International Experience on Grid Integration of Large Amounts of Wind and Solar

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***Abstract*— Findings on experiences with wind integration are gathered in IEA WIND Task 25 research collaboration from the 17 countries participating. Many wind integration studies incorporate solar energy, and most of the issues are valid for other variable renewables in addition to wind.**

Wind power has several impacts on electric power systems: long-term planning issues and short-term operational impacts. Long-term planning issues include grid planning and generation capacity adequacy. Short-term operational impacts include reliability, stability, reserves, and maximizing the value of wind in operational timescales (balancing related issues).

VARIABILITY AND UNCERTAINTY OF WIND POWER – AN IMPORTANT INPUT

The characteristics of variability and uncertainty in wind power are found from experiences of measured data from large-scale wind power production and forecasting. There is a significant geographic smoothing effect in both variability and uncertainty of wind power when looking at power system-wide areas. The smoothing effect is shown in the measured extreme variations and extreme forecast errors, which are relatively smaller for larger areas. Variability is also lower for shorter timescales. Regarding day-ahead and 1-hour shortest-term forecasts, improvements up to 50% and even 80% in terms of the mean absolute error (MAE) are expected by an aggregation of single wind power plants to a region such as Germany. Up until now, advanced forecast systems led to MAE values of approximately 1% of the installed capacity for 1-hour-ahead and 3% for day-ahead forecasts Germany's total wind power production.

WIND POWER IN LONG TERM PLANNING FOR GRID AND GENERATION ADEQUACY

The grid reinforcement needed for wind power is very dependent on where the wind power plants are located relative to load and existing grid infrastructure, and it is expected that results vary from one country to another. Not many studies report the costs of grid reinforcements caused by wind power because transmission lines in most cases are used for multiple purposes. In previous studies, only Portugal made the effort to allocate costs among different needs. In the combined efforts for ten-year network development plans (TYNDP) from the European transmission system operators (TSOs), estimates on allocation are depicted on a general level as the share of new grid that will be needed for renewables, markets, and security. The national results reported in recent studies also address flexibility needs mitigated through transmission to reduce curtailments of wind power and to access flexibility from hydropower.

Wind power's contribution to a system's generation capacity adequacy is its capacity value. In most countries, this is not a critical question in the starting phase of wind power deployment; however, there is already experience from conventional power plants withdrawing from the market due to reduced operating times and full load hours, leading to low income. This will raise the question of resource (or generation) adequacy in a power system. Wind power will provide more capacity and thus add to the reliability of the power system; however, the benefits of added capacity vary depending on how much wind resource is available during times of peak loads. The capacity value of wind power decreases with an increasing share or wind power in the system. The results summarized in this report show that most countries have a capacity value of 20–35% of installed capacity for the first 5–10% share of wind; however, for a 20% share of wind in a system, the capacity value is above 20% of the installed capacity for only one study assuming a very large interconnected system. Aggregation benefits apply to capacity value calculations—for larger geographical areas, the capacity value will be higher. Also, a large range is shown for a same share of wind: from 40% in situations where high wind power generation at times of peak load prevail to 5% if regional wind power output profiles correlate negatively with the system load profile (often low wind power generation at times of peak load).

IMPACTS OF WIND POWER ON SHORT-TERM RELIABILITY

The impact of wind power on power system dynamics is becoming increasingly apparent with larger shares of wind power, and it will become more important to study this aspect in wind integration studies. Wind generation, by its mere presence, does not necessarily worsen the stability of a system, but it does change its characteristics because it is increasingly connected via power electronic interfaces. Wind power plants can offer a promising option for defence against short-term voltage and frequency instability, and system capabilities can be enhanced through intelligent coordination of the controllers of the power electronic converters. Recent work has also taken into account possibilities for wind power plants to support the grid.

Results of transient stability simulations for after-fault situations for up to a 40% share of wind energy in the system show that this is not a challenging issue. Regarding voltage stability, it will be crucial to use wind power plant capabilities. Frequency stability challenges depend on the system size, share of wind power, and applied control strategies. With lower levels of directly connected, synchronous, large rotating machines, the inertia in the system will decrease, and there is a risk that after a failure at a large power plant the frequency will drop to a level that is too low before the automatic frequency control has stabilized the system. This was first studied in smaller systems such as Ireland, but it is increasingly being studied for larger areas that have higher shares of wind power. Frequency drops can be significant in cases of high levels of wind and solar energy, and studies of wind power providing very fast response to support the system are ongoing.

The impact of wind power on short-term balancing and frequency control has been the focus of many integration studies for decades. The experience so far is that wind power has not caused investments for new reserve capacity; however, some new pumped hydro schemes are planned in the Iberian Peninsula to manage wind shares of more than 20% in the future. New studies for higher shares of wind energy are increasingly looking at the dynamic allocation of reserves: if allocation is estimated once per day for the next day instead of using the same reserve requirement for all days, the low-wind days will make less requirements on the system. The time steps chosen for dispatch and market operation can also influence the quantity and type of reserve required for balancing. For example, markets that operate at 5 minute time steps can automatically extract balancing capability from the generators that will ramp to fulfil their schedule for the next 5-minute period.

MAXIMISING THE VALUE OF WIND POWER IN OPERATION

The value of wind power is maximized when there is no need to curtail any available wind power and when the impact on other power plants in the operational timescale is minimized.

Experiences in wind power curtailment show that curtailments do not occur in smaller shares of 5–10% of yearly electricity consumption if there are no severe transmission bottlenecks and wind power is dispatched first among the low marginal cost generation. However, in some countries substantial curtailments (10–20% of wind generation) started occurring at lower shares of wind. The mitigation efforts regarding transmission expansion in these countries have resulted in a reduction in curtailment rates with increasing wind power. Estimating future curtailments of wind energy as well as mitigation options to reduce them is emerging as one key result in integration studies. The participation of wind power generators in frequency control (ancillary services market) will decrease the overall curtailed renewable generation with large shares of wind power in the system because this will allow other generation to shut down and make room for more wind.

Balancing cost has traditionally been the main issue that many integration studies try to estimate. It is becoming less of an issue in countries where experiences in wind integration are accumulating. Analyses regarding integration costs evolve towards comparing total system costs for different future scenarios showing both operational and investment costs. In countries where wind power is out in the markets, balancing is paid by the operators in imbalance costs. There is some recorded experience in the actual balancing of costs for power systems that have growing shares of wind power. In Italy, costs have almost doubled; whereas in Germany, balancing costs have actually been reduced by 50% despite a growing share of wind and solar power because of the more profound impact of sharing balancing resources with the balancing areas.

Increased balancing due to thermal power plant cycling has been studied in detail to confirm that cycling costs are relatively small compared to the reduction in operating costs that can be achieved with wind and solar energy.

Measures to enhance the balancing task with high shares of wind power include operational practices and markets, demand-side flexibility, and storage. Electricity markets that have cross-border trades of intraday and balancing resources and emerging ancillary services markets are considered positive developments for future large shares of wind power. Energy systems integration among the electricity, gas, and heat sectors is studied for future power systems that have high shares of renewables. Enhancing the use of hydropower storage to balance larger systems is another promising option. Electricity storage is seeing initial applications by system operators in places that have limited transmission capacity. Electricity storage is still not as cost-effective in larger power systems as other means of flexibility, but different forms of storage have a large role in the emerging studies for systems that have 100% renewables.

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