Proceedings of the ASME 2014 Power Conference
POWER2014
July 28-31, 2014, Baltimore, Maryland, USA

POWER2014-32144

JUSTIFICATION FOR LONG DISTANCE TRANSMISSION

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ABSTRACT

Wind is always blowing somewhere. From this perspective, a logical hypothesis is that a constant power base load generator can be created by using long distance transmission to connect distant wind farms. This paper tests that hypothesis by putting numbers to it. A scenario of interest is the interconnection of wind farms on the East Coast (PJM Interconnection) with wind farms in the Midwest (MISO, the Midcontinent Independent System Operator). Wind is characterized by the Cumulative Distribution Function (DF). Effective Load Carrying Capacity (ELCC) is a metric that defines system capacity, the load that a system can deliver at an acceptable level of reliability. This paper compares standalone wind on PJM with standalone wind on MISO and with standalone wind for interconnected PJM + MISO. A fourth comparison shows the theoretical limit, what could be achieved if wind from PJM and MISO were independent of each other. This DF is calculated from data by randomly scrambling one of the time series. This analysis quantifies the capacity and overbuilding benefits of long distance transmission.

NOMENCLATURE

DF – Cumulative Distribution Function. The probability that a system value is greater (or less) than the abscissa.
EirGrid – The Irish national grid.
ELCC – Effective load carrying capacity, a statistical technique for measuring system capacity.
LOLE – Loss of Load Expectation, a reliability criterion, typically one-day-in-ten-years or 0.00027.
MISO – Midcontinent Independent System Operator
PJM – PJM Interconnection, LLC, The largest independent system operator

INTRODUCTION

The objective of this paper is to determine if long distance transmission between east coast wind farms (PJM) and Midwest wind farms (MISO) enables standalone wind to have system capacity.

Long distance transmission has been justified on the basis of transmitting power from where it is generated to where it is needed. A much stronger argument could be made if long distance interconnection increased the capacity of a system. That is, if wind is added to a system, can the utility reduce the capacity of conventional generators and still maintain the same level of reliability? Wind can contribute to system capacity in two ways: 1) If standalone wind has capacity when measured by traditional reliability metrics or 2) If the combination of wind with the traditional generators on the grid somehow increases system capacity. In Wind System Reliability and Capacity, Pavlak & Windsor [1] address the latter question. This paper is directed at the former question.

An intuitive argument is that wind is always blowing somewhere. If this is true, then the time series from a standalone wind system would with long distance interconnection never drop to zero and the standalone wind system would contribute to overall system capacity. The amount of the contribution can be measured by conventional Effective Load Carrying Capacity. To test this hypothesis, this paper addresses the question of whether an interconnection between PJM and MISO results in a standalone wind system with a firm, conventionally defined capacity.

METHODOLOGY

The methodology used in this paper was developed in a **Power2014** paper by Pavlak & Windsor [2]. Figures 1&2 below are taken from that paper.

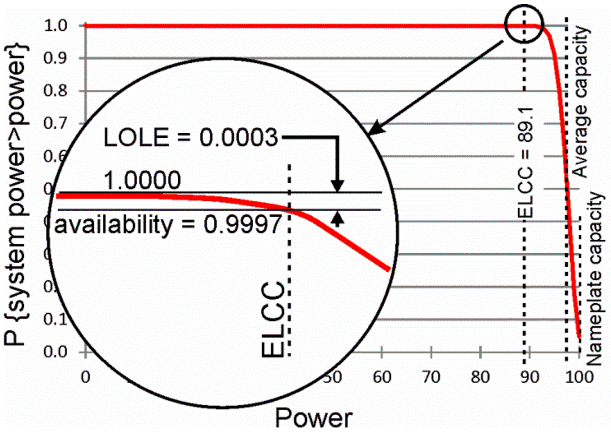

Figure 1: Calculating System ELCC

Effective Load Carrying Capacity (ELCC) is a statistical technique that was developed to calculate the capacity of electric power systems [3]. The red curve in Figure 1 above is a Cumulative Distribution Function (DF) a 100 independent generators. The ELCC is the power level at which the system can be said to have adequate reliability. The adequacy of the reliability is determined by a reliability factor known as the Loss Of Load Expectation (LOLE).

A typical LOLE for electrical systems is one-day-in-ten-years [4]. This does not correspond to a blackout or system failure, but an inability to satisfy load in which the load would have to be managed some other way such as demand management or importing power. In dimensionless terms, one-day-in-ten-years is equivalent to a LOLE of 1/3650 or 0.00027 (rounded to 0.0003). Alternatively, this corresponds to a loss of load for 0.0003 * 365 days * 24 hours/day = 2.6 hours/year. Any standalone wind system where wind production drops to zero for more than 2.6 hours/year has no system capacity. However, since any wind system has a parasitic electrical load, a more realistic evaluation might be to consider any wind system that drops below 0.5% of nameplate for more than 2.6 hours/year to have no system capacity.

Figure 2 shows the DFs calculated for several standalone wind systems; the solid red curve is the reference, the same 100 independent generator system depicted in Figure 1.

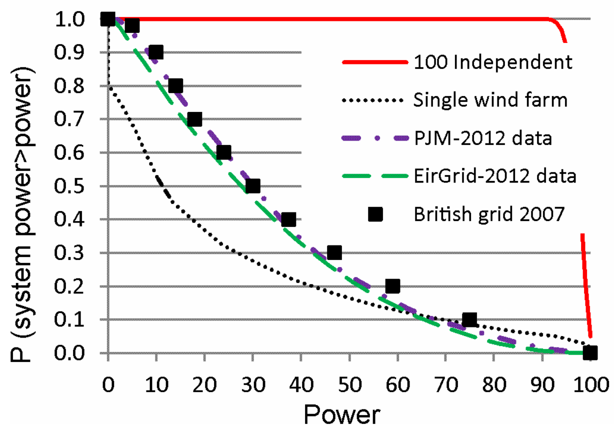

Figure 2: DFs for Standalone Wind Systems

The dotted black curve is the DF for a single (Vestas 3 MW) wind farm calculated by assuming Rayleigh wind fluctuations and an average capacity of 0.25. The purple dash-dot curve is the DF for standalone wind on the PJM grid for 2012. The long-dash green curve is the DF for standalone wind on EirGrid for 2012. The boxes are DF data reported by Cox for the British market in 2007[5].

The DFs for the standalone wind systems (PJM, EirGrid, and British grid) are all remarkably similar to each other, but drastically different from the 100 independent generator system. This shows that wind generators must be treated differently than classical generators.

The determination of the ELCC comes from the upper left hand corner of Figure 2.

INTERCONNECTED PJM+MISO

Using hourly averaged wind data from 2012, Cumulative Density Functions (DFs) were created for each of the time series (PJM and MISO) [6],[7] and the summation of the time series on an hour by hour basis (PJM + MISO). The wind data was given by both companies for every hour beginning on January 1st at 12:00AM of 2012 and ending on January 1st at 12:00AM of 2013. Inconsistencies due to time zone differences and daylight savings time were accounted for. PJM was also building wind during the year; this was corrected for by identifying the peak wind in the fall and spring and multiplying the spring data by the ratio to ensure it had the same nameplate as the fall as an approximation for the increased production. The resulting DFs are shown below in Figure 3.

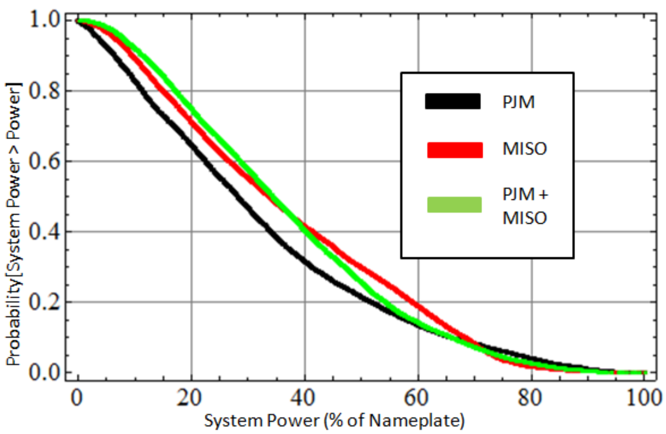

Figure 3: DFs for PJM, MISO, and PJM + MISO

The blue curve is the DF for standalone wind on the PJM grid in 2012, the red curve is the DF for standalone wind on the MISO grid in 2012, and the green curve is the DF for standalone wind on a theoretical interconnected PJM-MISO grid in 2012.

As outlined in Figure 1 in the methodology section, the ELCC can be determined by finding the power level where the DF crosses an availability of 0.9997 (corresponding to a LOLE of 0.0003). The determination of the ELCC comes from the upper left hand corner of Figure 3, depicted below in Figure 4.

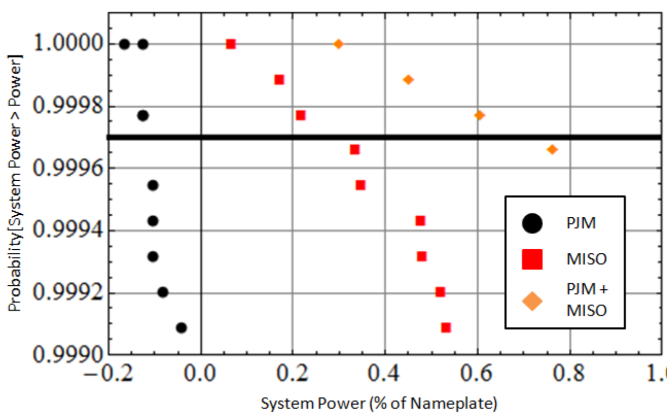

Figure 4: Calculating System ELCC

The DFs for standalone wind are represented in the same manner as in Figure 3 and the black line corresponds to an availability of 0.9997. Ergo, the power (% of nameplate) where these DFs cross this availability are the ELCC values. For this scenario, the ELCC values were determined to be: PJM = 0%, MISO = 0.29%, and PJM + MISO = 0.69% (values given in % of nameplate).

The PJM values include negative system powers as they account for the parasitic electrical loads inherent in wind systems. As the MISO data does not account for these losses, any wind system dropping below 0.5% of nameplate for more than 2.6 hours/year will be said to have no capacity. By this metric, both PJM and MISO can be said to have negligible capacity. However, the PJM + MISO interconnected system does have defined system capacity as it only drops below 0.5% of nameplate for 2 hours/year (based on 2012 data).

BALANCED INTERCONNECTED PJM+MISO

Another pertinent exercise is balancing the PJM and MISO data such that they have the same average power. By taking the ratio of the unbalanced averages and multiplying all of the PJM data by the result, the same three time series were reconstructed.

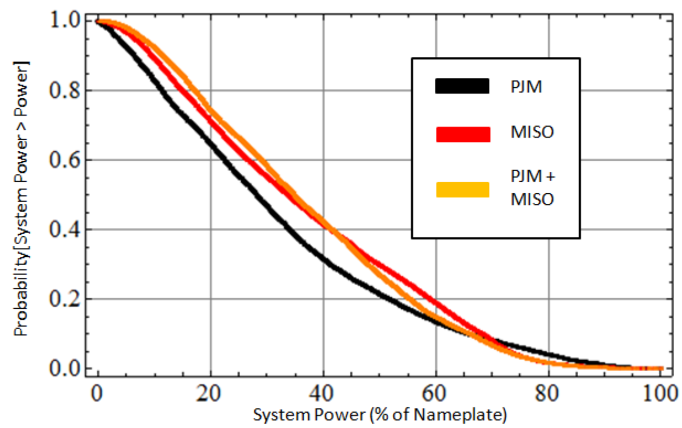

Figure 5: Balanced DFs for PJM, MISO, and PJM + MISO

The blue curve is the balanced DF for standalone wind on the PJM grid in 2012, the red curve is the balanced DF for standalone wind on the MISO grid in 2012, and the green curve is the balanced DF for standalone wind on a theoretical interconnected PJM-MISO grid in 2012.

In an identical fashion to the unbalanced DFs, the ELCC values were determined using the upper left hand corner of Figure 5, as depicted below in Figure 6.

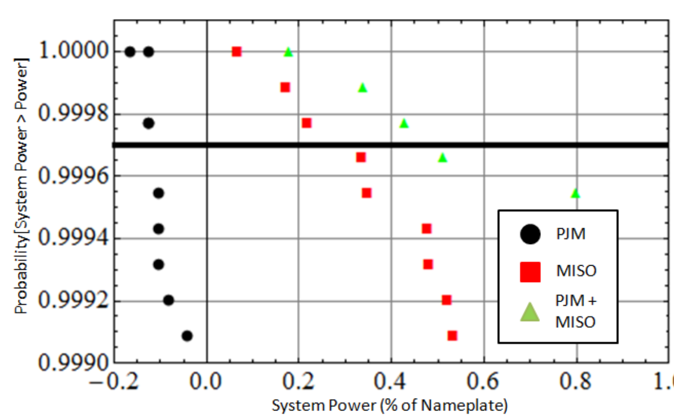

Figure 6: ELCC Calculation for Balanced DFs

The balanced DFs for standalone wind are represented in the same manner as in Figure 5 and the black line corresponds to an availability of 0.9997. Ergo, the power (% of nameplate) where these DFs cross this availability are the ELCC values. For this scenario, the ELCC values were determined to be: PJM = 0%, MISO = 0.29%, and PJM + MISO = 0.49% (values given in % of nameplate). In the balanced case, the PJM + MISO interconnected has more than 2.6 hours/year in which the power drops below 0.5% of nameplate as do the PJM and MISO time series. As a result, all three cases can be said to have negligible system capacity.

A summary of the ELCC values for both scenarios is provided in Table 1 below.

Table 1: Summary of ELCC Values

	PJM	MISO	PJM+MISO
Unbalanced	0.0%	0.29%	0.69%
Balanced	0.0%	0.29%	0.49%

STATISTICALLY INDEPENDENT COMBINATION

Pavlak & Winsor showed that the parallel connection of a large number of independent generators results in a system availability that is greater than that of any one generator. It is the statistical independence that makes a difference.

Wind farms are not independent of each other and exhibit correlations with space, time and load. So a pertinent question is whether the MISO and PJM wind farms are independent of each other.

By scrambling (disordering) the PJM data before summing it with the MISO data, a theoretical data set was created that predicts the behavior of PJM and MISO supposing they are independent systems.

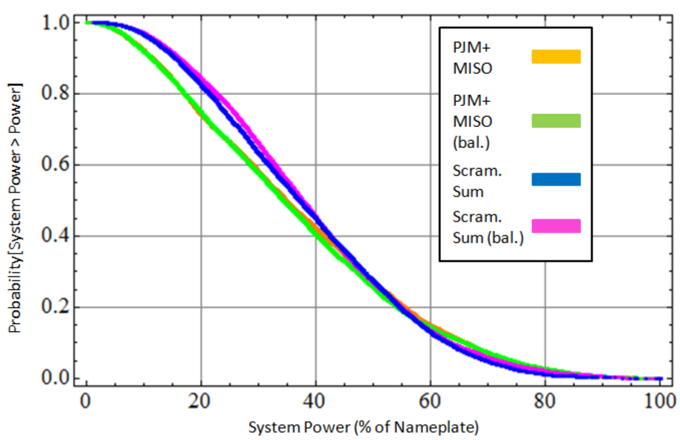

Figure 7: DFs for Independent and Interconnected Systems

The gray curve is the unbalanced, interconnected DF (data as published and seen in Figure 3) and the green curve is the balanced, interconnected DF (as seen in Figure 4). The purple curve is the unbalanced, independent DF and the orange curve is the balanced, independent DF.

In an identical fashion to the previous sections, we can compute the ELCC for the independent scenarios and analyze the results. The ELCC values were determined using the upper left hand corner of Figure 7, as depicted in Figure 8.

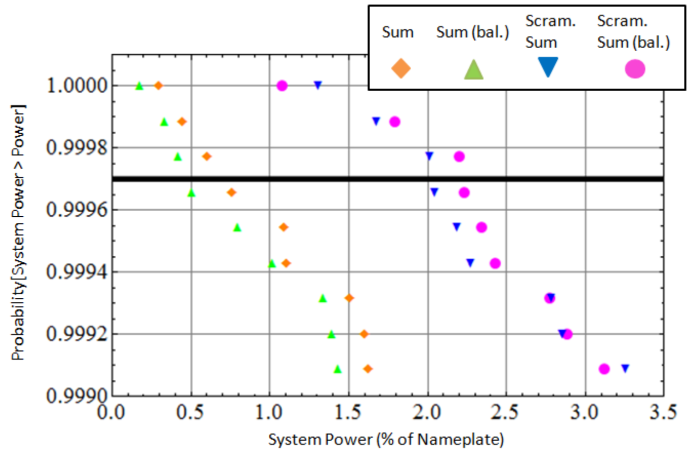

Figure 8: ELCC Calculation for Independent Systems

The balanced DFs for standalone wind are represented in the same manner as in Figure 5 and the black line corresponds to an availability of 0.9997. Ergo, the power (% of nameplate) where these DFs cross this availability are the ELCC values. For this scenario, the ELCC values were determined to be: independent PJM/MISO = 2.04% and independent PJM/MISO (balanced) = 2.22% (values given in % of nameplate).

Table 2: Final Summary of ELCC Values

	PJM	MISO	Interconnected	Independent
Unbalanced	0.0%	0.29%	0.69%	2.04%
Balanced	0.0%	0.29%	0.49%	2.22%

Both of the ELCC values for the independent scenario are well above the values calculated with the actual PJM and MISO data. This indicates that MISO and PJM are not independent of each other.

CONCLUSIONS

This paper looked at the value to be derived from the long distance combination of PJM and MISO wind farms. Specifically, does the combined standalone system offer more capacity than that of the separated systems? Capacity is determined by a reliability criteria of one-day-in-ten-years.. By this criteria a standalone wind system has no ELCC if the wind production time series is zero (or negligibly small) for more than 2.6 hours per year.

PJM wind has no ELCC. Indeed the number is negative for 8 hours because PJM subtracts parasitic electrical operating load from wind production resulting in 8 hours of negative net generation.

MISO has an ELCC of ~0.3% but MISO does not subtract parasitic electrical loads. It could well be that after subtracting parasitic loads, standalone MISO ELCC would also be zero.

The long distance interconnection of PJM & MISO wind does increase system ELCC but only to a level of 0.7%. Balancing the system so PJM and MISO are the same average size does not make a significant difference.

Fractional percentages are lost in the noise because MISO, unlike PJM does not subtract parasitic operational electrical loads.

If PJM and MISO wind systems were statistically independent of each other, ELCC would be on the order of 1.5-2.5%. This suggests that correlations are significant even at these distances.

From the practical perspective of comparing system concepts, when ELCC for independent generators are in the range of 90%, fractional percentages for standalone wind systems can be ignored as negligible.

ACKNOWLEDGMENTS

The authors acknowledge the support of the International Council on Systems Engineering Chesapeake Chapter and its Future of Energy (FoE) Initiative.

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