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Authors(s)	Tuohy, Aidan, Denny, Eleanor, O'Malley, Mark
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Rolling Unit Commitment for Systems with Significant Installed Wind Capacity

Aidan Tuohy, *Student Member IEEE*, Eleanor Denny, *Member IEEE*, Mark O'Malley, *Fellow IEEE*

Abstract— As wind power penetration grows, the amount of reserve needed on the system also grows, due to the increases in the uncertainty of wind power, which grows larger as forecast horizon increases. By scheduling the system more often the amount of extra reserve to be carried to cater for wind uncertainty decreases, depending on the flexibility of plant on the system. This reduces the costs of operating the system. There is a trade off between reduced costs due to more frequent commitment, the ability of wind forecasts to be made more accurately, and the increased costs of more flexible plant. This paper examines the benefits of committing the system more frequently, and how different factors such as reliability of the system, accuracy of the forecasts and plant mix impact on this.

Index Terms— Wind power generation, Costs, Power system economics, Power generation dispatch, Unit Commitment, Wind Forecasting.

I. INTRODUCTION

The unit commitment problem aims to schedule plant to meet forecasted demand at the lowest cost. Traditional systems, with conventional, dispatchable plant, usually carry out this commitment every 24 hours. This aims to satisfy demand over a specified period - usually 24 hours- at the lowest cost. With no wind on the system, reserve, normally based on the largest infeed, is carried to cater for unit outages. Extra reserve to cater for system demand forecast errors is also scheduled. Unit commitment is carried out with a half - hourly or hourly time resolution - the expected energy over a period is forecasted and units are then scheduled to meet this load. The methods currently used for unit commitment are well established [1], [2], [3].

As wind power penetration around the world grows, the uncertainty associated with this non-dispatchable plant changes the characteristics of unit commitment. The main characteristic of wind energy which affects unit commitment is the uncertainty of wind power forecasting. This adds a stochastic element to the previously deterministic problem [4]. Various types of forecasting are used to predict wind power. These generally fall into one of three categories- physical modelling of the area, statistical methods which use historical data to predict future wind power, and a combination of these methods. These various forecasting types give different errors,

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A. Tuohy, E.Denny and M. O'Malley are with the School of Electrical, Electronic and Mechanical Engineering, University College Dublin, Dublin 4, Ireland (Ph: +353 (0)1 7161857; e-mail: aidan.tuohy@ee.ucd.ie; eleanor.denny@ee.ucd.ie; mark.omalley@ucd.ie).

however, they generally increase as forecast horizon lengthens. Much work has recently been done to improve the accuracy of wind forecasting [5]. However, there still remains an error in the forecasted level of wind power output which needs to be catered for by scheduling units to act as reserve. When wind power penetration is small, wind is normally treated as a negative load and the operating levels of other units are changed accordingly. This method of operation is known as the *fuel saver* method [6], [7]. Here, units are committed on the basis of no wind, and then backed off in real time to accommodate the wind generation available. This method results in high system operation costs. A more optimal approach would be to use wind power forecasts when scheduling the system. In [8] the author uses wind speed and load forecasts to determine system reserve margins. Due to the uncertainty in wind power forecasts, extra reserves have to be carried in the system, so that an unexpected decrease in the level of wind power output does not lead to a shortfall in meeting the system demand.

When examining the costs of committing the system more frequently, the same system reliability will have to be maintained for each case, so as to ensure a fair comparison, and also so that the trade off between reliability, cost, and other system characteristics such as plant mix can be examined. To ensure a fair comparison, the system reliability for commitment every 6 hours should be the same as the reliability of the system when committing every 24 hours.

This paper examines potential cost savings by committing units on the system more frequently, i.e. rolling commitment. Other issues surrounding the unit commitment problem with large amounts of wind are also examined. These include the cost saving or increases when the accepted reliability of the system is changed and improved wind power forecasts.

II. METHODOLOGY

A. Rolling commitment

When doing rolling commitment, instead of carrying out commitment once a day the commitment is carried out more frequently - in this paper, from every hour to every 24 hours. This means that the scheduling is done more often. For example, 6-hour rolling commitment is carried out as follows: the first commitment is carried out, then the system is 'rolled' forward 6 hours and the relevant details (wind forecasts, load forecasts, plant availability, and current state of system) are updated, before the system is once again committed. Figure 1 shows this in the case of the units being committed every 24 hours and every 6 hours over a 48 hour period.

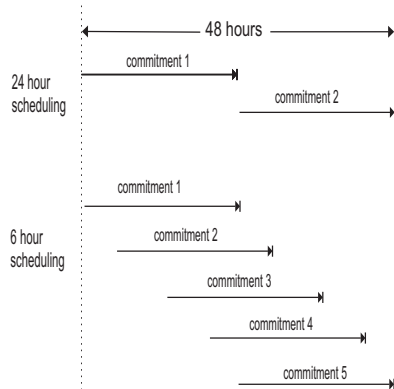


Fig. 1. Example of rolling commitment every 24 hours (top) and every 6 hours (bottom)

B. Models and software used

To study the effects of rolling commitment, two different models were used in this study. These models would commit the system, then roll forward the input data, and commit the system again. A flowchart showing operation of these models is given in Figure 2.

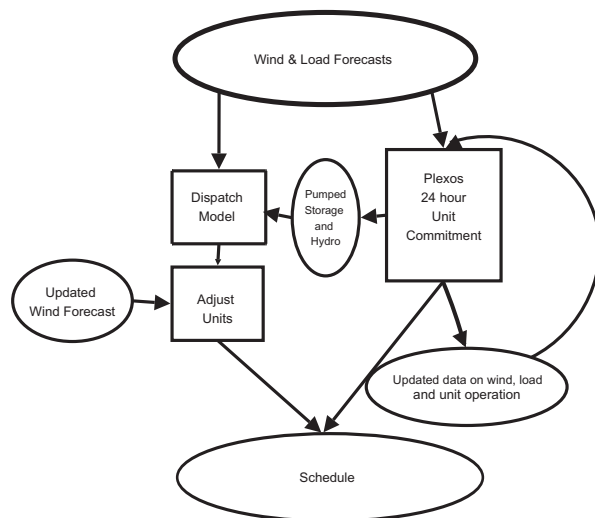


Fig. 2. Operation of two models used in study

1) *Dispatch Model*: The first model used code which had been developed for previous work [7], [9]. This code was a simplified version of unit commitment which aims to find the least cost for each hour of operation, ensuring that plant is kept within its operating limits. However, it does not take into account startup costs or ramp rates and does not try to reduce costs over the whole 24 hour period, rather it treats each hour separately.

This model first schedules units to be on or off so that the system can meet the load minus the forecasted wind. If the forecasted wind is different than the actual wind power output, this is then put into the model, and the operational levels of the units scheduled to be on are optimized with respect to the updated wind profile. This corresponds to real time

operation of the system, so units are not allowed to turn on or off during this second run -only those units scheduled, plus some open cycle gas units, are allowed to meet the demand. As the demand less wind has changed from that expected, this means units operating levels will need to be changed, and those which were supplying reserve may need to be called upon. In extreme cases, where, the wind is far greater than forecasted, wind may need to be curtailed. However, this is not examined in this initial study.

2) *Plexos*: This study also used the Plexos software package [10]. This is a unit commitment package which allows the user to model the plant on the system using various attributes such as the fuel use, startup time and costs, availability of reserve, etc. In this case, the wind on the system was treated as a negative load, and subtracted from the load before it was input to Plexos. Plexos uses either a Mixed integer solver or rounded relaxation method to solve the unit commitment problem. Mixed integer is a very accurate, reliable method of unit commitment, however it is also time consuming. Rounded relaxation gives a good approximation of this method, but takes far less time to solve, so this method was used instead. After doing an initial unit commitment, the results were taken and used to alter the input files to Plexos accordingly so that the system was 'rolled' on the necessary number of hours. For example, for 6 hour rolling commitment: after the first commitment was carried out, the dispatch schedule is examined and the units which were scheduled to be on in the sixth hour of the dispatch, the level they are at and how long each unit had been on or off for, determined. This was then fed back into the Plexos model, with an updated load forecast, an updated wind forecast, and an updated reserve requirement, as shown in Figure 2. The results for the first 6 hours of the dispatch were saved, and the next 24-hour unit commitment carried out in Plexos. Due to the temporal nature of scheduling hydro generators and pumped storage, the production profiles for these plant were produced in Plexos and fed as an input into dispatch model.

C. Reliability and forecast errors

In [11] the reliability criterion is defined as being the number of load shedding incidents (LSI) tolerated per year. This criterion is maintained through the allocation of reserve. For this analysis, the reserve needed is dependent on the largest infeed, plus the additional reserve to cover for the uncertainty in forecasted wind power. The extra reserve for wind depends on the forecast error, which changes as forecast horizon increases. The error in forecast horizon is examined in [12]. This shows that, as forecast horizon increases, so too does the error in wind power forecasting. This means that the amount of reserve the system carries decreases as the time between scheduling decreases. The reserve was calculated using methods described in [11]. Reserve for each hour is calculated by multiplying the amount of wind forecasted for that hour by a number based on the standard deviation of forecast error for the relevant number of hours ahead. This means that the amount of reserve needed over the course of the day, if the amount of wind energy being produced is the

same, will be greater for a system committing every 24 hours than one committing its units every 2 hours. For example, the amount of reserve needed for a forecasted level of 800MW of wind power, and a largest infeed of 360MW, is shown in Figure 3 as a function of forecast horizon, for a fixed reliability.

Load forecasts also have an error associated with them. However, due to the repetitive nature of the daily load profile, these are not especially dependent on time horizon, and have approximately the same standard deviation throughout the day [11].

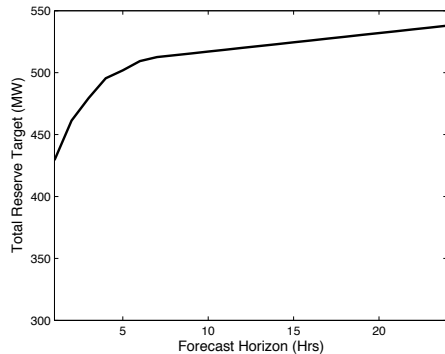


Fig. 3. Additional reserve due to 800MW of wind as a function of forecast horizon

III. APPLICATION TO IRISH ELECTRICITY SYSTEM

The method of rolling commitment described above was applied to the Irish system, and various factors associated with rolling commitment were examined.

A. All-island system

The all Ireland electricity system consists of two systems, the Northern Ireland and Republic of Ireland. These are interconnected using a 400MW ac link. At present, plans are being finalised for the Single Electricity Market (SEM), which will operate what was until now two separate systems as one system, which is what this paper examines. The SEM will be a gross pool market with centralized commitment [13]. This centrally committed market is something many electricity markets are moving away from, but it has been shown in [14] and [15] that centralized unit commitment is almost identical to a model which allows generators to bid incrementally and self-commit. Centralized unit commitment can be used for predicting operating decisions in decentralised markets [14]. This model could therefore represent alternative model designs as well as the centralised gross pool market used in this model [9].

The installed capacity for the single Irish system is approximately 7500MW. There is currently approximately 800-900MW of wind power installed, with plans to increase this in the next decade. There is currently just one 500MW HVDC interconnector to Scotland. Historical data is used in this paper for interconnector exchanges. For this study, one week's load

data was used, corresponding to a week in March, which would be expected to be somewhere between the peak load in winter and minimum load in summer. Fuel costs were obtained from [16]. Three weeks of wind profiles, also obtained from [16], were used. Between them, these profiles can be seen to reflect many of the wind profiles that would be expected over the course of the year - where wind increases quickly, decreases quickly, stays at a high level, etc. They were then scaled so that they would reflect a wind series for 1500MW of installed capacity, shown in 4. The rest of the power system is based on the current (2007) power system. Data for the other units was taken from [16]. For this study 75MW of error was assumed in the load forecast for the Irish electricity system.

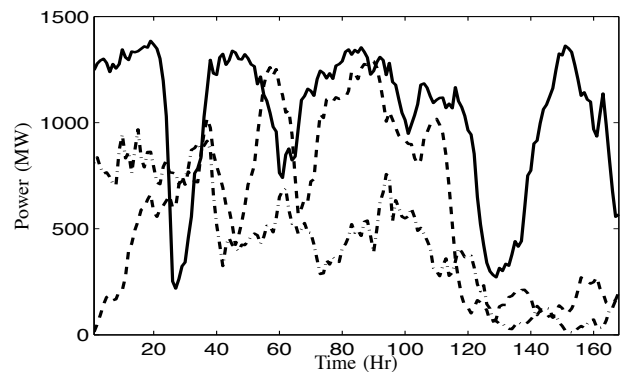


Fig. 4. Wind profiles used in study

IV. RESULTS AND DISCUSSION

The system described in Section III-A was examined. Various types of system operation, with different ways of utilizing wind forecasts, were examined as described in section IV-A. The costs of operating the system for each of these was then found using the models described in Section II-B.

A. Wind forecasting and generation of wind profiles

Various methods of wind power forecasting were used in this study. Five cases, each corresponding to a different type of forecasting, were examined.

1) *Perfect forecasting (a)*: Perfect forecasting was examined in two ways. The first of these is where the forecasting is known to be perfect - i.e., no extra reserve is needed to maintain system reliability.

2) *Perfect forecasting (b)*: The second method of perfect forecasting is one in which reserve is allocated based on the wind forecasting error. The standard deviation of error, illustrated in Figure 5 as forecasting, is multiplied by the amount of wind forecast to find reserve. This would correspond to a situation where the forecast is assumed to be imperfect, but turns out to be 100% accurate.

3) *Imperfect forecasting ('real case')*: To examine imperfect forecasting, the standard deviation in Figure 5 was also used. Here, the forecast was generated using a random number based on the standard deviation in a particular hour of the

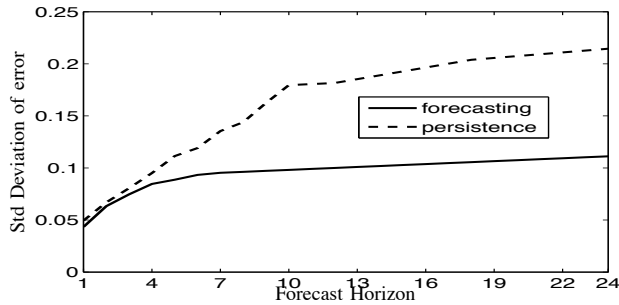


Fig. 5. Standard deviation of wind power forecast error versus forecast horizon for forecasting and persistence method

forecast. This was then multiplied by the actual wind power to give a forecasted wind power. This ensured that the standard deviation of forecast error was lower at times closer to the forecast than at a time hours later than the forecast was made. When carrying out the study, the standard deviations were increased and decreased to examine effects of more and less accurate forecasting.

4) *Persistence forecasting*: Persistence forecasting is forecasting that the wind power being produced for the entire forecasting period stays the same as in the hour of the forecast. This means that, for commitment every 24 hours, the wind power is forecasted as being at the same level in hour 12 or hour 20 as it is in hour 1. To calculate the reserve needed for persistence forecasting, the standard deviation of forecast error for persistence forecasting was examined using the wind series in [16] and is shown in Figure 5.

5) *Fuel Saver*: The system was also examined if no wind forecasting was performed - i.e., using what is known as the *fuel saver* method. This method is explained in Section I.

B. Costs of the system operation

The first results to be taken from this study concerned the cost savings associated with committing the system more often. Dispatches for each frequency of commitment were produced for the three separate weeks of wind profiles by the models described in Section II-B and costs were calculated. These were then added together to find the total cost of generation. The Plexos model described in Section II-B.2 was used with perfect wind forecasting and reserve based on forecast error. Errors in forecasting cannot be accounted for in Plexos so these were examined in the dispatch model.

The total costs for the system operation are shown in Figure 6 for the various wind forecasting methods described in Section IV-A. These are shown as cost, but do not include startups costs. It can be seen that the least expensive way to operate the system would be if wind forecasting was perfect, and it was known to be perfect, i.e. no extra reserve was carried for wind generation. When wind forecasting is used, the cost increases as the frequency of unit commitment decreases. If the wind turns out as forecasted, less cost is incurred than if it is not perfect. Persistence forecasting is seen to be more expensive again, while the fuelsaver method, where no forecasting is used, can be seen to be the most expensive method up to

approximately 15 hours when wind is on the system. This would be expected, as more units would be switched on if wind was not regarded in the initial commitment. It can also be seen that persistence is more expensive than the fuelsaver method if commitment is done less than approximately every 16 hours. This can be explained by the fact that wind generation 24 hours after the commitment is likely to be very different than at the time of commitment. The generation costs incurred when using the Plexos software package and perfect forecasting can be seen to be higher than using the dispatch model. This is explained by the fact that Plexos minimises startup costs, but the dispatch model does not take into account temporal constraints. The costs of the system operation with no wind installed is also shown, to give an illustration of the savings due to wind being on the system.

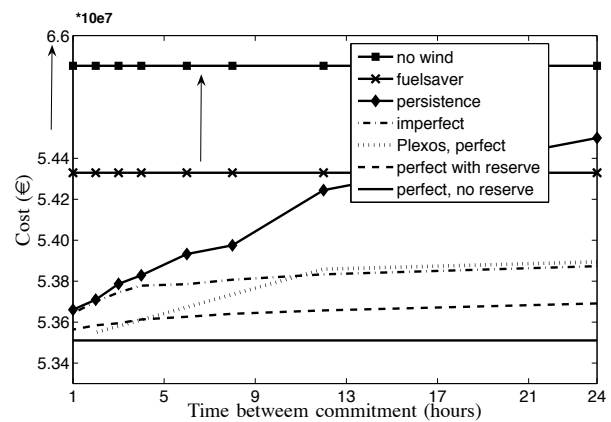


Fig. 6. System operation costs for 3 weeks versus time between commitment for different forecasting methods

Figure 7 shows the costs of operating the system over three weeks when startup costs are included. Again, perfect forecasting is the least expensive way to operate the system, and the fuelsaver method is the most expensive. These two costs can be thought of as bounds showing the benefits of increased forecast accuracy, with fuelsaver indicating no accuracy, and the perfect forecast not needing any extra reserve. The costs for perfect forecasting with extra reserve carried can again be seen to increase as frequency of commitment decreases. As expected Plexos is less expensive than the dispatch model when startup costs are included, due to the fact that Plexos minimises overall cost.

When the dispatch model is used with imperfect and persistence forecasting, it can be seen that operating costs oscillate rather than follow a clear trend when frequency of commitment decreases. This is due to the fact that startup costs are not being minimised and so expensive units are being switched on for short periods of time. As Plexos minimises these costs, it was decided to use the unit commitment schedules produced by Plexos as an input to the second part of the dispatch model, i.e. Plexos determines commitment based on perfect forecasting. The discrete commitment decisions are then fed into the dispatch model with an updated forecast and economic dispatch decisions are made accordingly. The resulting costs

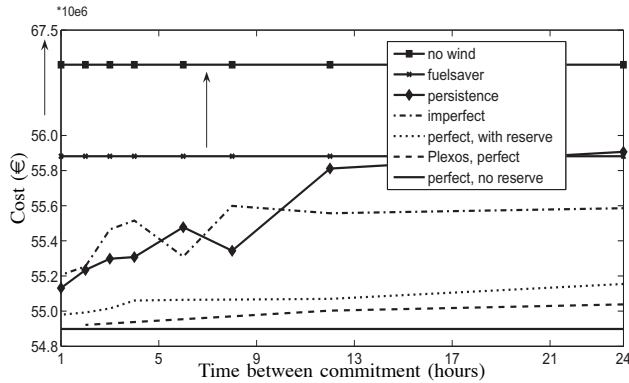


Fig. 7. System operation costs for 3 weeks versus time between commitment for different forecasting methods when startup costs are included

are shown in Figure 8, along with costs for perfect forecasting with and without reserve and operating the system with no forecasting, the fuelsaver method.

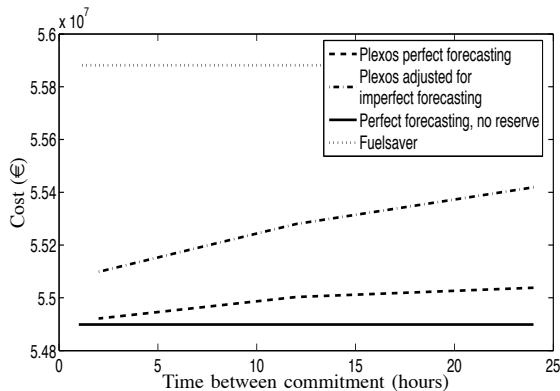


Fig. 8. System operation costs for 3 weeks versus time between commitment for Plexos when forecasting errors included

From this, it can be seen that the costs increase as the time between commitments increases. It can be seen that the costs savings of using forecasting with a standard deviation of error as shown in Figure 5 is approximately €700,000 over 3 weeks, if committed every 6 hours. The cost savings for perfect forecasting compared to no forecasting is €1,000,000. This indicates that improving forecast accuracy can lead to savings of approximately 40%. This is higher than the 25% figure from the New York state wind study [17]. However, that study uses state-of-the-art wind forecasting. This study uses historical performance of wind forecasting, and the standard deviation of error is higher than would be expected in state of the art forecasting. Also, that study is based on the New York state, a different system with different type of plant. The New York study was based on 3300MW of installed wind, 10% of the system's peak load of 33000MW, whereas this study has 1500MW of wind, approximately 20% of the peak load of 6700MW during the three weeks studied. It would be expected that, if this study were carried out using state-of-the-art forecasting over a full year, the answers would be

closer, however, the fact that wind penetration in this study is higher would be expected to increase the benefit of perfect forecasting.

V. CONCLUSIONS

This work was an initial study of rolling commitment. It has set out a methodology for rolling commitment and examined it using 2 different models. As expected it was found that operating costs increase as the system is committed less often. Different wind forecasting methods were also examined, and the costs of operating the system with these were investigated. The potential savings of increasing the accuracy of wind were indicated in these results. More work is needed to ensure that the results are as accurate as possible. The models should be run over a full year to ensure that the system is examined in different periods of the year, with different load and wind profiles than the narrow three weeks examined here. The Plexos model, in particular, due to its long run time, needs to be explored more.

The methodology will also be used to examine other characteristics of operating power systems with significant wind penetration. The reliability criterion for allocating reserve on the system and committing units is something that can be examined further. The plant mix on the system is important when attempting to integrate wind onto the system, and various plant mix setups can be examined.

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Aidan Tuohy received a B.E. degree in Electrical and Electronic Engineering from University College Cork. He is currently studying for a Ph. D. degree in the Electricity Research Centre, University College Dublin with research interests in the integration of wind energy in power systems



Eleanor Denny received a B.A. degree in Economics and Mathematics and a M.B.S. degree in Quantitative Finance from University College Dublin. She has just completed a Ph. D. degree in the Electricity Research Centre, University College Dublin on the costs and benefits of the grid integration of wind generation.



Mark O'Malley received B.E. and Ph. D. degrees from University College Dublin in 1983 and 1987, respectively. He is the professor of Electrical Engineering in University College Dublin and is director of the Electricity Research Centre with research interests in power systems, control theory and biomedical engineering. He is a fellow of the IEEE.