understanding as possible should be gained from the existing literature, and a report documenting the present practices and experience should be prepared in preparation for a series of site visits to the most important control centers identified.

Once the existing literature has been identified and examined, site visits to the relevant control centers should be arranged for meetings with the appropriate operations planning and system operations staff of the relevant organizations, which are:

Denmark	Energinet.dk, Fredericia, Denmark
Portugal	REN, Lisbon, Portugal
Public Service of Colorado	Xcel Energy/PSCo, Denver, Colorado
Spain	REE, Madrid, Spain
Ireland	Eirgrid, Dublin, Ireland

A meeting agenda should be prepared to identify all of the topics to be discussed. The agenda should include a description of the Chinese system and dispatch practices to help the meeting participants understand the similarities and differences with their own system. A report of each of the meetings should be prepared. A summary of the findings and major conclusions and recommendations from each meeting should be included in the final report. A consistent analysis of the findings should be conducted to identify those practices which are relevant for China, those which are not, and any new insights gained from the meetings with the foreign experts. As part of the review, an examination of the recent report from Alstom Grid on global experience with control center operating practices to accommodate high wind penetrations should be reviewed for any other relevant information. For example, ERCOT in Texas has extensive experience dealing with wind curtailment and alleviating it with transmission expansion, wind plant interconnection requirements, and wind plant control capabilities as well as with increasing the flexibility of the conventional generation fleet. ERCOT also has a unique probabilistic wind ramp forecast in the control room, both of which would be relevant for China.

In Denmark, an additional meeting agenda should be pursued to explore the history of CHP plant development and modification as the wind power expanded. The major engineering firm to include in the visit is Dong Energy, which owns and operates major CHP assets in Copenhagen. Three major areas should be explored: the evolution of the CHP plant design for increased flexibility in operation; the evolution of incorporating electric boilers, thermal storage and heat pumps into system design and operation; and the evolution of market operating strategy with increasing wind penetration. Just as with the electric system operation, this experience should be carefully examined and explored for similarities and differences to the Chinese situation, and to identify those practices which are relevant for China, those which are not, and any new insights gained from the meetings and site visits to the CHP plants in Denmark. The incorporation of demand response through the heating sector into providing balancing services in system operation is a clear example. It is anticipated that this visit will result in significant new ideas to increase the flexibility of CHP plant operation and accommodate increased penetrations of wind power.

Strong load growth may also provide an opportunity to utilize demand response to help integrate wind. Historic methods for reducing peaks should be explored with the distinction that the focus should be on times of peak net load (load less wind) rather than simply on times of peak load. China has the opportunity to go beyond traditional demand side management and look for ways to increase electrical load at times of excess wind. Electric boilers for CHP are one possibility and electric vehicles are another. The rest of the electric sector should be examined to look for opportunities to utilize as-available excess wind energy. Demand response can also be used for contingency reserves and to respond to wind ramps. The response duration is typically minutes rather than multiple hours, as with traditional demand response, and may be easier for some responsive loads to provide. ERCOT currently obtains half of its contingency reserves from responsive load. Smart grid technologies can help provide the required response speed.

Deliverables

A comprehensive final report with three major sections should be prepared. The first section should present and analyze the results of the literature review on operating practices; the second should document and analyze the results of the site visits to the operating centers; and the third should document and analyze the visits and findings regarding the Danish CHP plant experience, and the options for increased flexibility for operation of CHP plants and incorporation of demand response as a system flexibility resource.

Schedule

The completed study is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Alternative system operating procedures that increase flexibility and reduce wind integration costs while increasing power system reliability will result in an increased percentage of wind that can be reliably delivered to load, with a corresponding reduction in curtailment. Sensitivity analysis on the wind integration study results should be able to quantify the value of new or revised technology or operating procedures as compared with the current situation.

Track 2, Task 3: Expanding Flexibility Options

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. Track's 1 through 5 will design a transmission system to reliably and economically utilize the expected wind generation as well as recommend incentives to assure that the transmission system is built. They will analyze how variable and uncertain renewables will interact with the power system. They will specify operating practices and interconnection requirements, define grid friendly wind turbine and plant designs, and recommend grid access policies. Even so it is expected that there will be significant room to further improve the integration of wind into the power system by increasing the range of other flexible resources available to the power system operator. Increased flexibility in conventional generation (new and existing), alternative flexible generation, flexibility from loads including electric vehicle loads, and advanced smart grid technologies may all be useful.

Once identified as potentially advantageous technologies, benefits can be quantified by testing as alternative scenarios in the Track 2 Task 1 Integration Analysis.

Objective

The objective of this Track is to identify additional opportunities to increase reliability, reduce costs, and increase the amount of wind that can be integrated into the power system by increasing the flexibility of loads and conventional generators. Benefits are to be quantified through modeling.

Approach

Modeling results from the integration studies in Track 2 will identify times and conditions under which wind must be curtailed or under which further wind integration is impractical. Increasing the flexibility of the conventional generation and/or of loads may relieve constraints and allow more cost effective integration of wind. The effectiveness of more flexible technologies can be tested with sensitivity studies utilizing the modeling tools developed in Track 2.

Increased flexibility in new and existing coal fired generation will be examined. Lower minimum loads, faster ramp rates, more accurate control, and faster startup times will all be examined. Alternative generation will be considered including, at a minimum, reciprocating engine plants, gas turbine plants, and combined cycle plants specifically designed with greater flexibility than the coal plants they might replace. The benefits of increased wind production must be compared with the increased capital cost as well as the increased operating cost of the more flexible conventional generation.

Alternative designs of district heating plants will be examined with large-scale thermal storage added and electric boilers or heat pumps to compensate for inflexible fossil systems with CHP plants in winter.

Significant penetrations of electric vehicles will be studied both to utilize excess wind energy at night, helping with any minimum generation problem, and as suppliers of ancillary services. Electric vehicle charging can supply minute-to-minute regulation, spinning reserve, non-spinning reserve, and ramp mitigation.

The full suite of advanced smart grid technologies will also be examined allowing buildings to provide spinning and non-spinning reserves as well as energy management to deal with minimum loads and wind ramping events.

Each technology, alone or in combination, will be tested through the Track 2 wind integration analysis methodology.

Deliverables

Analysis of various flexibility enhancement options. Benefits will be estimated by comparing integration analysis results with and without each enhancement. Potential costs for each enhancement technology will also be developed. Several enhancement technologies, such as EVs, have additional benefits separate from wind integration. Wind integration benefits will be additional benefits that can be included in analysis determining if that technology is worthwhile. Technologies with benefit to cost ratios that are greater than one will be included in overall system recommendations.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Alternative technologies that increase flexibility and reduce wind integration costs while increasing power system reliability will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and required transmission capacity. These can be directly compared as results of the wind integration modeling.

TRACK 3: TRANSMISSION PLANNING ACTIVITIES

Track 3, Task 1: Develop a Transmission and Generation Expansion Plan for Immediate Use in Track 1 and Track 2 Modeling – Inner Mongolia

Background

The CRESP Phase II wind integration study will analyze the Inner Mongolian power system with the 35 GW of wind generation planned for in the near term and the 100 GW of wind generation planned for in 2020 as called for in the 12th five year plan. The current transmission system is inadequate for utilizing all of this wind generation. The current intra-province transmission systems will have to be greatly strengthened for the expanded wind generation to be utilized. The current inter-province transmission system will have to be expanded as well, both to accommodate exporting wind energy from Inner Mongolia to load centers in the rest of China but also to facilitate balancing of the variability and uncertainty of wind generation over a much larger area. A plan for the expanded transmission system is required before the hourly production cost modeling utilizing security constrained unit commitment and economic dispatch called for in Track 2, Task 1 can be performed to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value. This Task will develop that transmission system plan based on the criteria established in Track 1, Task 3.

Objective

Develop a transmission plan to accommodate the 35 GW of wind generation planned for in the near term and the 100 GW of wind generation planned for in 2020 as called for in the 12th five year plan. This transmission plan will be utilized in Track 2, Task 1: Perform Comprehensive Wind Integration Study Based on Track 1 Input.

Approach

Significant work has already been done outlining potential additional transmission lines. That work will provide the basis for designing a comprehensive, integrated transmission system to accommodate the 100 GW of wind generation planned for in 2020 as called for in the 12th five year plan, along with the additional expected coal, nuclear, and hydro generation. The expanded transmission plan should also provide sufficient inter-province transmission capacity to reduce wind variability, uncertainty, and reserve requirements through aggregation with other wind generation, load, and hydro generation. The transmission system will be designed based upon the criteria established in Track 1, Task 3. Since specific wind plant locations will not be known ahead of time consider designating Competitive Renewable Energy Zones (CREZ) where wind conditions are favorable. Transmission can be planned to serve the CREZs prior to selection of the exact wind plant locations. At a minimum consider inclusion of the following transmission facilities:

- ±800 kV Jiuquan-Changsha UHVDC transmission line
- ±1,100 kV Hami-Henan UHVDC line
- UHVAC transmission corridor from Zhangbei to Nanchang via West Beijing, Shijiazhuang and Wuhan,
- UHVAC transmission corridor from Ulanqab to West Beijing
- ±500 kV transmission lines from Jilin to the Northeast China grid
- Strengthening of 220 kV and lower voltage systems as needed
- 500 kV AC lines from East Inner Mongolia to load centers in Northeast China
- Strengthening of the Jiangsu power grid to connect wind power in the Yancheng area and Rudong, Qidong tidal areas

Power flow analysis will be used to test and refine the transmission system design under high and low wind conditions as well as high and low load conditions.

Deliverables

A provincial transmission system design for Inner Mongolia, complete with impedances and capacities, that is sufficient to accommodate all of the renewable and conventional generation included in the 12th five year plan and deliver it to the anticipated loads. The provincial transmission system must include sufficient inter-provincial detail to allow modeling of wind power exports to load centers throughout China.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a robust transmission system will enable more economic utilization of renewable and conventional generation to reliably serve the future load. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and curtailments of wind and conventional generation. Without an adequate transmission system plan and, ultimately the transmission system itself, it will not be possible to utilize all of the expected wind generation.

Track 3, Task 1: Develop a Transmission and Generation Expansion Plan for Immediate Use in Track 1 and Track 2 Modeling - National

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for in 2020 as called for in the 12th five year plan. The current transmission system is inadequate for utilizing all of this wind generation. The current inter- and intra-province transmission systems will have to be greatly strengthened for the expanded wind generation to be utilized. A greatly expanded transmission system is required not only to move the wind energy to load centers but also to accommodate balancing wind variability and uncertainty over a large geographic area. A plan for the expanded transmission system is required before the hourly production cost modeling utilizing security constrained unit commitment and economic dispatch called for in Track 2, Task 1 can be performed to evaluate system reliability, refine the transmission system design, determine reserve needs, assess required operating practices, and calculate wind integration costs and capacity value. This Task will develop that transmission system plan based on the criteria established in Track 1, Task 3.

Objective

Develop a transmission plan to accommodate the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for in 2020 as called for in the 12th five year plan. This transmission plan will be utilized in Track 2, Task 1: Perform Comprehensive Wind Integration Study Based on Track 1 Input.

Approach

Significant work has already been done outlining potential additional transmission lines. That work will provide the basis for designing a comprehensive, integrated transmission system to accommodate the 150-200 GW of wind generation planned for in 2020 as called for in the 12th five year plan, along with the additional expected coal, nuclear, and hydro generation. The expanded transmission plan should also provide sufficient inter-province transmission capacity to reduce wind variability, uncertainty, and reserve requirements through aggregation with other wind generation, load, and hydro generation. The transmission system will be designed based upon the criteria established in Track 1, Task 3. Since specific wind plant locations will not be known ahead of time consider designating Competitive Renewable Energy Zones (CREZ) where wind conditions are favorable. Transmission can be planned to serve the CREZs prior to selection of the exact wind plant locations. At a minimum consider inclusion of the following transmission facilities:

- ±800 kV Jiuquan-Changsha UHVDC transmission line
- ±1,100 kV Hami-Henan UHVDC line
- UHVAC transmission corridor from Zhangbei to Nanchang via West Beijing, Shijiazhuang and Wuhan,
- UHVAC transmission corridor from Ulanqab to West Beijing
- ±500 kV transmission lines from Jilin to the Northeast China grid
- Strengthening of 220 kV and lower voltage systems as needed
- 500 kV AC lines from East Inner Mongolia to load centers in Northeast China

- Strengthening of the Jiangsu power grid to connect wind power in the Yancheng area and Rudong, Qidong tidal areas

Power flow analysis will be used to test and refine the transmission system design under high and low wind conditions as well as high and low load conditions.

Deliverables

A transmission system design, complete with impedances and capacities, that is sufficient to accommodate all of the renewable and conventional generation included in the 12th five year plan and deliver it to the anticipated loads.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately generation of a robust transmission system will enable more economic utilization of renewable and conventional generation to reliably serve the future load. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and curtailments of wind and conventional generation. Without an adequate transmission system plan and, ultimately the transmission system itself, it will not be possible to utilize all of the expected wind generation.

Track 3, Task 2: Develop a Comprehensive Connection Studies Process

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for in 2020 as called for in the 12th five year plan. Such a massive development of wind generation will benefit from optimized connection size, connection circuit size, and connection circuit layout for the large-scale wind power plants in designated areas. Standardized wind plants will reduce engineering costs as well as equipment and construction costs. Wind plant economies of scale may extend to 10 GW or greater. For remote wind plant locations standardization can be extended to a significant portion of the interconnecting transmission network. It is important not to overstate this benefit and to exploit physical differences from location to location in order to minimize total costs but selecting optimal standard designs is likely to bring significant economic benefits. Determining the optimal wind plant size and configuration will require input from all stakeholders including wind turbine manufacturers, wind plant owners, wind plant designers and developers, transmission system operators, and provincial authorities.

Objective

Determine the optimum connection size or sizes, connection circuit size, and connection circuit layouts for the large-scale wind power plants based on engineering analysis with input from all stakeholders.

Approach

Examine the total cost of wind plant designs of various sizes, including interconnection costs and transmission costs, for wind plants up to 10 GW or greater. Focus on the optimum connection size, connection circuit size, connection circuit layout, and balance of plant equipment. Exploit economies of scale including designs with redundancy to trade off initial cost vs loss of production. This should reduce costs associated with cable size, substation layout, number of circuit breakers, etc. Optimize functions, such as dynamic reactive power supply and voltage control and real power output control, between wind turbine functionality and supplemental plant equipment such as static var compensators. Optimize the amount and placement of switched capacitors and other balance-of-plant equipment. Assure that the plant designs meet all grid code requirements. Conduct tradeoff studies of equipment rating and loading to achieve a minimum cost design recognizing the inherent thermal overload ability with an acceptable loss of life. Determine if standardization significantly reduces total wind plant costs. Optimize the wind plant design to minimize costs. Determine if a single standard design is best or if several plant designs further reduce costs by accommodating site differences. For example, different designs may be required in desert areas with extreme ambient temperatures versus coastal areas with more moderate temperatures. Involve all stakeholders to obtain the most current technical information and to assure that each party's concerns and considerations are addressed.

Deliverables

One or more standard wind plant designs that exploit economies of scale to optimize connection size, connection circuit size, connection circuit layout, and balance-of-plant equipment.

Schedule

The complete dataset is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Standardization of design can reduce total costs. Project success can be measured by comparing the total cost of the wind fleet utilizing standard designs for large wind plants vs the cost of engineering and equipment for custom designed plants.

Track 3, Task 3: Develop Transmission Pricing Policies and Incentives

Background

China has set a goal of 100 GW of wind by 2015 and 150 to 200 GW of wind by 2020. Because the best wind resources (and over 80% of current installed wind capacity) in China is located in North or Northwest

China, and most of China's load is in eastern and southeastern China, new transmission will be necessary to transmit the wind energy to load centers. In addition, China is planning eight GW-scale wind power bases, with some up to 10 GW in wind capacity. These eight wind power bases, most of which are located in the North and West of China, will account for over 70 GW of the 100 GW wind goal by 2015. Of this 70 GW, interprovincial and interregional transmission will be needed for 42 GW.

Part of the renewable electricity subsidy in China is intended to cover the costs of new construction or reconstruction and the operation and maintenance costs of transmission lines and substations necessary to integrate renewable energy generation. The grid access portion of the subsidy amounts to 0.01 yuan/kWh (about 0.16 cents/kWh) for transmission up to 50 kM; 0.02 yuan/kWh (about 0.32 cents/kWh) for between 50 kM and 100 kM; and 0.03 yuan/kWh (about 0.47 cents/kWh) for over 100 kM. It is believed that the grid access subsidy is insufficient to fully recover the expected costs of connecting new wind and other renewable energy projects. Furthermore, the allocation of costs for the long-distance transmission projects to transmit wind power has not yet been determined. It will be difficult, if not impossible, for China to meet its wind and solar goals without resolving the "who pays" questions for connecting renewable energy projects and the transmission necessary to transmit the wind power.

There are several transmission pricing methods in practice around the world. Transmission pricing may be based on the embedded costs of the transmission assets, with the transmission rate based on a "postage stamp" rate that does not vary with distance. More common with large regional transmission organizations in the United States is the use of locational marginal pricing, whereby grid prices are the same grid-wide if there is not transmission congestion, but prices may vary at different points of the grid to reflect transmission congestion costs and the price that generators or power buyers may pay to resolve the transmission constraints.

Transmission pricing and service may also be based on whether transmission service can be curtailed or not. Firm transmission means transmission is available around-the-clock and is curtailed only during emergency grid conditions, when such curtailment may be necessary to maintain grid reliability. Firm service is considered a priority service and is priced accordingly. Non-firm transmission is a lower priority form of transmission service, and is priced as such. The transmission operator has more ability to curtail non-firm transmission, and firm transmission has priority over non-firm transmission. Transmission may also be priced on a megawatt-mile basis to reflect the distance of the transmission transaction. Transmission losses may be accounted for with an average system-wide loss number, or through marginal losses that are defined as the percentage increase in system losses caused by a small increase in power injection or withdrawal at the interconnection point.

In other countries, generators typically pay the direct interconnection costs, while the costs for high-voltage transmission are paid by load, shared between load and generators or paid entirely by generators. In the United States, transmission incentives are available for transmission companies if they develop new transmission that meets various requirements, such as utilizing advanced technologies, or to reflect project risks that would likely preclude the project from being developed without the incentives. Incentives are also available for transmission companies that are members of a regional transmission organization, or to independent transmission companies that are not affiliated with vertically integrated utilities.

Finally, an important policy priority in the past has been to reduce or eliminate "pancaked" transmission rates that occur when power is transmitted over multiple transmission systems, and each transmission operator levies their transmission charge, resulting in multiple transmission charges. The formation of regional transmission organizations in the United States was in part fueled by the policy goal of reducing or eliminating pancaked transmission charges in order to broaden power markets and foster greater wholesale power competition.

Objective

The objective is to evaluate different approaches in transmission pricing and incentives that can help China achieve its wind power targets in 2015 and 2020. Because new transmission and increased inter-provincial and inter-regional transmission is considered necessary, different approaches in transmission pricing and incentives should be compared with that in mind.

Approach

The review should first begin by evaluating China's current approach to transmission pricing and incentives and whether it is adequate or not to meet China's wind targets for 2015 and 2020. An estimate should be prepared, or alternatively, review and verify outside estimates from other parties such as regional grid operators like State Grid concerning the costs of the interconnection and transmission necessary to meet China's 2015 and 2020 targets for wind power. Next, the review should determine whether the level of the renewable energy subsidy in China is sufficient to cover the transmission and interconnection costs, and if not, determine what subsidy level would be necessary.

In addition to or in place of the subsidy, the review should also consider what transmission pricing approaches would help facilitate inter-provincial and inter-regional power transfers. Most likely, that will be a single country-wide transmission rate, with no pancaked transmission charges between provincial and regional grid operators. Because transmission constraints are a pressing concern in China, the review should also consider different congestion pricing approaches to determine if congestion pricing should be implemented in China. Because the best wind resources in China are located in low-load areas, the review should evaluate whether a congestion pricing may inadvertently serve to "lock" the wind power resources into those low-load areas, as the congestion price may be too much to overcome.

Review incentive mechanisms for transmission in other countries. The review should include not only incentives for new transmission, but other transmission-related incentives, such as increasing throughput over a transmission line or transferring transmission facilities to an independent system operator. Different incentive mechanisms such as higher return on equity, adders to rate of return, or direct incentive payments should be considered.

Review transmission cost allocation mechanisms in other countries and determine whether they can be applied to China or not. A broad survey should be performed before selecting a diverse sample of approximately six countries for a more detailed analysis. In particular, the review should focus on transmission cost recovery mechanisms in other countries that are intended to foster renewable energy technologies. The review should also consider whether transmission costs should be allocated to all electricity customers in China, should be divided between provincial electric customers and all customers in China, be recovered solely from provincial customers, or from some combination of generators, provincial electricity customers and all electricity customers in China.

Grid companies in China have had difficulty in keeping pace with the rapid pace of wind development in China, and as a result, some wind capacity is not interconnected to the grid for sometime after project construction is completed. Therefore, a review of how costs for interconnection are recovered should be performed. It is expected that most countries require generators to pay for the direct interconnection costs, but any countries that have cost recovery for generator interconnection costs other than direct assignment to generators should be emphasized in the review. The review should draw on the results of the survey above. The review should also estimate the cost impact of generators in China if they were responsible for directly paying the interconnection costs and on the impact of meeting the 2015 and 2020 wind targets if generators were directly responsible for interconnection costs.

Deliverables

Written report describing different transmission pricing and incentive approaches and their applicability to China, and making recommendations for interim and new transmission pricing and incentives that would contribute to China meeting its 2015 and 2020 wind power targets.

Schedule

The recommendations are due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

China already is curtailing significant amounts of wind in some regions of the country, particularly during the winter when the combined output of CHP and wind plants exceeds load. In addition, the rapid development of wind projects has exceeded the ability of regional grid operators in China to interconnect the wind plants. Several metrics can be used to evaluate the project: reduction in wind curtailment from year to year; reduction in the amount of wind capacity that is not interconnected; increases in interprovincial and interregional power transfers; and increases in the amount of new transmission or transmission upgrades that are developed.

TRACK 4: SYSTEM OPERATION STUDY ACTIVITIES

Track 4, Task 1: Incorporating Wind Plant Forecasting Into System Operations

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. With so much wind generation it will be critical to incorporate wind power forecasting into system operations. If wind output is over-forecast and the system operator is counting on more wind generation than is actually available, system reliability will be seriously threatened. If wind output is under-forecast and the system operator plans to serve the full load from other resources, the power system will operate very inefficiently with conventional generators backed down to inefficient minimum loads and wind power curtailed. Wind power forecasting is critical for power system reliability and economics.

Hourly energy forecasts supplied one to three days in advance help system operators economically schedule conventional generators to serve the load-net wind. Ramp forecasts help system operators assure that there are enough flexible resources available to respond to changes in wind output. Wind forecasting, like load forecasting, is more accurate when the forecast is made for a large aggregation. Plant specific forecasts, on the other hand, are necessary to address transmission congestion.

Objective

Determine what wind power forecast practices are most appropriate for China based on experiences from around the world. Recommend how wind forecasts should be incorporated into power system operations. Recommend best practices for security constrained unit commitment and economic dispatch with high penetrations of variable generation. Recommend best practices for managing the power system with excess energy.

Approach

Wind power forecasting methods from around the world will be compared. Best practices for incorporating wind power forecasts into power system operations will be identified for all time scales. The benefits of centralized and decentralized forecasts will be addressed and best practices for China will be recommended. Methods to incorporate wind power forecasts into the security constrained unit commitment and economic dispatch will be identified. Both hourly energy forecasts and ramping forecasts will be addressed. Individual and ensemble forecasts will be considered. Forecasting methods that maximize the amount of wind energy that can reliably and economically be utilized will be identified. Metrics for evaluating forecast accuracy and usefulness will be identified.

Deliverables

A report that identifies best practices for wind power forecasting from around the world will be provided. The report will also recommend best practices for incorporating wind power forecasts into power system operations for China, addressing the appropriate use of both centralized and decentralized wind power forecasts. The use of hourly energy forecasts and ramp forecasts will be addressed. The report will also recommend how wind power forecasts should be incorporated into the security constrained unit commitment and economic dispatch.

Schedule

The complete report is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Ultimately high quality wind power forecasts and wind ramp forecasts will enable the power system to utilize more wind energy with higher reliability and lower cost, resulting in lower wind curtailment. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and expected wind curtailment. Without accurate wind forecasts it will be necessary to schedule increased amounts of conventional generation and curtail more wind when it is available.

Track 4, Task 2: System Balancing and Ancillary Services

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. Flexible balancing resources will be critical for dealing with the variability and uncertainty associated with that much wind generation. Three different techniques have proven effective for dealing with high wind penetration on large power systems; all will likely be required in China: use transmission and large balancing areas to aggregate as much wind and load together as possible before balancing the aggregate system, utilize sub-hourly scheduling to access as much flexibility as possible from the conventional energy producing generation fleet, define and establish ancillary services (reliability services) in a technology neutral manner so that required response can be obtained from generation and responsive load.

The use of multiple energy scheduling intervals benefits the power system, the loads, and the generators. Significant quantities of energy can be scheduled in advance through bilateral arrangements. Additional energy can be scheduled for each hour, day-ahead. Hourly schedules can be further refined hour-ahead. Sub-hourly scheduling can provide a final opportunity to balance generation and load and accommodate changes in both. An economic equilibrium can be established for each scheduling interval that minimizes costs while maintaining reliability.

Generators and loads incur both direct and opportunity costs when they provide balancing services to the power system. Generators must forgo the opportunity to produce energy when they reduce output in order to provide regulation or spinning reserve ancillary services. This results in less profit from energy production than they could have made if they did not need to provide ancillary services. Loads that stand ready to respond also incur opportunity costs. Defining the ancillary services as specific products that are required to help balance wind variability and uncertainty is one important step in obtaining the required flexibility. Establishing mechanisms to compensate generators and loads that provide response is the next critical step.

Large independent system operators in North America have found that it is possible to co-optimize energy and ancillary service provision such that total costs are minimized for the power system while revenues are maximized for the supplying generators. Further, this co-optimization is compatible with security constrained unit commitment and economic dispatch and energy scheduling every five minutes. Over half the load in North America is currently served under this type of optimization and two thirds of the load will be by 2014. A similar scheduling paradigm may be appropriate for China.

Objective

Identify the ancillary services that are required to provide the flexibility needed to reliably and economically balance wind variability and uncertainty. Establish a system of sub-hourly energy scheduling and hourly ancillary service provision that appropriately compensates generation and responsive load resources.

Approach

Develop an integrated set of dispatch practices that provides multiple opportunities to schedule generation to meet load. At a minimum consider hourly schedules established day-ahead, hour-ahead schedules, and sub-hourly schedules with five minute dispatch intervals and schedules set no more than ten minutes before the interval. Generators should be scheduled based on minimizing the marginal cost during each interval.

Define the ancillary services that are required to reliably operate the power system with a large penetration of wind generation. Define the ancillary services in technology neutral terms so that they can be provided by generators and appropriately responsive loads. At a minimum consider regulation, following, spinning reserve, non-spinning reserve. Define the required response time, ramp rate, duration, and response frequency for each of the services. Establish criteria for determining how much of each service is required by the power system each hour.

Establish a mechanism for determining the appropriate compensation for providing each ancillary service during each scheduling interval. Include both direct and opportunity costs. Consider compensating all providers at the same rate during each scheduling interval as a method for encouraging generators and responsive loads to be flexible and offer that flexibility to the power system.

Deliverables

A set of integrated scheduling practices that provide multiple opportunities to schedule generation to meet load. The set will include sub-hourly scheduling. A set of ancillary service definitions designed to provide the flexibility required to reliably integrate large amounts of wind generation. A mechanism for determining the appropriate compensation for providing each ancillary service during each scheduling interval including both direct and opportunity costs.

Schedule

The complete report is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Sub-hourly energy scheduling and technology-neutral ancillary services are two mechanisms that have prove to be useful for reliably and economically integrating large amounts of wind generation into power systems in North America. They are also useful for reducing costs and increasing power system reliability without wind generation. They will enable the power system to utilize more wind energy with higher reliability and lower cost, resulting in lower wind curtailment. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be fully testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and expected wind curtailment.

TRACK 5: INTERCONNECTION STUDY ACTIVITIES

Track 5, Task 1: Specify Interconnection Requirements

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. With so much wind generation it will be critical to specify appropriate interconnection requirements in the form of a grid code for all generators including wind plants. Interconnection requirements are needed to assure that wind plants have operating characteristics that support power system reliability.

Grid codes benefit the power system, wind plant owners, and wind equipment manufacturers. The power system benefits because reliability requirements are established and met. Wind plant owners benefit because all wind projects are treated equally, different generation technologies are treated equally, and the wind plant owner has a larger pool of manufacturers to choose from since they all know what requirements must be met. Wind plant manufacturers benefit because requirements are specified ahead of time and turbines can be designed and manufactured to meet known uniform requirements.

Grid code requirements are typically specified at the point of common coupling between the wind plant and the power system. This allows wind plant designers to use a combination of wind turbine characteristics and additional plant equipment to meet the power system's needs.

Grid codes are often applied to new plants and equipment with existing wind plants exempted from new requirements unless there are specific reliability needs that make retroactive application, and retrofitting existing equipment, necessary.

Wind plants need active power control to limit ramp rates and to facilitate controlled curtailment by the power system operator. They may also need to have governor control so that they self-curtail (with a droop response) when power system frequency is above 50 Hz. Synthetic inertia may also be needed, depending on the stability sensitivity of the power system.

Reactive power capability is required to support and control power system voltages. Some of the wind plant reactive power capacity may be able to come from static devices such as capacitors but some will likely need to come from dynamic sources such as static var compensators or from the wind turbines themselves. It may be necessary to specify how much reactive power a wind plant must be capable of supplying during fault conditions. Some grid codes specify reactive power capabilities in terms of power factor, which allows for reduced MVAR output as the wind plant MW output declines. Other grid codes require wind plants to be capable of providing the full MVAR capability down to low MW output.

Grid codes typically specify the range of system voltage and frequency which wind plants must be capable of operating under. Grid codes often specify power quality requirements for wind plants including allowable harmonics and voltage fluctuations. Wind plants must also be capable of riding through power system faults if wind power is a significant percentage of the total generation. Grid codes differ on the specific ride through requirements but most specify the requirement at the point of interconnection of the wind plant with the power system.

Grid codes typically evolve over time. In 2006, China issued a voluntary wind power connection standard, with no specific requirements for active power, reactive power capability or low voltage ride-through. This standard expired in 2008. In December 2009, State Grid issued its own grid code that includes requirements for power control, LVRT, monitoring and communication. A country-wide grid code is in final stages of consideration and is expected to be issued at the end of 2011 or early 2012. A country-wide grid code is preferable to multiple provincial grid codes as it will provide a more uniform environment for power system designers, wind plant owners, and wind equipment manufacturers, resulting in higher reliability and lower costs. This is an area which could benefit from periodic review and updating to ensure that the grid code reflects the changing needs of China's power system and incorporates the best practices available from around the world.

Objective

Establish a process to determine what interconnection requirements are needed to reliably integrate large amounts of wind generation into the power system of China. Specify national Grid Code Requirements including dynamic models, testing and certification.

Approach

Compare current grid codes from around the world including, at a minimum: Germany, Denmark, Spain, Ireland, UK, Quebec, and the USA (U.S. grid codes are partly contained in proposed NERC standards). Determine what characteristics should be addressed by the national grid code including, at a minimum: reactive power capability, voltage control, ramp control, frequency-response/governor-control, and synthetic inertia, low voltage ride through requirements. Specify the studies and analysis techniques required to establish each of the grid code criteria. Also specify the requirements for initial and ongoing testing and certifying wind plants as grid code compliant. Establish requirements for dynamic models as well as requirements for verifying those models either through staged testing or event monitoring.

Deliverables

A process for establishing national grid code requirements based on system specific reliability needs as well as grid code criteria from around the world. The grid code will address real power control including limiting ramp rates, control during curtailment events, and frequency response requirements. It may include requirements for synthetic inertia. The grid code will include reactive power and voltage control requirements as well as low voltage or fault ride through requirements. The technical studies required to determine the specific grid code requirements will be established. Dynamic model requirements as well as model verification requirements will also be specified.

Schedule

The complete report is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Grid codes assure that power system reliability is maintained as new generators are added to the power system. They increase the allowable wind penetration and reduce the need for conventional generation. This will result in an increased percentage of wind that can be reliably interconnected with the power system at a reduced cost. Many additional factors also contribute to maximizing useful wind penetration and the results will not be testable for years. In the shorter term project output can be judged by the reduction in required planned reserves and expected wind curtailment due the forced operation of conventional generation.

Track 5, Task 2: Define Grid Friendly Wind Turbine and Wind Plant Designs

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. With so much wind generation it will be critical to specify appropriate interconnection requirements in the form of a grid code for all generators including wind plants. Interconnection requirements are needed to assure that wind plants have operating characteristics that support power system reliability. Track 5 Task 1 will establish a process for specifying the applicable grid code. This Task 2 will define wind turbine and wind plant designs that meet the grid code.

Grid codes benefit the power system, wind plant owners, and wind equipment manufacturers. The power system benefits because reliability requirements are established and met. Wind plant owners benefit because all wind projects are treated equally, different generation technologies are treated equally, and the wind plant owner has a larger pool of manufacturers to choose from since they all know what requirements must be met. Wind plant manufacturers benefit because requirements are specified ahead of time and turbines can be designed and manufactured to meet known uniform requirements.

Grid code requirements are typically specified at the point of common coupling between the wind plant and the power system. This allows wind plant designers to use a combination of wind turbine characteristics and additional plant equipment to meet the power system’s needs.

Grid codes are often applied to new plants and equipment with existing wind plants exempted from new requirements unless there are specific reliability needs that make retroactive application, and retrofitting existing equipment, necessary.

Wind plants need active power control to limit ramp rates and to facilitate controlled curtailment by the power system operator. They may also need to have governor control so that they self-curtail (with a droop response) when power system frequency is above 50 Hz. Synthetic inertia may also be needed, depending on the stability sensitivity of the power system.

Reactive power capability is required to support and control power system voltages. Some of the wind plant reactive power capacity may be able to come from static devices such as capacitors but some will likely need to come from dynamic sources such as static var compensators or from the wind turbines themselves. It may be necessary to specify how much reactive power a wind plant must be capable of supplying during fault conditions. Some grid codes specify reactive power capabilities in terms of power factor, which allows for reduced MVAR output as the wind plant MW output declines. Other grid codes require wind plants to be capable of providing the full MVAR capability down to low MW output.

Grid codes typically specify the range of system voltage and frequency which wind plants must be capable of operating under. Grid codes often specify power quality requirements for wind plants including allowable harmonics and voltage fluctuations. Wind plants must also be capable of riding through power system faults if wind power is a significant percentage of the total generation. Grid codes differ on the specific ride through requirements but most specify the requirement at the point of interconnection of the wind plant with the power system.

Wind power plants have evolved to become very reliable and controllable elements of the power system. In order to provide the basic services of real and reactive power control and ancillary services in a manner that contributes to the safety and reliability of the power system, it is necessary that the plants operate with a well-functioning relay, protection and control system, and be able to send and receive status and control information as a node in a secure and reliable communications network. The plant must also have an appropriate division of local control and remote control capability. In some situations, it will also be desirable for the plant to be able to provide a wind plant output forecast to a central location.

Objective

Define grid friendly wind turbine and wind plant designs including: real power control, fault ride through capabilities, reactive power, dynamic voltage support, frequency response, synthetic inertia, and relay, protection, communication and control capability.

Approach

Develop wind turbine and wind plant designs that meet grid code requirements. Develop designs for wind plant sizes selected in Track 3, Task 2. Determine which capabilities should be provided directly by wind turbines and which should be provided by plant equipment. It is likely that some functions will be provided by a combination of wind turbine and plant equipment capabilities. Establish plant control schemes that coordinate individual turbine output and control with overall plant ramp rate limits, curtailment requirements, and frequency response capabilities. In coordination with power system stability studies, determine the optimal method for providing synthetic inertia that maximizes the stability benefits for the power system. Based on grid code requirements for static and dynamic reactive support, design an appropriate mix of switched capacitors, static var compensators, and reactive power capability coming directly from wind turbines. Develop models of wind plant dynamic response and testing procedures that will verify the models accuracy. Develop the necessary relay, protection, communication and control capability to enable the plant to effectively contribute to the safety and reliability of the power system.

Deliverables

Wind turbine and wind plant designs that meet grid code requirements and provide the necessary reliability support at lowest cost.

Schedule

The complete report is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Standardized and optimized wind plant designs will provide the required power system reliability support at lowest cost. This will directly result in wind plant cost savings and will also result in increased wind penetration because grid code reliability requirements are met by wind plants. This will reduce the requirement to operate conventional generation to support power system reliability and minimize wind curtailment.

Track 5, Task 3: Recommend Grid Access Policies for Variable Generation

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. Conventional generation will be expanding as well, as will the load that this generation will serve. With the power system expanding to such a large extent it is necessary to establish a process to manage the necessary transmission growth and control grid access. In much of the world it also takes much longer to design, permit, and construct transmission than wind generation, further adding to the importance of the process that manages transmission growth and grid access. The lack of transmission capacity can become a dominate consideration for where wind generation gets built, equaling or exceeding the wind resource quality in importance.

Interconnection plays a crucial role in bringing much-needed generation to meet the growing needs of electricity customers. Further, relatively unencumbered transmission access is necessary to assure that the lowest cost and most effective generation is built. However, requests for interconnection frequently result in complex, time consuming technical disputes about interconnection feasibility, cost, and cost responsibility. This delay undermines the ability to develop the most cost effective generation and provides an unfair advantage to utilities that own both transmission and generation facilities. A standard set of procedures for all transmission facilities will promote fairness and expedite the development of new generation, while protecting reliability and ensuring that transmission costs are reasonable. It will encourage needed investment in generator and transmission infrastructure.

Some countries provide priority access to transmission for wind and solar generation. Others establish a first-come-first-served process for interconnecting all generators and managing transmission enhancement. In both cases it is necessary to establish a clear and effective process for generators to determine the cost and schedule for obtaining transmission access. This Task will set forth the procedures that generators and transmission providers are required to follow during the interconnection process to prevent undue discrimination, preserve reliability, increase energy supply, and lower wholesale prices for customers by increasing the number and variety of new generators. The process must specify the technical analysis required to evaluate interconnection requirements for new generators as well as fairly manage requests from multiple generators in diverse locations and multiple generation technologies.

Objective

Establish the procedures that generators and transmission providers are required to follow during the interconnection process to prevent undue discrimination, preserve reliability, increase energy supply, and lower wholesale prices for customers by increasing the number and variety of new generators. Specify the steps that must be followed and deadlines that must be met when a generator requests interconnection with the transmission system.

Approach

Compare grid access policies from around the world including, at a minimum: processes that provide priority access for wind and solar generation vs processes that treat all generation technologies equally. Determine if establishing preferred zones for wind generation development, similar to the Texas Competitive Renewable Energy Zones (CREZ), along with transmission that is built to serve the CREZ prior to specific generation interconnection requests is appropriate for China. Design an interconnection queue process to manage generator grid access requests. Determine what studies are required to enable the transmission provider to determine the cost and schedule for interconnecting each generator in the ordered queue.

The study process should include a number of steps with increasing complexity to provide the generator with the opportunity to modify its plant design and interconnection request based on the transmission providers study results. Specific time limits should be established for each step to assure that the process keeps moving. Consider an initial interconnection feasibility study using power flow and short-circuit analyses to be completed within perhaps a month or two. This might be followed by an interconnection system impact study to evaluate on a comprehensive basis the impact of the proposed interconnection on the reliability of transmission provider's transmission system, using stability analysis, power flow, and short-circuit analyses to be completed possibly within another two months. A third interconnection facilities study could follow to determine a list of required new or upgraded transmission facilities, the cost of those facilities, and the time required to interconnect the generator with the transmission system to be completed within three to six months or so. The generator might then request additional studies or sensitivity analysis to identify any alternate generation configurations or transmission paths that might lower interconnection costs. A procedure to remove non-viable projects from the evaluation process should also be established.

With numerous wind plants seeking interconnection essentially simultaneously it may be more efficient to group projects for combined evaluation. Evaluations could be done at scheduled intervals, perhaps every three or six months.

This Task will also develop a standard Interconnection Agreement, with specifics to be filled in for each generation project, that specifies the required interconnection facilities engineering, procurement and construction; testing and inspection, including start-up and synchronization, system protection and controls requirements; emergency, and disconnect obligations; metering and communications; and operations and maintenance requirements.

Deliverables

A multi-step procedure that specifies the interconnection studies to be performed, including the study schedule, to determine what new transmission facilities or facility upgrades are required to reliably provide grid access for new generators. A standard interconnection agreement that specifies the required interconnection facilities engineering, procurement and construction; testing and inspection, including start-up and synchronization, system protection and controls requirements; emergency, and disconnect obligations; metering and communications; and operations and maintenance requirements.

Schedule

The complete report is due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Standard grid access policies, including an established process for performing interconnection studies and a managed interconnection queue will reduce generator development time and costs. This will result in larger amounts of wind being integrated into the power system at reduced cost. Many additional factors also contribute to maximizing useful wind penetration. Project output can be judged by the reduction in required time to successfully integrate new wind plants into the power system and deliver their output to load centers.

TRACK 6: INSTITUTIONAL SETUP

Track 6, Task 1: Institutional Process and Policies

Background

The CRESP Phase II wind integration study will analyze the multi-province power system with the 70 GW of wind generation planned for in the near term and the 150-200 GW of wind generation planned for by 2020 in the 12th five year plan. It will create a preliminary conceptual inter-province transmission system design and will devise ways to reliably maximize wind utilization while minimizing costs. Hourly production cost modeling utilizing security constrained unit commitment and economic dispatch will be used to evaluate system reliability, refine the transmission system design, determine reserve needs, and assess required operating practices. The production cost modeling will determine the power system conditions under which the wind plants are expected to operate including the capabilities and limitations of both the transmission system and the conventional generators.

China's wind power targets for 2020 and 2030 and plans for installing eight 10 GW wind power bases will require new transmission, changes in grid operating practices and procedures, and perhaps changes in government policy as well. Among other things, costs for new transmission need to be defined and allocated, whether among electricity customers, generators, or a combination of the two. The definition of and amount of ancillary services must be defined, as well as how prices for ancillary services will be determined and who pays for the ancillary services. Wind power curtailments are particularly high in some regions of China, in part because of the limited flexibility of existing conventional units.

In addition, several lessons learned from the international experience with integrating high levels of wind can be applied to China, including sub-hourly scheduling; additional transmission; creating large balancing areas; allowing for and encouraging inter-provincial power transfers; encouraging flexible generation (either new or existing); allowing for greater demand-side management and demand response; facilitating Smart Grid initiatives and new technologies such as plug-in electric vehicles; and changing unit commitment practices to include more frequent intra-day unit commitment schedules, or to use probabilistic methods. In addition, changes to existing electricity practices without significant institutional reforms can be pursued in China in the near term, such as providing either higher payments for flexible generation, or more hours of guaranteed running time, or both.

Objective

To determine whether existing institutional, regulatory and business arrangements for electricity regulation need to be amended with higher levels of wind generation, and if so, how, and to consider what additional policies are required to facilitate integration of large amounts of wind generation.

Approach

Assess whether existing electricity practice in China can be amended to aid in integrating higher levels of wind generation. This assessment should be considered as an interim measure to encourage the development of ancillary services, flexible generation, new transmission, inter-provincial transmission and wholesale transactions and new transmission needed for integrating wind generation while larger changes (e.g., changes in scheduling requirements, new institutional arrangements, etc.) are considered. This assessment should include but not be limited to compensation and cost allocation for ancillary services, incentives or higher levels of guaranteed running time for flexible generation, defining and determining payments and cost allocation for demand response to accommodate wind generation, and incentives for lowering levels of wind curtailment. This approach can provide near-term results for integrating wind generation while working within the existing institutional framework in China, but it should be viewed as temporary and near-term measures, not as substitutes for more significant changes in operating practice and planning that will be necessary for China to meet its future wind goals.

Define new policies and practices necessary to integrate large amounts of variable generation in China. This should assess whether the practices used in other countries to integrate large amounts of variable generation can be applied in China, and if so, how. There are several common policies and practices from other countries that are known to be successful in integrating higher levels of wind generation, such as priority access, sub-hourly scheduling, large markets, and use of forecasting. The challenge is how to incorporate them in China, given China's current electricity framework and business practice. The assessment should consider what changes in institutional and business practices will be necessary in China to incorporate policies and practices known to be successful in integrating higher levels of wind generation.

Evaluate the existing division of regulatory authority in electricity among the National Development and Reform Commission (NDRC), the National Energy Administration (NEA) and the State Electricity Regulatory Commission (SERC). The assessment should review the existing roles of the NDRC, the NEA and SERC and determine whether there are gaps in existing authorities, and recommend how to address those gaps. The assessment should also review the responsibilities of the NDRC, NEA and SERC as to whether they can implement and administer potential interim policies and practices within China's existing electricity business practices, as well as implementing common and well-known policies and practices that have been successful in other countries, or whether new institutions should be created to fulfill these functions.

Deliverables

Written report with recommendations for changes to China's institutional and regulatory framework for electricity regulation and recommendations for interim and new policies or business practices necessary to accommodate higher levels of wind generation.

Schedule

The recommendations are due by mm/yyyy.

Budget

$X,XXX thousand

Project Output Indicators

Several common themes emerge when comparing the international experience with integrating large amounts of wind generation. These themes include new transmission; sub-hourly schedules; larger balancing markets; encouraging flexible generation; and incorporating demand response and demand side management. Implementing some or all of these items will help China integrate more wind generation than if these items were not in place. In addition, China faces several pricing and cost recovery issues for defining and determining the level of ancillary services that is required (and who pays) as well as for new transmission. Addressing these issues will assist China in increasing the amount of wind energy that can be interconnected and operating at a lower cost.