Use of Forecast Uncertainties in the Power Sector: State-of-the–Art of Business Practices

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***Abstract*—The work we present is an investigation on the state-of-the-art use of forecast uncertainties in the business practices of actors in the power systems sector that is part of the "IEA Wind Task 36: Wind Power Forecasting". The purpose of this task is to get an overview of the current use and application of probabilistic forecasts by actors in the power industry and investigate how they estimate and deal with uncertainties. The authors with expertise in probabilistic forecasting have been gathering information from the industry in order to identify the areas, where progress is needed and where it is difficult to achieve further progress. For this purpose, interview questions were compiled for different branches in the power industry and interviews carried out all around the world in the first six months of 2016. At this stage, we present and discuss results from this first round of interviews and draw preliminary conclusions outlining gaps in current forecasting methodologies and their use in the industry. At the end we provide some recommendations for next steps and further development with the objective to formulate guidelines for the use of uncertainty forecasts in the power market at a later stage.**

I. Introduction

The relevance of forecast uncertainties for wind power and other renewable energies grows as the penetration of these sources in the energy mix increases. Once a certain level of penetration is reached, ignoring the reliability of forecasts not only becomes expensive in terms of reserve requirements, but can also become dangerous in terms of grid stability. The flexibility requirements in both grid handling and remaining generation capacity are increasing as well, and require tools and mechanisms that can predict when forecasts can be trusted and when there is need for buffers, thereby assisting in decision making. We can act rationally and efficiently only if we are warned and can prepare to a given situation. Therefore, we need to understand these new needs in order to serve the industry and to guide research towards development of the tools that will be needed in the future.

The development of weather ensemble forecasting systems has started more than 25 years ago. Computing advances have made it possible to generate ensemble forecasts with many different models or perturbations of models that reflect a realistic uncertainty of the weather development. This is a capability that deterministic forecast models don't have as in general they suppress extremes. For this reason, a so-called *meta-forecast* or *poor-mans-ensemble* made of a number of such deterministic forecasts does not produce a realistic uncertainty spread in more extreme weather situations. In the power industry the target parameter is wind power, which roughly goes with wind speed to the power of three, and small errors and uncertainties are thus amplified and have an even higher impact compared to wind speed uncertainties. Weather development associated with fronts moving over large areas where wind is increasing rapidly over a short time are the most critical situations for a balance responsible party or a transmission system operator (TSO): it is under these circumstances that a deterministic forecast may be strongly incorrect and suppress steep ramping that can cause system security issues as well as large imbalances. Translated in the market, it means that there can be a sudden lack of power during a down-ramping event or too little flexible power that can be down-regulated fast and efficiently, which then results in curtailment. As long as the penetration level of wind is below 20% of generation, such uncertainty can usually be dealt with with a reasonable amount of reserves. As penetration increases, or in the case of island grids or badly interconnected grids, reserves and ancillary services grow above a desirable level.

In order to get an understanding of the current state of use of uncertainty forecasts and to find the gaps in the understanding of uncertainties and the associated forecasting tools and methods, we have been carrying out a study with a combination of questionnaires and interviews, which will be described in the next sections.

II. Part 1: Interviews and Questionnaires

The authors, work group members in work package 3.1 of the IEA Wind Task 36, formulated a number of relevant questions that were compiled into an interview document. Since the different actors use forecasts in slightly different ways and with different purposes, we decided to customize the questionnaires depending on the object of the organisation. We created five categories: system operators ((SO)), energy system management companies ((ESO)), power producers and power management companies ((PP_PMC)), electricity trading companies ((ETC)) and research institutions ((R&D)). Since some companies are prone to keep information confidential due to the high level of competition, it was important to allow everybody to provide the information anonymously. A Dropbox folder and an email account were set up for this purpose. The details of the Dropbox folder and the state of the interview collection are available and updated throughout the project at the IEA Wind Task 36 website[1].

[1] http://www.ieawindforecasting.dk/news/nyhed?id=70BCAB20-CB95-4BB0-9D5D-3D00765C584F

The questionnaires include a common set of questions aimed at identifying the impact that players may have and in which type of markets they operate (see also [1]). This should provide an indication of the market structure and whether the amount of power managed has a direct influence on the tools used to perform the tasks. Another objective is to investigate whether the use of uncertainties in the management of wind power is connected to market incentives, company structure or available tools from vendors.

A. Participation

We carried out 15 interviews in Denmark, France, Germany and Portugal and send questionnaires to all countries with significant amounts of wind power. We received filled out questionnaires from Australia, Canada, Ireland, Germany, Denmark, Lithuania, Spain and USA. Approximately 25% of the questionnaires were submitted anonymously. This first round contained information from 24 participants, which were analysed. Where possible, we asked the respondents also about the status in their country with regards to the use of uncertainties in order to further increase the knowledge base by seeking and receiving information that is beyond the individual participant's own use or application of uncertainties.

III. Analysis of the Questionnaires

In [1] we have already presented a few of the main findings and compared some of the tendencies in the market structures with a study funded by the US Department of Energy by Lawrence E. Jones [2]. As an outcome of this study in 2012, Jones predicts that the focus time horizon in the power markets will move from day-ahead to hours ahead, i.e. the short-term market. In our investigation five years down the road, we can however not see this happening yet. There were 58% of the participants active in the intraday market and only 29% were active in the reserve market. These two markets are those where uncertainty information is most important. Nevertheless, from the interviews we carried out we can see a tendency towards increased attention for short-term markets, especially for system operators with centralised forecasting and obligations to trade the wind power in their grid. This is due to increasing penetration levels of renewables. So, even though interviewees answered "no" when asked if they use uncertainty forecasts, they confirmed that the implementation of uncertainty information is on their agenda for their next generation forecasting system. Another interesting general tendency regarding use of uncertainty information was that 71% of participants knew something about probabilistic forecasting, but only 21% used any kind of uncertainty information in their operation. The same is true for weather forecasts: here 71% used weather forecasts, but only 21% employed meteorologists or staff with an equivalent education (e.g. atmospheric science, environmental engineering, geography etc.). Especially among system operators we observe a significant lack of meteorologists in the handling of renewable energy.

The returned questionnaires covered organisations with an overall portfolio of 71GW of wind power and 33GW of solar power, where 50% are participating in the market, i.e trading wind energy or renewables in general. The remaining participants were managing companies, 14%, organisations that balance power, 27%, and power producers, 9%. The average time of activity in the wind power or renewables area was 15 years, with the longest time frame being 25 years and the shortest 2 years.

Although day-ahead forecasts are still the main focus for the largest part of participants, 92%, intra-day forecasts are attracting more interest, as 63% of participants said that they were also using them and acting in the intra-day market; 46% of the total are also using demand forecasts, 29% work with price forecasts, and 63% additionally make use of weather forecasts. To which extent the weather forecast was used for wind power or demand forecasting was not clarified. Other forecast applications being mentioned were hydropower, biomass, economic dispatch and reserve allocation.

Participants were asked to indicate which factors they reckoned to be an obstacle to the use of information on forecast uncertainty; answers are presented in table I.

TABLE I
Obstacles to using information about forecast uncertainty.

Factors	Agree [%]	Not-Agree [%]
Weather is one out of many uncertainty sources	100	0
Insufficient knowledge about tools and approaches	53	47
Fear that speculative planning may result in a loss	64	36
Lack of staff to undertake the job	37	63
Lack of IT solutions	35	65
More information may lead to slower decision making and loss of important time	32	68
Flexibility in real-time staff resources would be desirable, but is not feasible	42	58
Company has access to confidential market information and is not allowed to speculate	33	67

From the answers in table I, it can be seen that there is a considerable lack of knowledge about tools and applications to deal with uncertainty (53%), although 35% think that there is a lack of IT solutions. This indicates that there might be a gap in understanding existing solutions and relating them to the problems that they can solve. This result is consistent with the interviews that we have been carrying out in Denmark and Germany, where especially small actors have difficulties seeing the advantages of uncertainty information. On the other hand, the questionnaire clearly revealed that current business practice is focused on multiple deterministic forecasts from multiple providers. Even though such a collection of forecasts sometimes is referred to as multi-model ensemble or meta-forecast, this strategy is problematic because by using deterministic forecasts outliers are by definition filtered out; this means that the spread of a set of deterministic forecasts seldom reflects a realistic weather or wind power production uncertainty. There is still a mistrust towards uncertainty information and a kind of wrong perception of probabilistic or uncertainty forecasts associated with speculation, as 64% of the participants said that they feared that speculative planning may result in a loss. That 64% did not agree with the fact that more information leads to slower decision processes shows that it is not the concern for overwhelming amounts of information, but rather a lack of understanding of how to make use of such additional information. These answers are therefore again consistent with what we observed when interviewing: larger organisations had more focus on optimisation and were deploying more staff resources to test and verify new technologies in comparison to smaller organisations. Moreover, 78% of participants operate as “price takers” in the market and only 60% of those trading energy in the market run a 24/7 type of service; 5% work with extended business hours from 7-22h and 35% run with common business hours.

Critical situations

Our objective was to understand what the drivers to the use of uncertainty forecasts are. The questions on which are the most critical situations in their operation and whether these are connected to weather uncertainty were supposed to provide insight on that matter. Since a key feature of uncertainty forecasts is the ability to predict extreme events and hence critical situations in advance, these questions should provide insight on whether this was a known associated feature of uncertainty forecasts.

As table I shows, all participants agreed with the statement *weather uncertainty is only one out of many uncertainty*, but more than half of the participants indicated fear that speculative planning results in a loss. Among the power traders, there is a clear tendency for the most critical situations being those, where forecast errors cannot be balanced anymore as well as curtailments not being communicated in time or with automatic methods. The latter has been named as problematic in some of the interviews. In Europe, there are no standards regarding the so-called ”REMIT” messages (Regulation on Wholesale Energy Market Integrity and Transparency) that announce outages to the market [3]. As of today, there is no common platform, where all market participants can get the information from. The EEX-transparency platform has established an *ad-hoc ticker* messaging side[2], where market participants can announce outages and reductions of their active capacity. However, this is not mandatory and therefore it does not allow to establish a complete knowledge base of reductions in the active capacity that may impact prices and volumes. Many participants still announce outages only on their homepage. They fulfill the technical requirements, but the information is in practice not really accessible, as it is impossible to scan all individual market participants home pages for outages.

Among system operators, ramps and grid constraints are named by almost everybody as critical situations. Power producers are most weary with respect to component failures and the corresponding repair procedures. Although a large part of the repair time uncertainty is due to crane availability, weather uncertainty also plays a role.

When asked what barriers would remain to implementation, if the needed tools were available, organizations’ answers indicated a general resistance to change due to current practices, costs, education and limited resources. Another aspect were the limited IT resources and the associated adaptation costs in the organization.

From the answers we can conclude that uncertainty in weather forecast and power production is a key element of volatility in the market and a driver for competition, as well as playing a role in security constraints and risk management. Among actors in the power market, there is some sort of awareness of the risks associated with weather variability, but clearly this is still not enough to change effectively the common practice. The consequence of these answers may also indicate that the use of uncertainty forecasts, whether as ensemble forecasts or statistic-probabilistic forecasts, could require the same effort as starting to implement forecasting tools from scratch. It seems like a paradigm shift or political-economical incentives are required in order to move to the next or a new level. As a result, such change in business practices seems limited to those organisations that are in a growth phase or those required to change practice due to grid code or legislative changes. The review of the interviews in the next section will reveal some additional challenges that come with higher penetration levels in more established markets.

IV. Analysis of Interviews

A. Review of Interviews carried out in Denmark

Denmark was the first country world wide to exceed 20% penetration from wind and to privatize trading and balancing of wind power staring in 2002. When this happened the evolution has since been determined by the market, which is the reason why Denmark has become a net importer of power. Denmark was also the first country, where several large coal based generation units were closed starting around 2012 due to too strong competition from wind power [4]. In recent years, load exceeded local generation between 5 and 15% as shown in Figure 1, where the relationship between Danish electricity demand and the amount of generated electricity in Denmark that was sold in the day-ahead market is shown.

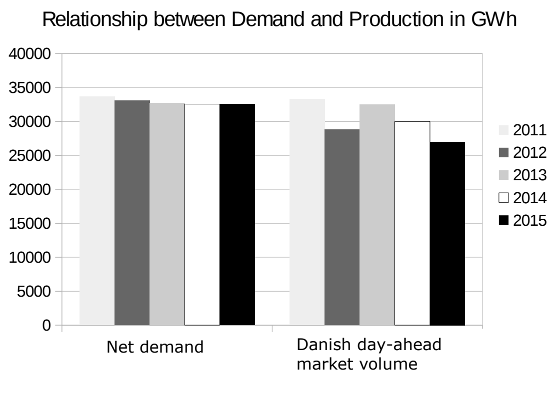

Fig. 1. Relationship between the Danish electricity demand and the amount of generated electricity in Denmark that was sold in the day-ahead market in the years 2012-2015. The year 2012 is noteworthy, as it is the year where the largest single plant of 1GW closed down.

[2]https://www.eex-transparency.com/homepage/news/ad-hoc-ticker

The net flow of energy is determined by the market coupling, which has a very strong day to day weather dependency. The market coupling maximizes the value of renewable energy, but only as far as the transmission and load allows. The solar expansion in Germany has thereby been able to reduce the amount of high price hours over an area beyond Germany, although today's transmission would not be able to bring the energy that far. The day-ahead auction assumes free flow of energy, which is physically impossible within most countries and therefore dampens virtually the spot market price more than possible with the existing grid. There are debates among market players and experts of the power market and some of our interviewees argued that it is unacceptable that authorities accept virtual competition as a mean to avoid price volatility. Nevertheless, it is done and there are many that have the opinion that it is a matter of time before the situation is brought to court.

Concurrent generation in low demand periods is the causer of negative spot market prices. Thus, low price volatility occurs more often and high price volatility less and less. With strong inter-connections, Denmark has a minimum of price volatility and depends on neighbors both with respect to export and import. In a market, where the normal situation is characterized by low price volatility and high competition, there are few opportunities for large power plant to achieve a utilization level, which is economic.

Changes in the weather combined with weekly and daily changes in the load pattern on different time scales cause continuously changes in the flow of energy and spot market prices. Under these circumstances one would expect forecasts including their uncertainty to play a major role for the bids into the spot market. Our market survey however indicates that this is not the case for the bulk of the generators. It is therefore worthwhile to look deeper into the market structures and discuss why a large fraction of the generators participates in the market with low staff allocation for the trading of energy and why they choose to not optimize their forecast processes, but rather work from own past experience.

B. *Decentralised production: a blessing or a curse?*

In Denmark, there are 755MW oil based thermal capacity and 3385MW coal based capacity with the largest single power plant in 2016 being 665MW and 1150MW non operational. According to a recent published report by Energinet.dk, the Danish TSO, [4], the capacity for coal and oil based thermal power plant will be further reduced to half the capacity over the next years. This is due to that large coal based generators are no longer competitive to get production contracts as soon as there is wind, solar production or massive precipitation. In these periods the consumed energy in Denmark is a mixture of wind, solar, foreign nuclear power or hydro power and generation from as many small local generators as needed.

Common for the small generators is flexibility to start-up and stop and that power generation is not the primarily purpose of their business. They were built to supply heat for environmental reasons. In the beginning, this was to replace oil with gas and later biomass. As a result, even small generators have over-capacity. On top, the small units still receive support until 2018, i.e. all non-competitive capacity is only kept in the market until then. Even though a under-capacity is expected from 2020 on-wards by the TSO and the Danish Industry Union, our interviews revealed that the over-capacity is the main reason for these generators to not consider using forecasts. There is enough independent small generation capacity in the market and small generators have insufficient volume to impact market prices. The inter-connectors have enlarged the market and thereby reduced the price volatility inside the country. Shorter periods of high renewable energy generation somewhere on the grid confuse the market's understanding of price variations. These variations, the fact that a small party does not influence the price combined with, that there is continued heat demand, enforces the small generators to bid into the market as price takers. It does only play a secondary role that staff resources are limited at the small generator side and that power generation is a secondary business process for many of these.

In our interviews, some small generators expressed their preference for the intra-day market as being due to flexibility reasons. Although it was not explicitly said, it appears that the reasons are the possibility to use persistence based forecasts as well as the flexibility to pull back offers from the market. The intra-day market was considered more convenient, because of the flexibility to act upon an unexpected change of the heat reservoir caused by solar energy. However, this expresses indirectly the unwillingness to use forecasts, although it is know to be better to participate in the day-ahead spot market and correct with smaller corrections in the intra-day as shown in a 1-year study [5]. One would also expect intra-day balancing to partially compensate for the virtual competition in the day-ahead auction. The small generators are indirectly bidding into the market via balance responsible trading parties (BRP). Although this is not increasing transparency of what is ongoing, the potential optimization then lies at this level due to that there is enough MW in the BRP's portfolio to finance optimisation.

It is not new that wind in Denmark at times delivers all power to meet demand and spot market prices become negative, but it is new that the high competition in the power market will sooner or later lead to that some of today's CHP generators will focus entirely on heat generation [4]. Lack of price volatility caused by too high competition results in the market being economically unattractive. Too low price volatility also suppresses innovation in smart grid technologies. At present there are periods where the penetration of renewable energy is low, but due to increased transmission and additional capacity, these periods will gradually become shorter.

The lesson from Denmark is that if competition is increased beyond a certain natural level, innovation and large-scale system optimisation can stall. The market coupling causes virtually low spot-market prices and this enforces market participants to participate in the markets for intra-day and reserve, but these markets are also getting more and more populated by wind generators and high-voltage electrode boilers with the lowest marginal costs for down regulation of generation. Thus, building new capacity year after year have led to an overcapacity in wind, over-competition and stalled optimisation and innovation capacity as well as a growing lack of capacity from non-weather dependent sources.

C. Interviews carried out in Germany

In the framework of the national research project EWeLiNE ("Development of Innovative Weather and Power Forecast Models for the Grid Integration of Weather-Dependent Energy Sources") funded by the German Ministry of Energy and Economics from 2013-2016, the Fraunhofer IWES research institute and the German Weather Service (DWD) interviewed the 3 participating transmission system operators (50Hertz, Amprion and Tennet). The project's objective is to systematically improve forecasts and develop tailored tools for dealing with forecast uncertainties. In the initial phase, two main fields of interest had been identified with respect to uncertainty forecasts: probabilistic forecasting for the marketing of power from wind and solar on the European Power Exchange (EPEX) and scenario forecasting for the feed-in power from wind and solar at grid node level. Additionally, the project established an industry and research platform, a group of around 70 persons from grid operators, weather services, direct marketer, forecast provider, services companies and research institutions. They met every six month from 2013-2016 to discuss current challenges in the power market and addressed regularly the use of probabilistic forecasts. Many different probabilistic forecasts, such as quantile forecast and scenario forecasts have been developed by weather services and forecasts providers and are under ongoing development by research institutions. An important field of application is the intra-day-trading on the electricity exchange. Some participants report on the principal importance and on the value of uncertainty forecasts, but they keep a low profile with respect to technical details. Two things might be the reason: either they have a competitive advantage or the use of probabilistic forecasts has not yet been extensively developed. System operators examine the value of uncertainty forecasts for their work with no final conclusion yet. Their main focus is grid security and supply reliability which they basically intend to guarantee with improved deterministic forecasts or a meta-forecast, typically a weighted average of a number of deterministic forecasts, respectively. Up to now grid operators are thinking about a potential illustration of probabilistic forecast in terms of traffic lights. But the definition of events and threshold that are critical for the grid security that should lead to a change of light is still unclear. Although they see a potential in the use of quantile forecasts in their trading activities, their systems are so much geared to meta-forecasts that the move to other strategies lacks incentives. In wind power the power to be traded by the TSOs has become too small for investments in new forecasting strategies ($< 10\%$ of the total installed capacity). Since all new capacity has to be direct marketed by private BRPs since January 2016, trading by TSOs will gradually be out-phased. Another obstacle is the clocked time table of power flow calculations and the subsequent exchange of information about cross border flows within the European alliance of grid operators. Grid simulations using uncertainty forecasts has been mentioned as another potential application as penetration increases. Tight time tables regarding data exchange and load flow calculations and software built upon deterministic forecasts are named as obstacles towards development in that direction. What can however be observed is that the TSO with the highest wind power penetration level, is more open to the integration of uncertainty forecasts in grid simulations and situational awareness than the others. It can therefore be concluded that the penetration level and the market structure have a significant impact on the integration plans and the use of uncertainty forecasts.

D. Interviews carried out in France

In France, due to the current feed-in tariff, there is no clear forecasting market yet for the wind power producers. Some producers already use forecasting, but in contexts where they do not think that uncertainties are useful, or at least worth paying for.

We interviewed 11 French wind power producers and aggregators from April to July 2016. The small producers reported to use free NWP services for deterministic wind forecasts. The medium-size producers also reported using free services and some specific services such as thunderstorm alerts, forecasting for maintenance planning and day-ahead forecasting in the French Island, where the wind power pricing depends on forecasting. The aggregators were more used to forecasting and used it for others energies concerned by the electricity market system such as hydro-power and PV. Two medium-sized producers and an aggregator reported developing their own wind power forecasts and two other were considering to buy a wind power forecasting company.

When asked about their forecasting needs, most reported that they chose a free or cheap forecast that was enough for their current needs. They pointed out a lack of accuracy and a meteorological mesh too coarse, and only one of them spontaneously reported a need for probabilistic forecasts.

When we specifically asked about it, seven producers said that uncertainties would be *very important*, one answered *important*, three answered *not very important* and no one answered *not important at all*. When asked about their improvement strategy, opinions were divided between challenging their current providers, setting a benchmark, buying forecasting companies, except one who wanted to keep using deterministic forecasts.

Overall, we observe a very immature sector about forecasting, due to the absence of financial incentives. Wind power producers are interested in the topic, but most of them wait for the last elements of the French energy transition law (expected in October 2016) to address it. There should be new elements, especially the coefficients of the new support system (feed-in premium *ex-post*) and therefore allow the voluntary producers to sell electricity in the market, but the real switch to a mandatory market system for new wind power plant is not expected before the end of 2017. The whole process lacks quite some transparency and is therefore also criticized by the wind power unions and producers.

V. Status-quo in selected Countries

A. Portugal

In Portugal, the interest in wind power uncertainty forecasts is driven by the system operation needs, particularly considering the high integration levels of wind power, e.g. in 2015, 23% of the annual consumption (48.964 TWh) was supplied by wind power, in contrast to 18% from large hydro-power plants and 39% from thermal generation. Days with extreme wind power levels are more and more frequent, e.g. on 28th December 2015 a maximum of 84% of installed capacity (4210 in 4954 MW) was reached during a night period, representing around 125% of the total system load.

A probabilistic reserve setting tool was developed and demonstrated in the framework of the FP6 EU Project ANEMOS.plus [6], [7]. This work established the first steps towards use cases at the TSO level, which use information from wind power probabilistic forecasts represented by a set of quantiles. A few years later, this methodology was enhanced to include other sources of uncertainty (e.g., PV, small hydro). Presently, it is under test in the Portuguese TSO dispatch center. A second probabilistic methodology, aiming to support the operator in setting the maximum import net transfer capacity (NTC) value in a way that the risk of renewable energy curtailment remains below a pre-specified threshold, was also developed and currently is under operational tests [8].

The lessons learned from these two use cases were: (i) the forecast skill of extreme quantiles is a critical requirement since TSOs are risk averse (i.e., the most important quantiles are below 1% and above 99%) and the lack of data in the distribution's tails makes this task more difficult; (ii) risk quantification is the added value of this framework since even in cases, where the operator prefers to use a deterministic rule or expert knowledge, the possibility of having a numerical quantification of the operating risk is very useful for *post-mortem* analysis; (iii) decision-aid methodologies remove the "psychological burden" of the probabilistic forecast, however, and in complement, new visualization methods for uncertainty forecast should be developed to supply the operator with an idea of the "degree of uncertainty".

All the wind power plants are remunerated by a fixed feed-in tariff. However, the regulated retailing company is responsible for making a single offer in the day-ahead and intra-day markets with all the special regime generation (PV, wind, CHP and small-hydro) and financial penalties are imposed to the imbalances. The current practice is to use deterministic forecasts for all generation technologies and significant reductions in the forecast error were achieved during the last years.

B. Spain

In Spain, the TSO is using wind power uncertainty forecasts for sizing the day-ahead reserve requirements, in particular, the 85% confidence interval is used [9]. According to [9], the use of information from uncertainty forecasts reduces the reserve capacity (and cost) in days with a "stable" wind regime and increases the reserve capacity when the predictability is low. However, if the remaining 15% of this reserve is not being sufficient, it might result in additional dispatch of conventional power plants and consequently higher operating costs.

Presently, an interesting challenge with a relevant impact in the forecast error and uncertainty modeling is the impact of wind power forecast errors on market prices. [10] showed a day in which the forecast error is -1.5 GW (overestimation) and the price is under 10 €/MWh (valley period) and 3 GW (underestimation) around the peak period. This illustrates that in power systems where the wind power plants participate directly in the electricity market, the dependency between the price and wind power forecast errors can be non-marginal, increasing the complexity of uncertainty modeling. It should be stressed that in Spain portfolio bidding is allowed, which contributes to decrease the overall forecast error of market players.

C. Ireland and the UK

The islands of Ireland and Great Britain have a very similar wind regime and terrain, but a very different integration of wind power into the power grid. In the highly liberalised UK market, wind power producers generate their own forecasts and are obliged to submit them to the transmission system operator, who in turn publishes the aggregated forecast for the wind production. There is no incentive nor penalty for good or bad forecasts, and under such conditions it is practically impossible to find a fair error measure. On the other hand, if there is no incentive, the market is inclined to do the least amount of effort. The uncertainty of generation from wind results in volatility of prices. The higher the penetration of wind, the higher the volatility generated by the market in response to variable weather conditions. In an interview with TSO National Grid, it was mentioned that they have little control over ramping events, where fronts move over areas with lots of installed wind capacity that concurrently ramp fast. Since strong ramps are dampened in deterministic least-square-error optimised forecasts, the TSO strictly speaking would require their own forecast system to get that information.

Ireland, as of today, has a centralised forecasting system and wind power producers receive a fixed tariff for the electricity they produce. The two transmission system operators, EirGrid plc. for Republic of Ireland (ROI) and SONI Ltd. for Northern Ireland (NI), carry out the trading of power into a gross mandatory pool market called Single Electricity Market (SEM). The principle works like this: a post-optimisation of the dispatch is carried out after each day and the performance of the SO is measured against the best possible way of running the grid. This way, the regulator ensures and controls the quality of the processes. Being Ireland a small island with limited interconnections, both power and meteorological measurements are a requirement for short-term forecasting in dispatch processes. Ireland started using uncertainty forecasts in the form of minimum-maximum bands in 2008 and uses percentile bands since 2013. These are used for situational awareness in the control room. For the trading of energy, a best guess forecast from an ensemble prediction system is used in an ex-ante indicative run of the market that determines direction and limits on tie-lines flows. The market as such is settled ex-post. However, this wholesale market is due to change considerably at the end of 2017 to take account of the requirements of the European Network Codes and the Target Model. Key elements of the new Integrated Single Electricity Market I-SEM[3] design include: active participation by supplier companies; suppliers and generators paying/being paid based on prices and quantities determined through ex-ante trading; and cross-zonal power flows determined based on energy market trades and power flowing from the cheaper to the more expensive bidding zone. As balance responsibility will be introduced for wind generators as well, the use of forecasts by all market players is expected to increase sensibly.

The exit of UK from the European Union, commonly referred to as *Brexit*, might affect to some extent the implementation of the I-SEM project. In fact, Northern Ireland is no longer obliged to pursue it for reasons of compliance with European law. However, this project, when implemented will facilitate enhanced electricity exports between the two markets and deliver economic savings. To date there are no signals hinting that Northern Ireland will pull out of the all-island electricity market.

D. North America

In North America, variable energy resources (VER), i.e. wind power and solar power are treated different than in Europe and non-EU countries that use fixed tariffs. Here, most of the VERs are integrated via power purchase agreements (PPA) and forecasting is done by the independent system operators (ISO) or regional transmission organisation (RTO). While most ISOs or RTOs with significant amounts of VERs have forecasting in place, there are only few using uncertainty forecasts, mostly because there is no real incentive, where uncertainty forecasts are of benefit such as in reserve allocation, dispatch, market bids. Ramping events are connected to large moving weather systems and extreme events and often require uncertainty information in the short-term for dispatch to not act counter productive. In Hawaii, which is an island grid, uncertainty forecasts in terms of confidence bands have helped the control room to gain better overview and trust in the forecasts. Their strategy was to enhance the forecasting system with a weather measurement network, collecting relevant weather information to better predict strong ramps in both wind and solar power. Integrating weather data in form of a GIS interface and an state-estimator and grid simulation capability to evaluate actions and impacts in the Energy Management System (EMS) system of the control room. The interviews we conducted revealed that by bringing in probabilistic forecasts, operators gained more confidence in understanding what essentially could happen. In a small island grid, where reserve is limited not knowing what was to come, had created enormous stress in the control room.

There is in general more focus on weather measurements in the USA and Canada, where the projects are also larger in size than in Europe and part of Asia (China, Japan, Taiwan). As in Hawaii, there are a number of system operators that run their own network of meteorological instrumentation, mostly met masts, but also other newer instrumentation such as remote sensing. HECO, the Hawaiian system operator has been developing a so-called "wind NET" network including met masts, LiDARs and SODARs and a "solar NET" network including radiometers and pyranometers in selected and for the power grid relevant places in order get a better situational awareness and trust in forecasts. The Bonneville Power Administration (BPA) also has built up an own measurement network of 34 met masts in their area in order to provide wind measurements to their forecasters and to have a online tool to see weather developments that are critical for the system. The system operators in Texas, California, New York, the Mid-Estern Part, and in Alberta require the wind farms to supply measurements from met masts at hub height near the wind farms.

[3]http://www.sem-o.com/isem/Pages/Home.aspx

Interviews with a number of SOs in North America have shown that as penetration is increasing, uncertainty forecasts have started to enter the system operators control and planning rooms in form of confidence bands. The Texianian system operator ERCOT is today using uncertainty forecasts to evaluate their resource adequacy, if the wind forecast is off track. BPA in Oregon is using min-max bands and has been testing dynamic reserve predictions based on ensemble forecasts. The Canadian system operator in Alberta (AESO) is using uncertainty bands for situational awareness and a best guess from an ensemble prediction system for planning, market and dispatch. The Hydro Quebeck, the SO in Quebec, has developed a dynamic reserve prediction and allocation system using probabilistic forecasting [11].

VI. Conclusion

Even though our survey has not reached out to all countries that integrate wind power in their energy mix, we were able to get a critical number of interviews and answers from our questionnaires from those countries that have the highest penetration levels and have longest experience with wind integration. A very general conclusion from our study regarding the use of uncertainty forecasts in the power industry is that as wind penetration increases, the interest for uncertainty forecasts increases. This trend is evident once penetration goes beyond 20% of energy consumption and installed wind capacity is at times capable of delivering the bulk of power demand. While it seems like the interest and demand for uncertainty forecasts is not that large yet, we can conclude from our study that it is only a matter of time until this demand will rise. The most common applications for uncertainty forecasts today are:

- reserve allocation (see e.g. [12], [7], [6], [11], [5], [8])
- trading and dispatch processes using a best guess from uncertainty forecasts (see e.g. [9], [6],[5])
- situational awareness and risk assessment (see IV-C, V-C, V-D)

To summarize, this overview about the current use of wind power uncertainty forecasts showed that there are many different levels of knowledge about the application of uncertainty forecasts in the power industry today. In some countries regulations lack transparency, insecurity is spread among the market players and the investors, while in other countries the wind penetration is not high enough yet for uncertainty in production being a bottleneck to efficient integration of Renewables. We can therefore conclude that further work is needed to shed more light on areas, where definitions are sometimes unclear and lead to misconceptions and stalled developments. It is however equally necessary to further support the pioneers that use uncertainty forecasts in their operation and to use the lessons learned for further improvemants and to describe examples of excellence as well as failures and misunderstandings in the adaptation to needs and requirements.

VII. Recommendations and next steps

The following recommendations and next steps are suggested as a first deliverable in the IEA Wind Task 36 work-package 3.1 to provide guidelines for the use of uncertainty forecasts in the power industry:

- Derive and test business cases for the use of uncertainty forecasts, particularly at the system operation level, where it is mainly used for situational awareness. The imbalance costs that wind power generators are already paying in several countries (e.g., Denmark, Spain, Romania) make the business case for the electricity markets very attractive and hence easy to show their value. The major gap is on the system operation tasks, except for the use of probabilistic forecasts for setting operating reserve requirements. Therefore, additional work and funding is needed to demonstrate the value of uncertainty forecasts in different use cases, such as technical constraints violation detection, predictive maintenance, unit commitment, etc. In fact, islands or weakly interconnected systems are the perfect candidates for first assessments and integration of uncertainty forecasts.
- It is important to overcome computational barriers related to the scaling of stochastic optimization solutions. One of the key barriers mentioned in the surveys was that the time available to make decisions is very little. Several computational solutions (e.g., probabilistic power flow) are time consuming and may not provide information "on-time". Recent advances in parallel computation should be explored to overcome this limitation.
- The quality of measurements is becoming very relevant due to the increasing need of intra-day balancing. Spatial-temporal modeling of wind power time series can improve the forecast skill (see [13], [14]), but require data with good quality and high update frequency, which calls for additional work related to standardization of data exchange, including information about curtailments and installation of weather sensors.
- Dependency between prices and renewable energy uncertainty is becoming an important issue for systems with high penetration levels of renewables. This opens new avenues of research to create models capable of jointly modeling both uncertainties and their impact on electricity market prices. Moreover, it stimulates creativity to find R&D solutions with added value for the end-users since the recent developments in wind power forecasting are today mainly focusing on feature engineering and machine learning algorithms.
- The increasing integration of renewable energy resources at the distribution grid level will create a new challenge in forecasting the nodal injections at the transmission network. This will require new frameworks for data exchange between TSO and DSO (see [15]) and new tools to forecast the active and reactive power operating point and flexibility at the TSO-DSO interface (see [16] and [17]). The new generation of forecasting tools could be a hybrid of statistical algorithms and electrical system calculation algorithms.

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