3.2.1 RESILIENCE

Introduction

Scope of prototype

The primary aim of the RESILIENCE prototype ('Strengthening the efficiency and security of energy networks') is to facilitate and strengthen energy management by having a more robust knowledge of the future variability of wind power. The highest priority for the energy network is to maintain a balanced system to avoid black-outs. However, the rapidly evolving energy system is in an increasingly vulnerable position due to the growth of highly variable wind power contributing to the total energy supply.

Scope of vulnerability analysis

With respect to power production the focus of RESILIENCE is on wind power and related decision-making processes. Wind power is a rapidly growing but highly variable power generation in European grids especially with respect to the North Seas Countries Offshore Grid Initiative (NSCOGI) where off-shore wind power constitutes a significant contribution to power production. The need for climate information on wind to enhance decision-making is therefore desired. The focus of this vulnerability analysis will therefore be on wind power production and problems of grid integration.

System of concern

The system of concern in the context of RESILIENCE comprises the North Seas Countries Offshore Grid Initiative (NSCOGI) which is a collaboration of the EU member states and Norway. It interconnects the countries of the North Sea Region and provides connection and integration of off-shore wind energy with on-shore power plants using especially hydroelectricity as storage for off-shore excess wind energy (E3G 2006-2015). It is the task of the grid-operators to actively manage the balance of supply and demand. Thus, the attribute of concern is the net power output (supply) which is the fundamental basis to meet the power demand to keep the system stable. A balanced system at economic conditions can be considered as success criteria for the system of concern.

Critical situations

The general hazard is a black-out caused by a significant discrepancy of power supply and demand. Small discrepancies can be balanced by changing the speed of alternators which is assumed to be constant in permanent regimes. A technical guiding value can thus be expressed in the frequency of alternators which is at 50 Hz. A specific deviation (which is system dependent) from this value may cause a disconnection of power generators from the system causing chain reactions and consequently black outs (Dubus 2015).

Wind speed for power production is challenging to manage since it is highly variable and often fluctuates over very short time periods comprising hours and even minutes and thus difficult to predict. This has consequences for the production of wind power, which is consequently very variable in space and time and can cause problems for the integrity of the grid (i.e. the power quality, the system security and system stability). Grid operator's task is to maintain the balance between the total supply of electrical power generated by all power plants feeding into the system and the aggregated demand (Ayodele, Jimoh et al. 2012).

Short-term variability of wind power

Hazard: In large highly interconnected power systems, short-term variability of wind power in the range of seconds to minutes are hardly felt by the system and thus pose no crucial problems (van Hulle, Fichaux et al. 2010). Such variabilities are automatically balanced by primary and secondary reserves, which comprise spinning reserves (power plants in part load operation mode) and standing reserves (rapidly starting plants). Both reserve modes run permanently and adjustments occur automatically since power imbalances in this temporal scale are normally not predicted or scheduled (Gül and Stenzel 2005, Dubus 2015). In contrast, wind power variabilities within a temporal range of a sub-hour to a day pose the most significant challenge for system balancing, since this has to be done manually. Magnitudes of variability in this temporal range are quite high and forecast systems are of limited certainty (van Hulle and Gardner 2009, van Hulle, Fichaux et al. 2010).

Decision-making processes: Decision-making in this situation relates to the organization and coordination of balancing options. This implies the activation of capacity reserves (tertiary reserves) which are flexible power plants and energy storage systems like hydropower (which is specifically important for the NSCOGI) and the import of energy from interconnected neighbouring grids. The specific reserve capacity required to balance supply-demand discrepancies in the very near future has to be declared until an agreed point in time (gate-closure time) at which a price for the energy will be determined. Common gate-closure-times in Europe are between 2 and 36 hours. Reserve capacities are declared on the back of wind power forecasts and the amount of required reserve power is a result of forecast error especially extreme forecast errors. Forecasts errors decrease with the reduction in time forecasting ahead (Gül and Stenzel 2005). Therefore there is great interest to have short-term gate-closure-times to reduce the time span between the final declaration of capacity and the actual use of it. This is to reduce the costs of power reserves due to uncertainty (van Hulle, Fichaux et al. 2010, Dubus 2014). However, the operation of appropriate power reserves often demands specific lead times. Smaller changes in wind generation are potentially challenging, since replacements with shorter lead time are required which is often more difficult. Consequently there is a trade-off between reduced gate-closure-times and thus short-term forecasts with lower errors and the increased demand for flexible operational reserves which come along with potentially higher costs (van Hulle, Fichaux et al. 2010, Dubus 2014).

Critical situation: Wind power is generated at very low marginal operating cost. Therefore, it is typically used to meet users demand when it is available. Considering that, it is not the total amount of wind power (i.e. wind speed) which is critical but rather the knowledge of expected wind power produced in the very near future. Thus, the rate of wind power change over different relatively short time periods is critical since it may significantly influence the certainty of wind power forecasts (Wiser, Yang et al. 2011). Consequently, for grid operators the critical factor is not even wind speed but rather the ability or certainty to forecast it assuming that compensation of power supply and demand is generally possible if the demand is known.

The critical situation arises by unexpected wind speed resulting in wind power variabilities deviating from the alternator's guiding value frequency of 50 Hz over a time period of up to 36 hours.

Long-term variability of wind power

Hazard: Active balancing operations of wind power variability occur on time scales between minutes and several hours. However, longer periods of electricity deficits especially where periods of peak demand coincide with periods of low wind power production may cause problems in managing appropriate balancing measures. Especially in power systems where the share of wind power is high (e.g. NSCOGI) energy deficits due to still weather or stormy conditions for a longer period may be significant.

The threshold for black-out is defined for the smallest scale (significant deviation from a frequency of 50 Hz). For larger time scales a maximum amount of black outs per year is determined by the 'security of supply' which is at 99% to 91% security level for Europe. The ability of system to meet expected cover peak load demands in the future considering uncertainties in the generation availability and load level and providing adequate transmission capacities for in- or export flows is expressed by the system's adequacy (van Hulle and Gardner 2009, van Hulle, Fichaux et al. 2010).

Decision-making processes: Decision-making processes refer to adjusting balancing units and measures for a long-term compensation of expected energy deficits. Since the interconnection of grids provides a kind of 'unlimited' availability of power, the challenge is rather the timely organization of appropriate and economic power reserves. Critical factors are capacity limits of transmission lines which only allow a certain amount of energy imported at a time as well as the limited availability of power sources of neighbouring grids which might be limited due to maintenance activities or limited storage or production capacity (e.g. water level for hydropower production) (van Hulle and Gardner 2009, Dubus 2014, Najac 2014, Dubus 2015). Climate information on this scale does not contribute directly to technical operations. Other important factors, like commodity prices and political issues are much more uncertain to make a decision at this point of time (Dubus 2014, Najac 2014). Thus, climate information on this scale rather provides orientation for decision-making on respective planning issues (Dubus 2014). Critical time frames of operational relevance are therefore very problem specific. However, estimated temporal scales for long-term management operation are between a few days up to a couple of months. But in general it can be stated that the more time available for planning (i.e. climate information is available) the greater the benefit (Dubus 2014, pers. com. Dubus).

The critical situation arises due to a long-term low-level of wind power production for periods of a couple of days to a couple of months causing discrepancies between supply and demand of energy which challenges the reserve capacities available on a day-to-day basis.

Buffer system characteristics

Wind power production is directly dependent on wind speed or more precisely on the cube of wind speed. Wind turbines commonly operate at wind speeds between 2.5 and 25m/s. Above and below this range wind power may become unavailable due to the lack of wind or shut-down measures to avoid damage of equipment (Gül and Stenzel 2005). Thus, to produce wind power no temporal buffer effect is required and threshold values are climatic.

However, the attribute of concern which is the total power output from the power system should be considered as the basic element of critical situations. Sources of electrical energy are diverse and wind power is only one of many which feed power into the system. Thus the power grid can be considered as buffer system which consolidates electricity from different power sources producing a net power output (and also net power variability). In contrast to other buffer systems, this buffer system does not buffer the climate input signal (wind speed) but the power input to the power system (no matter what source). Variabilities in power generation can be reduced by smoothing output variability of specific power generators. Wind power output can be smoothed by the use of wind farms and their geographically diverse locations which do not correlate with respect to power output. Total power output can be balanced by the interconnection of different power generation technologies and the interconnection with neighbouring grid systems. The broader the interconnectivity and diversity of the grid system the greater the robustness or resilience to variable wind power (Gül and Stenzel 2005, Wiser, Yang et al. 2011). The outstanding characteristics of this buffer system are its technical nature and the ability to control or at least accurately measure the individual components which contribute to the total output.

Critical climate conditions and climate information

Critical climate conditions

The production of wind power is directly linked to thresholds in wind speed and thus to climatic parameter. Wind speeds need to be above 2.5 and below 25 m/s to be used as power generator. (However, these values are due to the current standard of wind turbine and may be changing in the future with new technology.) *Critical weather conditions are high changes of wind speed rates especially on the scale of 2-36 hours at which decision on power balancing have to be made.* Thus, critical climate conditions for the production of wind are on the scale of weather events (very short-term) similar as the related decision-making processes which imply respective balancing measures.

However, the challenge to balance supply and demand increases with an increase of the lengths of wind still periods. The thresholds which define critical situations and especially its temporal delineation are primarily dependent on the prevalent grid system and its characteristics (generation mix, i.e. share of wind power, degree of interconnection), the efficiency of the operator to handle variability (use of forecasts, balancing strategy) (van Hulle, Fichaux et al. 2010). The critical climate or weather conditions for longer-term discrepancies of wind-power supply and power demand are periods with low wind speeds which go beyond seasonal intermittency. The longer such periods last, the greater the probability to create a critical situation. For example, periods of low wind with a durations of around 1-2 weeks had significant economic impact in Denmark and Germany in 2007 (Bach 2010) and can serve as a landmark to assess critical time periods. However, the point in time at which periods of low wind may have significant impact can clearly be determined since they are strongly related to periods of peak demand which are commonly in winter and summer when extra energy for heating or cooling is required (Sinden 2007).

Critical climate conditions are low-wind (below average) speed conditions over periods of 1-2 weeks or longer.

Climate information

Decision-making on sub-seasonal to seasonal time scales implies planning and organization of power supplies to balance expected gaps of power supply in the near future. Forecasts on periods of below average wind speeds starting from one week and more are desired and of potential use. However, the longer the periods of low wind speeds the greater the effort to compensate expected lack in wind power production. Thus, longer lead-times for decision-making are required. Consequently, wind speed forecasts on multiple scales are potentially useful but also desired. However, winter and summer times are obviously risky periods, since high power demands are expected.

Vulnerability attributes

Criticality of decision-making processes: the assessment of the future power supply is of elementary importance to avoid black-outs and keeping the power system stable. However, the share of wind power is still rather low for most power systems and its particular relevance for systems stability manageable. Of much more relevance is the total contribution of variable energy sources (renewable energies) for power supply and most important is the variability of power demand (Dubus 2014). Thus, climate takes the role of a production factors rather than a resource. With respect to the problem of balancing supply and demand to avoid black-outs the adequacy of the grid, i.e. its ability and flexibility to cope with power imbalances (resilience) is probably the most sensitive factor. For a robust (resilient) grid it doesn't much matter whether wind is blowing or not as long as its share for the power system is not too high and as long it can be sufficiently accurately predicted. A more relevant impact of longer-term low wind periods is probably on the pricing of wind power and thus for energy traders.

Usability of S2D climate forecast information: the informational content of S2D forecasts comprise mean values of wind speed for temporal periods at different time scales (1-12 months) is basically compatible with the information needs of DMP's on these scales. Since decisions on specific power balancing measures are made on the day-to-day basis, information with high resolution on wind power timing and temporal distribution are not yet required on S2D scales. Information on the approximate amount of power to be supplied for a specific period is sufficient planning issues. This has also consequences for the ***level of certainty***: any skill of the forecasts provides some benefit in terms of additional information. Due to the smoothing effect of wind farms the relative coarse ***spatial scale*** of the North Sea region is favourable for the usability of S2D forecasts since no substantial down-scaling is required. Finally, the planned S2D forecasts for RESILIENCE do meet the demands for decision making with respect to ***timing*** (winter and summer months) and ***temporal scales*** (1 month to 1 year) and constitute no barrier from the technical point of view.