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Managing Wind Uncertainty and Variability in the Irish Power System

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Abstract— **This paper summarizes work that has been done to examine the impact of the uncertainty and variability of significant installed wind power on the Irish system. As more and more wind power is installed on the system, the operation of conventional plant on the system will be dramatically different. In this paper, three different aspects of the hour-to-hour operation of the Irish power system are examined. An innovative method to schedule the system is described, together with key results giving the effect of the uncertainty of wind on unit commitment of the system. The increased cycling of traditionally base-load units due to large amounts of wind power is quantified, and the steps to reduce this unwanted behavior are outlined. Finally, the use of intelligent decision tools based on sophisticated wind power forecasts for scheduling and provision of reserve is described.**

I. INTRODUCTION

Wind power is seen as one of the major contributors to Ireland's renewable energy targets - the Republic of Ireland plans to meet 15% of electricity demand using renewable sources by 2010 and 40% by 2020 [1]. This indicates that approximately 6GW of wind will need to be installed on the Irish system by 2020, out of a total of approximately 14 W of installed capacity [2]. There is currently approximately 1000MW of installed wind power on the Irish system at the beginning of 2009. While these targets for wind power would constitute a challenge for any system, the fact that Ireland is an isolated and weakly interconnected power system only exacerbates many of the challenges associated with high wind penetration [3]. However, as it is a relatively isolated system, some of the effects of the variability and uncertainty of wind power can be seen more clearly on a system of this type, making it a good candidate for the type of studies described here.

With only a single dc interconnection of 500MW to Great Britain currently in operation and another 500MW planned to be built, wind power presents a formidable challenge in the day-to-day operation of the Irish power system due to its inherent variability and uncertainty. These will come in various time frames, from seconds (i.e. maintaining sufficient inertia on a relatively small system with high amounts of wind power), to minutes (load following) to hours and days (scheduling and unit commitment). This paper will examine three aspects of the management of uncertainty and variability of wind on the Irish system, particularly in the hourly timescale, where this uncertainty and variability is most apparent. Three studies are summarized here, of which two were previously undertaken and the third is a work in progress. Important results are taken from each regarding the management of variability and uncertainty on the future Irish power system with high levels of installed wind power. The same model is used in all three referred studies, and is described in Section II. The scheduling of the system with wind power is also examined in Section II, where the benefits of using stochastic optimization techniques to account for wind uncertainty in unit commitment is shown. Then the effect of wind on the operation of base-load units is summarized in Section III, while Section IV examines the use of advanced wind forecasting techniques for operation of the Irish power system. The system examined here is the All Island power system, consisting of the power systems of Northern Ireland and the Republic of Ireland, which have operated as a single electricity market since 2007 [4].

II. SCHEDULING OF IRISH POWER SYSTEM WITH SIGNIFICANT WIND POWER

As the wind power installed on a power system increases, so does the effect of the uncertainty of wind on the optimization of the power system unit commitment and dispatch. At lower levels of wind, it is sufficient to plan the system assuming no wind, and adjust the dispatch to account for the wind produced, using conventional unit commitment methods as described in [5]. However, at higher levels of wind, forecasts should be taken into account to avoid overcommitting the system, with reserves carried to account for the uncertainty of wind, as shown in [6]. As wind continues to increase, it becomes important to account for its stochastic nature when scheduling the system, so as to produce schedules that can deal with the uncertainty of wind power. The impact of the uncertainty and variability of wind power on the unit commitment of the Irish power system has been examined in [7] and [8]. This work examined the impact of using stochastic optimization for the unit commitment of the power system. The model used to carry out this analysis is a version of the Wilmar planning tool [9], [10]. Wilmar was developed to examine the integration of wind in the Nordic market, and further developed to examine the Irish system in 2020 as part of the All Island Grid Study [11], which examined the effect of increasing renewable penetration for various plant mixes on the Irish system in 2020 (it is the

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Irish model which is used in the work presented in Sections II and Section III here). The main functionality of the Wilmar planning tool is in two parts. The Scenario Tree Tool produces scenarios for wind and load based on historical data and the performance of wind forecasting. Each scenario corresponds to a different set of wind and load forecasts with their pertaining probabilities of occurrence and with a replacement reserve target to account for the uncertainty of the wind forecast. The scenarios produced here are used as inputs to the Scheduling Model. This is a mixed integer, stochastic optimization model, which aims to schedule the conventional units on the system to meet demand at the lowest expected cost, taking into account multiple scenarios for wind and load. Planning is carried out in a 'rolling' fashion, whereby the system is re-optimised as new wind forecasts are available, taking into account the plan from the previous planning loop. An illustration of the scenario tree used for the All island grid study, with rolling planning every three hours, is shown in Fig. 1. A full unit commitment is carried out, taking into account constraints on units such as minimum up and down times, start-up times and costs, emissions, ramp up and ramp down rates, and the reserve targets for the system, to minimize expected costs over all scenarios. This model is also used for work in Sections III and will be adapted for the work described in Section IV.

In [7] and [8], the Irish power system in 2020 is examined with 6GW of installed wind power - based on a possible plant portfolio produced for the All Island Grid Study [12]. 6GW of wind would provide approximately 34% of energy, with a peak demand of approximately 10GW and a minimum demand of approximately 3.5GW on the system. The system has a DC connection to Great Britain, assumed to be 1GW in 2020. This study concentrated on two aspects concerning stochastic unit commitment of this plant mix for the future Irish system - the effect of using stochastic instead of deterministic methods, and the effect that the rolling planning frequency has on the results. Three different methods of scheduling were examined. Firstly, a perfect forecast of wind and load was assumed, in which no additional reserve is carried to cater for deviations from wind or load forecast, only unit contingencies. Secondly, an imperfect deterministic forecast was used, where units need to be up or down regulated to account for the deviation in wind and load from what was expected, with additional spinning and replacement reserves carried for wind. Finally a stochastic scheduling was performed, as described above and as shown by the forecasts in Fig. 1. This is expected to be more robust to the different scenarios for wind and load than an imperfect deterministic schedule. Additional reserve is also carried here for wind and load uncertainty. In addition, rolling planning, where the unit commitment is re-optimized as new information becomes available, was carried out every one, three and six hours, to examine how more frequent scheduling will impact on the schedules produced. It would be expected that rolling more often would improve the performance and costs of the results.

It was shown that stochastic planning, taking into account multiple possible future scenarios of wind, results in a less costly schedule, in the order of 0.25% of total costs of the island of Ireland, compared to an imperfect deterministic schedule using the same wind forecasts. This can be compared to a possible cost saving due to perfect forecasting of 1.75%. In stochastic power system planning, the reliability of the system would also increase, with less hours in which reserve targets are not met compared to deterministic scheduling. More robust and less expensive schedules are produced this way, since the expensive peaking units are not used as often as when a single deterministic forecast is used. The change in production by unit type is shown in Fig. 2, with zero percent corresponding to the production when perfect forecasting is assumed. It can be seen that including the wind uncertainty, whether stochastically or deterministically, causes an increase in the use of the more flexible plant on the system - this would be expected as it will be these plant that react quickest to a deviation from forecasted wind or load. However, by using stochastic scheduling, these are called on slightly less often,

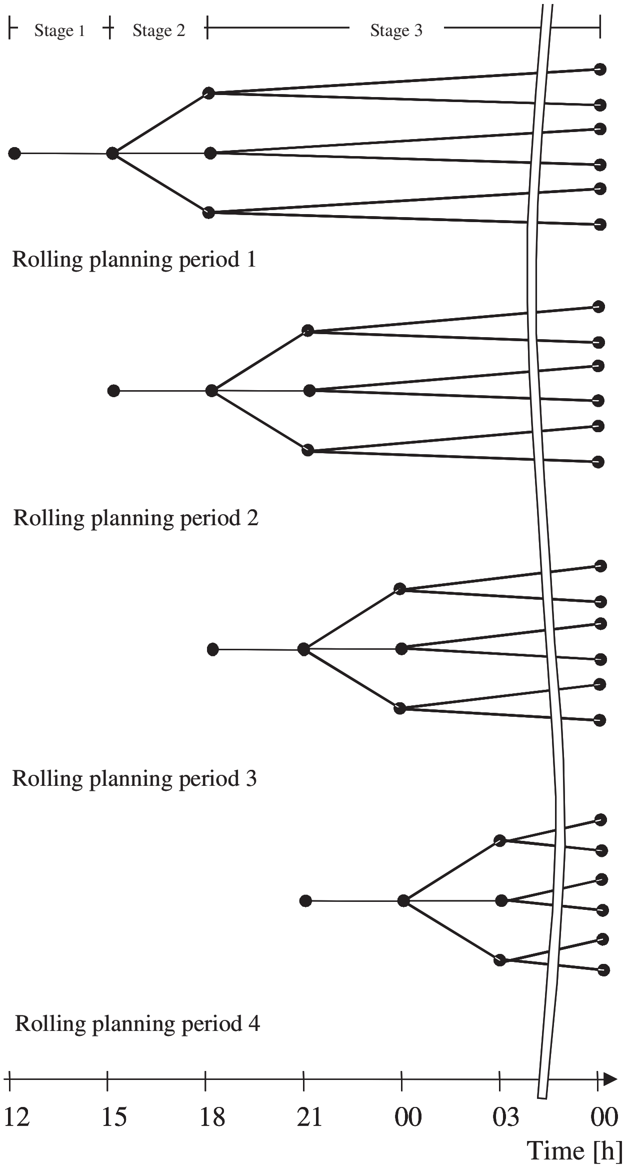

Fig. 1. Stochastic scenario tree for WILMAR, with rolling planning every 3 hours

as more intelligent schedules are being produced. Meanwhile, when the uncertainty of wind is taken into account, more start-ups of all units are observed in the system, compared to a case where perfect forecasting of wind is assumed - showing that uncertainty increases the cycling of these units. This topic was dealt with in more detail in the work described in the next section. As perfect forecasting is unrealistic, the results indicate that stochastic scheduling is preferable to deterministic scheduling, both from a cost and performance point of view. The importance of open cycle gas turbines, shown as mid merit gas in Fig. 2, when dealing with uncertainty can also be seen.

The effect of changing the frequency of schedule rolling was also examined, by changing the frequency at which the system was planned from once an hour to once every six hours. It was shown, as expected, that more frequent planning leads to a decrease in the required replacement reserve demand, while the schedules better meet the targets for load and reserve. Planning the system every three hours is less costly than every six hours. Due to modelling limitations (an assumption of perfect forecasting for the first stage of the rolling planning schedule as shown in Fig. 1), the cost benefit of rolling every hour compared to every three hours is not quantified. More realistic amounts of uncertainty are included as the system is planned more frequently and the length of the perfect foresight stage in the model decreases. This causes an increase in costs for planning every hour compared to every three hours - this result is due to the assumption of perfect foresight and would not be seen in operation, unlike the effect of increasing the replacement reserve which causes the increase in costs between rolling every three hours and every six hours. However, what be seen from including more realistic amounts of the uncertainty of wind in the model by rolling more often is the increase in the use of mid merit flexible units to cater for this uncertainty - again indicating the importance of these units for dealing with uncertainty of wind.

The results from this study can be interpreted for two different uses - as a planning tool for system integration type studies, and also as an indication of the likely operation for power systems with large amounts of wind. For system integration studies it shows that, unless uncertainty is included, the costs and use of mid merit units may be underestimated. It also shows the impact that the type and frequency of scheduling has on the results for system integration studies. Regarding operation of the system, it can be seen that mid merit units are very important when dealing with wind, and cycling is increased due to the uncertainty of wind. Stochastic optimization offers better schedules in terms of costs and performance when operating the power system.

III. CYCLING OF BASE-LOAD UNITS DUE TO INCREASED WIND POWER

In [13], the impact of the variability of wind power on the operation of base-load units on the Irish system is examined. The same model is used as described in the last section, and described more fully in [8] and [10]. Here, increasing levels of installed wind power on the Irish system in 2020 were examined, from 2GW to 6GW (based on portfolios produced in [12]), and the cycling of the base-load units was examined. Cycling is defined as the operation at varying outputs, low outputs or on/off operation of electricity generating units. Cycling causes serious degradation of base-load units' components, as these units were designed to operate in a base-load fashion. This could result in long term revenue losses for the plant operators, and may affect their viability in any current or future type of electricity market. Cycling is difficult to account for when bidding into a market, due to the fact that its effects are not always evident in the short term, and therefore, the bids submitted to a market may not always account for it. The effects will only be seen after some years, by which time it may dramatically increase unit operation and maintenance costs. As installed wind power on the system increases, it was found that the cycling of the base-load units also increases, due to the variability and uncertainty of wind power. While all units will cycle more with increasing wind penetrations, only the effect on the base-load units is examined as it is assumed mid-merit and peaking units were designed for flexible operation. Regarding the base-load units, the more flexible units, such as the CCGTs were found to cycle more than the inflexible base-load units, such as the coal units.

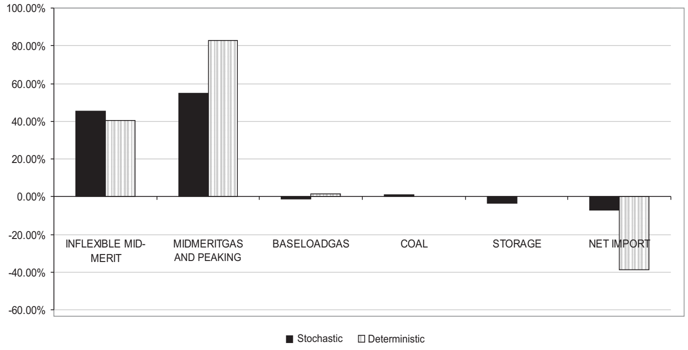

Fig. 2. Change in production of units by fuel type for different methods of scheduling

Assuming the cycling costs imposed on the base-load units would increase their start-up costs to some degree, the effect of increasing start-up costs on the operation of these units was also examined. Figure 3 shows the change in capacity factor for base-load units as the start up costs of these units are increased, with 6GW of wind installed. The results show that by increasing the start-up costs of base-load units, those units will be scheduled to operate in a more conventional base-loaded manner, which is desirable, and is shown by an increase in capacity factor. The extent of this change depends on the amount of wind power present - as wind power increases, this strategy is not as effective. By including the cycling costs in the plants start-up costs (or by just increasing the start-up cost), the plant will not be scheduled to cycle as often, thereby increasing the life expectancy of the plant and its long term revenue. Another strategy would be to change the constraints on unit operation, i.e. start-up times, minimum up times or ramping rates to more accurately reflect the fact that these constraints, if not chosen correctly, may increase the damage on the unit due to cycling. At very high penetrations of wind power, it is expected that the unit commitment and dispatch algorithms will have to be changed to avoid damage to these units and the subsequent additional costs this will cause. This may involve optimising the cycling over a longer time horizon, e.g. allowing only a certain number of start-ups in a certain time frame.

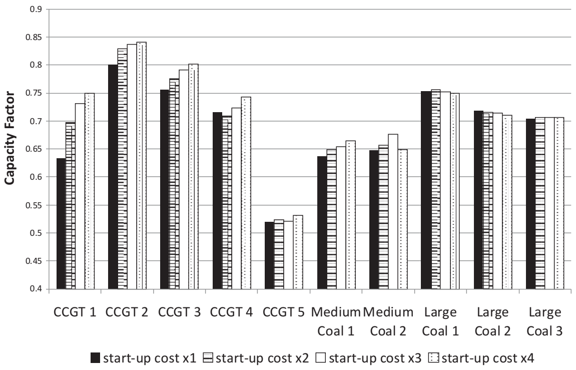

Fig. 3. Change in capacity factor of base-load units for varying start-up costs of unit

IV. INTEGRATION OF WIND FORECASTING INTO OPERATION OF POWER SYSTEM

To ensure the optimal management of electricity grids to which large-scale wind power generation is connected, new intelligent management tools are needed for addressing the variability of wind power. In the Anemos project [14], an advanced wind power forecasting system was developed which featured improved statistical estimation methods. Anemos features advanced approaches for on-line uncertainty estimation of wind power forecasts using an optimal combination of various short-term prediction models or models fed by different numerical weather prediction models. The Anemos.plus [15] project aims to build on the Anemos forecasting techniques to develop new intelligent management techniques to address the variability and uncertainty of wind power. Existing wind forecasting tools will be enhanced with new features such as probabilistic forecasting. Operational tools for management of wind and trading in electricity markets will be developed. These tools will then be demonstrated in a number of demonstration projects, concentrating on scheduling power systems, planning reserves for wind, operating storage and transmission, and trading wind power.

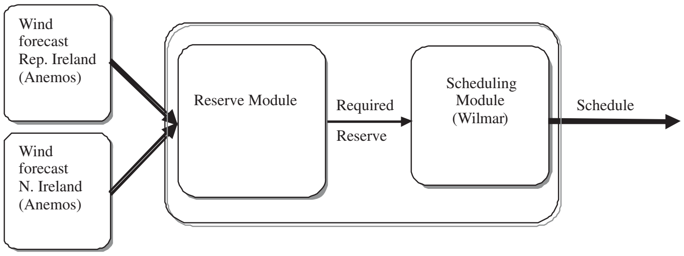

Fig. 4. Integration of the Anemos wind forecasting tool into reserve planning and scheduling of Irish system with Wilmar planning tool

In [16], the requirements for the Anemos.plus system to run operationally in a power system control center were investigated. The State of the Art in intelligent management tools for large-scale wind integration, focusing on the functional requirements in the areas of reserve, scheduling, storage and trading of wind on the market were also reported, and requirements for an intelligent energy management tool which successfully integrates large scale wind power forecasts into generation scheduling were defined. The Anemos wind power forecasts can be used to optimise the provision of reserve to ensure that the system is operated according to defined security standards most efficiently. In order to ensure that generation is dispatched according to the defined security standards and to define the appropriate operational policy, it is necessary to set out precisely how wind power forecasts should influence the amount of reserve required. In this work, the Wilmar planning tool described above has been used for scheduling of the system to integrate the wind power forecasting into the optimal generation scheduling, as illustrated by Fig. 4. This will be applied in the control centers of the Irish TSOs, Eirgrid and SONI. Using load and wind forecasts (both deterministic and stochastic), deterministic and stochastic scheduling will be produced, both on a day-ahead and intra-day time frame. These Anemos.plus schedules will then be compared to a reference case, the Reserve Constrained Unit Commitment currently in operation in the two control centers. The comparison will show the benefits of using stochastic optimization, as well as the effect of using new information to re-schedule unit commitment intra-day, as opposed to day-ahead only. While the results would be expected to be similar to the results summarized in Section 1 and in more detail in [8], there is an important distinction between the two setups. The former results can be considered describing the expected system operation based on a planning tool, while the Anemos.plus project will compare the scheduling simulation results to the actual operational schedules. Therefore, it is expected to achieve greater understanding of how stochastic optimization could be implemented in the operation of power systems. The effect of using new information to re-schedule intra-day, as opposed to day-ahead only, will also be shown.

V. CONCLUSIONS

This paper summarizes some of the work that was carried out to examine the various effects wind variability and uncertainty will have on a power system as wind penetration becomes more significant. The Irish system is used as a test case, with the WILMAR model, a stochastic unit commitment tool, used in the studies. It is shown that using this stochastic type of optimization will improve the schedules compared to those obtained using deterministic schedules. The uncertainty of wind is also shown to increase the number of start-ups and the use of mid merit gas units on a possible plant mix for the future Irish system. The cycling of base-load units is shown to increase with increased wind penetration, which will cause deterioration in these units, and possibly will need a change in market operation to mitigate this. Finally, future work that will be done to integrate the WILMAR planning tool with advanced wind forecasts in the control center of a TSO was described, which will show the benefits of using these intelligent wind management tools when operating the Irish power system. More detailed results and analysis of all three sections presented here can be found in the three papers referenced in each respective section, that is [8], [13] and [16].

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