Calculating Reserve Needs and Costs in Wind Integration Studies: A Review

Kevin Porter

Exeter Associates, Inc.

Consultant to the Energy Foundation's China Sustainable Energy Program

April 28, 2011

Background

- Several wind integration studies have been performed in the United States to evaluate the grid impacts of increased levels of wind power
- One of the factors considered is whether additional reserves are required, what quantity of reserves, and what type of reserves
- Reserve needs reflect the increased variability *and* uncertainty of higher levels of wind generation

Definition of Reserves

- No universal definition of reserves, and many terms used, sometimes somewhat interchangeably.
- Will use the following terms for this presentation:
  - Balancing reserves as global term for reserves used in operating time frame (minutes to hour) to balance load and generation and to assist with frequency control.
    - Excludes what may be needed for reactive power and/or long-term planning (i.e., capacity reserves)
  - Frequency response—provides initial response for major system disturbance (seconds).

Definition of Reserves, continued

- Regulating reserves—Balance load and generation in faster time frame than can be met through energy markets or by most generation or demand (minute to minute)
- Load following reserves—10 minutes to a few hours for balancing load and generation
- Spinning reserves—on-line and synchronized generators capable of responding within defined, short period of time
- Non-spinning reserves—similar to spinning reserves but does not have to on-line and synchronized. Must also respond within defined but longer period of time, e.g., 10 minutes. Also called replacement reserves.

Definition of Reserves, continued

- Supplemental reserves—similar to non-spinning reserves and also does not have to on-line and synchronized. Must also respond within defined period of time, but sometimes longer period, e.g., 30 to 60 minutes.

Definition of Reserves, cont.

- Contingency reserves—used for handling instantaneous failures (e.g., generator or transmission outages).
  - In U.S., represents the reserves needed to manage the loss of the single largest unit (generation or transmission)
  - May include combination of spinning and non-spinning reserves
  - Regions may require that at least 50% of contingency reserve is spinning
  - For instance, the single largest contingency for Minnesota is 1500 MW from a 500-kV transmission line.

What Has Been Learned So Far from International Wind Integration Studies

- Studies have found that variations in load and wind are not strongly correlated, reducing reserve requirements
- Geographic diversity of wind helps smooth wind variability and can lower need for incremental reserves on short time scales
- Impacts of wind are relatively modest on short time scales, e.g., regulation
  - Variability of wind generally low from minute-to-minute, though not all studies agree with this
  - Regulation impacts may be higher if study definition assumes a longer scheduling time frame, or if it is assumed that generators providing regulation are slow to respond to changes in load and generation

What Has Been Learned So Far, cont.

- Impact of wind more pronounced in longer time scales (hourly and multi-hourly)
  - For example, greater impact on load following
- Wind does not contribute to single largest contingency
  - Changes in aggregate wind output occur over hours, not instantaneously, so contingency reserves generally not impacted
- Wind may require different types of reserves, or a reclassification of existing reserves
  - Reserves to handle multi-hour wind ramps may be needed

What Has Been Learned So Far, cont.

- Wind forecasting accuracy affects level of necessary reserves, both hourly and sub-hourly level
  - Some grid operators, such as the Electric Reliability Council of Texas, are factoring wind forecast errors into their need for non-spinning reserves
  - Some wind integration studies are recommending another unit commitment period besides day-ahead, such as six-hour ahead, to incorporate updated wind forecasts that will likely be more accurate the closer to the operating hour

Study Results Should Be Viewed with Caution, as They Are Subject to Many Assumptions and Uncertainties

- Wind forecasts in modeling based on statistical extrapolations of wind resource models, not based on "real" wind forecasts
- Production cost models run hourly and therefore don't evaluate all balancing reserves (since some are sub-hourly)
- Balancing reserve requirements determined statistically through analyzing wind resource time series and are typically not validated in production cost modeling
- Methodologies have changed as studies have evaluated higher levels of wind penetration and are covering larger areas

Early Study Methods to Quantify Reserve Needs / Costs

- Analyzed the standard deviation of sub-hourly changes in net load (load minus wind) versus load alone for regulation and load following
- Multiply standard deviation by three to capture 99.7% of all potential instances for regulation and load following
- Approach used in GE's NYSERDA (2005) and CEC study (2007) for determining regulating reserves and in other wind integration studies
- Provides estimate of quantity of regulation and load following reserves needed (cost impacts are estimated separately)

Minnesota Study (2007)

- NREL analysis of operating wind projects showed that variability in regulation time frame (minute-to-minute) was 1-2 percent for every 100 MW of wind
- Study used 2 MW regulation requirement for every 100 MW of wind
- For combination of load and wind variability, used formula on following slide to estimate overall regulation needs…

Minnesota Study (2007), cont.

New_Regulating_Requirement : =

$$k \sqrt{\sigma_{Load}^2 + N \left(\sigma_{W100}^2\right)}$$

Where

K = a factor relating regulation capacity requirement to the standard
deviation of the regulation variations; assumed to be 5

σ_{Load} = standard deviation of regulation variations from the load

σ_{W100} = standard deviation of the regulation variations from a 100 MW wind plant

N = wind generation capacity in the scenario divided by 100

Minnesota Study, cont.

- Load following estimated as twice the standard deviation of five-minute changes in net load
- First study to consider dynamic balancing reserves to reflect hourly wind forecast errors
  - Quantity of reserves needed a function of expected wind generation during operating period
- Found that variability of wind is highest when wind capacity is in middle range of installed capacity, as wind turbines are on the steepest part of the power conversion curve.
  - Therefore, more reserves are needed for the middle range compared to times of low wind generation or high wind generation

All Island Grid Study (Ireland 2007)

- Study looked at two of reserves: spinning (fast response) and replacement reserves (slower response)
- Replacement reserves defined as off-line units with start-up time of under 60 minutes or online units not allocated to spinning reserves
  - Demand for replacement reserves assumed to be a function of installed wind capacity and wind forecast error over longer time periods
- Spinning reserves defined as the size of the largest on-line unit plus an additional contribution for wind generation
  - Assumed 100 MW could be provided through interconnections
  - 50 MW by interruptible load
  - Pumped storage hydro limited to 50% of reserve amount
  - Wind can provide reserves through curtailment
- Additional spinning reserves required, but largest contributor still the loss of the largest conventional generating unit

Ireland, cont.

- Replacement reserves determined as combination of the forced outage rates of plants and an additional margin that is the 90% percentile of net load for each scenario
- Used rolling unit commitment
- Demand for replacement reserves a function of installed wind capacity and wind forecast errors
- Need for replacement reserves increased over longer time frames (e.g., multi-hour) as wind forecast errors are larger

Eastern Wind Integration Study (2010, US)

- Wind forecast uncertainty factored in for determining regulating reserve
  - Economic dispatch programs run over 5 minutes, use information from 10 minutes ago
  - Only regulating reserves can meet deviations from schedules
  - Highest variation occurs near 50% level of wind production, when 10 minute changes in output can be up or down and are located in the steepest part of the wind power output curve

Eastern Wind Integration Study (cont.)

- Similar approach used for hour-ahead wind forecast errors, but assumed deviations could be met by spinning and non-spinning reserve
  - One standard deviation of hour-ahead wind forecast error could be met by spinning reserve
  - Two standard deviations could be met by non-spinning reserves
- Model releases reserves in real-time if needed because less wind was available than predicted

Western Wind and Solar Integration Study (2010, US)

- Calculates hourly reserve requirements based on expected wind and load levels
- Demonstrated that simple rules can be used to calculate reserve requirements with wind
  - X*wind + Y*load up to max Z of wind
  - For WestConnect (southwestern U.S.), equals 1.1% of load + 5% of wind generation up to 47% of nameplate wind.
  - Reserve requirements may be considerably higher for smaller balancing areas
- Suggested that reserves are released in unit commitment from units being dispatched down instead of being de-committed

Recommendations

- Reserve determinations should be based on the net load variability of load and wind, not on load alone or wind alone. Aggregate wind generation should be considered, not the variability of individual wind plants.
- Reserve impacts from wind generally tend to increase with time frame
  - Modest increases in sub-hourly (regulation)
  - More significant increases in hourly (load following)
- Earlier wind integration studies typically multiplied standard deviation of net load ramps by three to estimate both the hourly and sub-hourly potential reserve impacts from wind.

Recommendations, cont.

- Wind does not contribute to need for additional contingency reserves
- Geographic smoothing offers significant benefits and should be accounted for in determining reserve requirements
- Most reserves are currently static (i.e., do not vary) and if they do vary, change based on hourly rules, not on forecasted conditions. Dynamic reserve requirements that vary based on forecasted wind generation are increasingly being called for in recent wind integration studies

Recommendations, cont.

- Easy to be conservative and hold much more reserves than needed
  - Could also end up paying more for reserves than necessary
  - Consider relying on demand response if reserves are needed for a small number of hours per year instead of building additional generation
- Requirement for ramping reserves, load following and regulating reserves influenced by quality of wind forecast. Vital that study wind forecasts emulate real wind forecasts

Recommendations, cont.

- No standard definition for reserves; requirements depend on how one defines reserves (sub-hourly and hourly). Need to clarify what reserves will be defined and how in China.
- Future reserve requirements may also vary by time horizon, as wind can be better predicted the closer to real-time operations
- Future reserve requirements may vary based on load forecasts, wind and solar forecasts, net load forecasts, uncertainty of the wind and solar forecasts and expected production and availability of conventional generation.

For Further Information…

- Minnesota Public Utilities Commission, *2006 Minnesota Wind Integration Study*. http://www.uwig.org/windrpt_vol%201.pdf and http://www.uwig.org/windrpt_vol%202.pdf.
- General Electric, New York State Energy Research Development Authority, 2005, http://www.nyserda.org/publications/wind_integration_report.pdf.
- General Electric, California Energy Commission Intermittency Analysis Project, 2007. http://www.energy.ca.gov/2007publications/CEC-500-2007-081/CEC-500-2007-081-APB.PDF
- Republic of Ireland, Irish All-Island Grid Study, 2008. http://www.uwig.org/Irish_All_Island_Grid_Study/Study_Overview.pdf; and http://www.uwig.org/Irish_All_Island_Grid_Study/Workstream_1.pdf; and http://www.uwig.org/Irish_All_Island_Grid_Study/Workstream_2A.pdf and http://www.uwig.org/Irish_All_Island_Grid_Study/Workstream_2B.pdf and http://www.uwig.org/Irish_All_Island_Grid_Study/Workstream_3.pdf and http://www.uwig.org/Irish_All_Island_Grid_Study/Workstream_4.pdf.

For Further Information, continued

- National Renewable Energy Laboratory, and Enernex Corporation. *Eastern Wind Integration and Transmission Study*, 2010. http://www.nrel.gov/wind/systemsintegration/ewits.html.
- National Renewable Energy Laboratory and GE. *Western Wind Integration and Solar Study*, 2010. http://www.nrel.gov/wind/systemsintegration/wwsis.html.
- Erik Ela, et. al. "Evolution of Operating Reserve Determination in Wind Power Integration Studies." Presented before the IEEE Energy and Power Conference, July 2010, Minneapolis, Minnesota.

Contact Information

Kevin Porter

Exeter Associates, Inc.

10480 Little Patuxent Parkway, Suite 300

Columbia, MD 21044

410-992-7500

410-992-3445 fax

kporter@exeterassociates.com