Title	Current methods to calculate capacity credit of wind power, IEA collaboration
Authors(s)	Ensslin, Cornel, Milligan, Michael R., Holttinen, Hannele, O'Malley, Mark, Keane, Andrew
Publication date	2008-07
Publication information	Ensslin, Cornel, Michael R. Milligan, Hannele Holttinen, Mark O'Malley, and Andrew Keane. "Current Methods to Calculate Capacity Credit of Wind Power, IEA Collaboration." IEEE, July 2008. https://doi.org/10.1109/PES.2008.4596006.
Conference details	Paper presented at IEEE Power and Energy Society 2008 General Meeting, July 20-24, 2008, Pittsburgh, PA, USA
Publisher	IEEE
Item record/more information	http://hdl.handle.net/10197/3213
Publisher's statement	Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.
Publisher's version (DOI)	10.1109/PES.2008.4596006

Current Methods to Calculate Capacity Credit of Wind Power, IEA Collaboration

Cornel Ensslin, Michael Milligan, *Member, IEEE* Hannele Holttinen, Mark O'Malley, *Fellow, IEEE* and Andrew Keane, *Member, IEEE*

***Abstract*— Power systems must have enough generation to meet demand at each moment of the day. In addition, they must also have enough reserve to deal with unexpected contingencies. The increase in the penetration of wind generation in recent years has led to a number of challenges in the calculations required to facilitate wind generation while maintaining the existing level of security of supply. A key calculation in this process is the capacity credit or value of wind generation. Capacity credit/value of wind generation can be broadly defined as the amount of firm conventional generation capacity that can be replaced with wind generation capacity, while maintaining the existing levels of security of supply. This topic has been the subject of much study and debate in recent times. The aim of this paper is to give an overview of the state of the art in this area, in particular with regard to the work of IEA WIND Task 25 and the work detailed in its state of the art report on the design and operation of power systems with large amounts of wind power.**

***Index Terms*— Wind Power, Capacity Credit, Power system operation**

I. INTRODUCTION

POWER system reliability consists of system security and adequacy. A power system is adequate if there is a sufficient installed power supply to meet customer needs. A system is secure if it can withstand a loss (or potentially multiple losses) of key power supply components such as generators or transmission links. This paper focuses on the impact that wind generation has on generation adequacy. The analyses for generation adequacy are made several months or years ahead and associated with static conditions of the system. This can be studied by a chronological generation load model that can include transmission and distribution or by probabilistic methods. The estimation of the required production needs includes the system demand and the availability data of production units.

Capacity credit (sometimes called capacity value) is the contribution that a given generator makes to overall system adequacy. Even the availability of conventional generation is not assured at all times because there is always a nonzero risk of mechanical or electrical failure. Because reliability is expensive it is common to adopt a reliability target for the system. The capacity value of any generator is the amount of additional load that can be served at the target reliability level with the addition of the generator in question.

An R&D Task titled Design and Operation of Power Systems with Large Amounts of Wind Power has been formed within the IEA Implementing Agreement on the Cooperation in the Research, Development and Deployment of Wind Turbine Systems (www.ieawind.org) as Task 25. This paper gives an overview of the state of the art in this area, in particular with regard to the work of IEA annex Task 25 and the work detailed in its state of the art report on the design and operation of power systems with large amounts of wind power [1].

The general approaches and metrics used to assess wind power capacity effects are discussed in Section II. Sections III and IV detail chronological and probabilistic approaches respectively. A summary of the results of the state of the art report is given Section V.

II. APPROACHES TO ASSESSING GENERATION CAPACITY EFFECTS

Although there are several methods used to calculate wind capacity value, most methods are based on power system reliability analysis methods. The criteria that are used for the adequacy evaluation include the loss of load expectation (LOLE), the loss of load probability (LOLP) and the loss of energy expectation (LOEE), for instance. LOLP is the probability that the load will exceed the available generation at a given time. This criterion gives an idea of the possibility of system malfunction but it lacks information on the importance and duration of the outage. LOLE is the number of hours, usually per year, during which the load will not be met over a defined time period. One key capacity value metric is effective load carrying capability (ELCC). This metric is calculated by calculating a suitable reliability measure such as loss of load probability or loss of load expectation for the year.

During the course of system operation through the year, generating units can be in one of several states. Units are scheduled for maintenance at regular intervals, and this is typically scheduled during noncritical system periods. However, it is always possible that any generator could fail unexpectedly at any time of the year. The unexpected nature of these forced outages is the primary concern and focus of reliability analysis.

Contingency reserves (sometimes called disturbance reserves) are provided to ensure against system collapse in the event of a forced outage. System adequacy assessments must take planned outages and forced outages into account, although the different types of outages are treated very differently in

This work has been carried out as part of an R&D Task entitled "Design and Operation of Power Systems with Large Amounts of Wind Power". It has been formed within the "IEA Implementing Agreement on the Cooperation in the Research, Development and Deployment of Wind Turbine Systems" as Task 25. This R&D task will collect and share information on the experience gained and the studies made on power system impacts of wind power, and review methodologies, tools and data used (http://www.ieawind.org).

the reliability model. Additional considerations includes hydro system operation, both run of river and reservoir hydro power (and pumped storage, if available). Other system services may also be quantified in the reliability model.

III. Chronological Reliability Models

Capacity credit is a probabilistic value that is derived from system observation in the time domain using several time series that include load, wind, and conventional capability. The different ways of transition from the chronological values to frequency distributions provide an essential distinction between approaches for the calculation of capacity credit. In the time step or chronological simulation approach the hourly or 15 min values of the total wind power production are subtracted from hourly or 15 min load data and the residual power is assigned to the available conventional generation units by a scheduling or reliability model, e.g. the National Grid model [2]

The chronological approach requires:

1) Correct load time series for the period of investigation
2) Unbiased wind power time series for the same period as the loads
3) A complete inventory of conventional generation units capacity and forced outage rates
4) Target reliability level.

To calculate the capacity value of wind, three reliability model runs are required. Each run may require several iterations to achieve the various reliability targets. First, the model is run to ensure that the reliability target can be attained. If the system does not achieve this reliability level, generation must be added or load decreased (or both changed) to achieve the target. Second, the wind generation is added to the modelled system. The new higher reliability value (lower LOLP) is recorded, and the wind is then removed from the model. Third, either a benchmark unit is added to the system or the load is increased so that the reliability level matches the one from the second step. The increase in load (or benchmark generation) from this step is the capacity value of wind.

Capacity value, as measured by a reliability metric such as ELCC, is quite sensitive to the timing of wind energy delivery relative to peak load periods. Recent work in the U.S. has utilized high quality wind data that is from the same time period as the load [3]. This provides the most realistic assessment of winds contribution to system adequacy if these time synchronized data series are used as inputs to a chronological reliability model. Wind and load vary from year to year, so it is important to perform a multi year analysis using time synchronized wind and load data if possible. Otherwise, sequential Monte Carlo can be used as long as the Monte Carlo method can retain the diurnal and seasonal characteristics of the wind generation through time.

IV. Probabilistic Reliability Methods

While hourly load and wind generation profiles for at least one year are essential prerequisites for wind power capacity credit calculations, a number of studies such as the DENA study have been exposed to a lack of load profiles for the power system investigated. As an alternative, several of those studies used a probabilistic representation of wind generation for the capacity credit calculation (also called load duration curve method).

The reliable capacity of the system including wind is determined by convolving the wind power probability density function with conventional power plant probabilities. In the studies, [4], [5], all installed wind power has been defined as one wind power unit. In order to determine the power probability function of this aggregated wind power block, it is again assumed that long term statistics on wind power availability deliver its probability to be available during hours of significant system risk (high LOLP or equivalent). Reliability models look for periods of time with significant risk. The capacity credit is calculated as the difference between the two reliability curves at the target risk level: the power system without and with wind energy.

Weather influences both electricity consumption and wind power generation. Although it may be difficult to directly calculate the statistical correlation between them, there are certainly complex interrelationships between wind and load. Even in cases with wind separated from load centres by relatively large distances, the weather correlation may consist of a complex lag structure that varies based on time and weather conditions. Because of this, it is critically important to use wind and load profiles that result from a common weather driver to calculate wind capacity value. In a practical sense this means that at least one year of hourly wind generation and load must be obtained from the same calendar year. Because wind generation profiles and energy capture can vary from year to year, it is preferable to assess wind capacity value on multiple years of time synchronized wind and load data. The probabilistic approach immediately converts wind power time series into probability density of power levels, to be combined with the probabilities of conventional power stations availabilities. A main reason to apply this approach can be the lack of appropriate chronological data. However, the probabilistic approach will not be informed by variability of wind generation and is not as accurate as the chronological approach.

The probabilistic approach requires:

1) Correct load time series for the period of investigation
2) Wind power probability density, varying by month or season that can accurately represent the same period as the loads
3) A complete inventory of conventional generation units capacity and forced outage rates
4) Target reliability level

If a probabilistic representation of wind generation is used it should be consistent with the load year(s) used in the analysis. An analysis that uses wind and load data from different years will yield invalid results. Many reliability models have the capability to perform Monte Carlo analysis, in which random states of the conventional generation are sampled repeatedly. Even though this is computationally expensive, it can be valuable to more accurately assess the risk of alternative system states. However, the intrinsic Monte Carlo ability that is provided by most, if not all, reliability models is inadequate for wind because of the more complex probabilistic structure of wind power generation.

V. Summary of Results of State of Art Report

The capacity credit of wind power answers questions like: Can wind substitute for other generation in the system and to what extent? Is the system capable of meeting a higher (peak) demand if wind power is added to the system? This is related to the long term reserve or planning reserve that power systems carry.

Wind generation will provide some additional load carrying capability to meet projected increases in system demand. The capacity factor and thus the capacity credit is fundamentally linked with the quality of the wind regime at each of the sites. The contribution can be up to 40% of installed wind power capacity (in situations with low wind penetration and high capacity factor at times of peak load). It can also be as low as 5% in higher wind penetrations, low capacity factor at times of peak load or if regional wind power output profiles correlate negatively with the system load profile. Aggregation of larger geographical areas will result in the capacity credit being higher.

The wind capacity credit in percent of installed wind capacity is reduced at higher wind penetration, but depends also on the geographical smoothing. In essence, it means that the wind capacity credit of all installed wind in Europe or the US is likely to be higher than those of the individual countries or regions, even if the total penetration level is as in the individual countries or regions. Indeed, this is true only when assuming that the grid is not limiting the use of the wind capacity, i.e. just as available grid capacity is a precondition for allocating capacity credit to other generation.

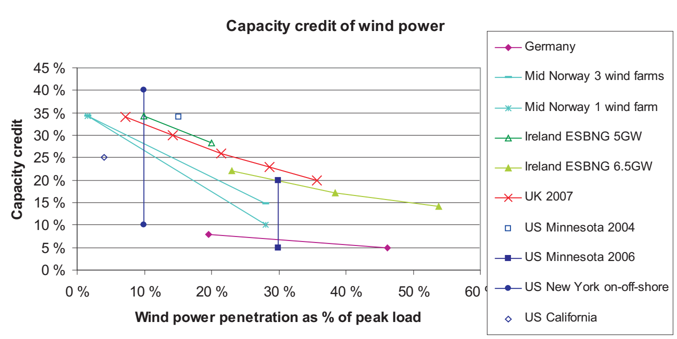

Fig. 1. Capacity Credit of Wind Power

Results for the capacity credit of wind power are shown in Figure 1 [3], [4], [6]–[8]. One reason for the considerable spread in results arises from the wind regime at the wind power plant sites and the dimensioning of wind turbines. This is one explanation for the low German capacity credit seen Figure 1. For near zero penetration level, all capacity credit values are in the range of the capacity factor of the evaluated wind power plant installations. The correlation of wind and load is very beneficial, as can be seen in the case of US New York offshore capacity credit being 40%. Results for the capacity credit of wind power showed a considerable spread between countries and approaches. One reason for different resulting levels arises from the wind regime at the wind power plant sites and the dimensioning of wind turbines.

References

[1] IEA Task 25, "Design and operation of power systems with large amounts of wind power state-of-the-art report," *VTT Publications 82*, 2007. [Online]. Available: http://www.ieawind.org/AnnexXXV.html/

[2] G. Giebel, "On the benefits of distributed generation of wind energy in europe," Ph.D. dissertation, 2000.

[3] M. Milligan and K. Porter, "The capacity value of wind in the united states: Methods and implementation," *Electricity Journal*, no. 2, pp. 9199–9204, March 2005.

[4] "Planning of the grid integration of wind energy in germany onshore and offshore up to the year 2020," Deutsche EnergieAgentur, Tech. Rep., March 2005. [Online]. Available: http://www.dena.de/themen/thamareg/projektarchiv/

[5] ILEX Energy and G. Strbac, "Quantifying the system costs of additional renewables in 2020," Tech. Rep., 2002. [Online]. Available: http://www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf/

[6] ESB National Grid. (2004, Feb.) Impact of wind power generation in ireland on the operation of conventional plant and the economic implications. [Online]. Available: http://www.eirgrid.com/

[7] G. Strbac, A. Shakoor, M. Black, D. Pudjianto, and T. Bopp, "Impact of wind generation on the operation and development of the uk electricity systems," *Electrical Power Systems Research*, vol. 77, no. 9, pp. 1143–1238, 2007.

[8] J. Tande and M. Korpås, "Impact of large scale wind power on system adequacy in a regional hydrobased power system with weak interconnections," in *Nordic Wind Power Conference*, Finland, May 2006.