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Calculating the Peak Load Carrying Capability (PLCC) of Wind Plants

Materials Originally Presented at UWIG Annual Meeting
April, 2006

The Need to Calculate PLCC

It is important to look at the peak load contribution of any resource in the context of the system into which it interconnects, and not simply the resource by itself.

In isolation, even a relatively reliable resource cannot, on its own, provide acceptable reliability to meet ANY amount of load. In the power reliability world, it truly takes a village, and diversity really does matter.

- PacifiCorp's 2003 Integrated Resource Plan (IRP) assumed no contribution from wind projects with respect to meeting system peak load.
- PacifiCorp's 2004 IRP estimated the PLCC for a few projects and generalized the result.
- Wind projects can contribute to meeting peak loads, but their contribution is a relatively complex interaction between the existing power system, and the added wind plants.

Usual Recipe for Calculating PLCC of an Incremental Power Plant

"Stochastic models" simulate power system operations for some future time period, and capture the uncertainty in the future (loads, resource performance, prices, etc.) by running iteratively with different assumptions each time for the uncertain variables. They report out statistics such as the average number of hours on which loads exceeded resources, and the average amount of load that could not be served.

- Start with a base system, close to a target reliability level (reserve margin, LOLP, etc.).
- Run a stochastic model of the base system and note some probabilistic level of reliability (LOLP, EUE, etc.).
- Run the model again after adding a resource and an incremental load.
- Repeat the above step, changing the incremental load, until the level of reliability returns to what it was with the base system.

Shortcomings of the “Usual Recipe”

- Stochastic models are usually large and slow.
  - Repeatedly running them to test different amounts of load takes a long time.
  - Determining the PLCC is not easily automated, and takes a lot of analyst time in addition to computer time.
- Calculating PLCC for large numbers of projects in different resource portfolios is not usually practical.

There is Hope!

- A relatively simple, very fast method for estimating the PLCC for wind plants (and other resources) has been proposed and is being explored in PacifiCorp's 2006 IRP.
- The method takes into account the relevant power system and wind characteristics and their interactions.

Entering Math World

Math World ends with Slide 12.

- The next few slides describe how to actually calculate the PLCC– It may be more important for you to know that it can be done, than exactly how to do it.
- We'll pass through fast out of respect for those of us who don't really care about the specifics.

The PLCC Equation

This equation is the result of a paper: "Z Method for Power System Resource Adequacy Applications", K. Dragoon and V. Dvortsov, IEEE Transactions on Power Systems, May 2006, Volume: 21, Issue: 2, pp 982-988.

http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=1626406&isnumber=34141

- For incremental resources added to relatively larger base systems, the PLCC has the general form:

$$P \approx R - K \cdot \sigma_R^{\,2}$$

Where; P = Peak Load Carrying Capability,

R = Expected on-peak generation,

K = Factor characterizing the base system,

$\sigma_R^{\,2}$ = Variance of the on-peak generation.

So What is K?

» The value of K is defined as:

$$K = \frac{\overline{S}}{2\sigma_S{}^2}$$

Where; $\overline{S}$ = Expected on-peak system surplus, and

$\sigma_S{}^2$ = Variance of hourly on-peak surplus,

Calculating K

- Several ways to compute K:
  - Bottom Up Approach
    - ⇒Find the expected load resource balance.
    - ⇒Calculate the joint variability of loads and resources over the peak hours.
  - Top Down Approach
    - ⇒From existing stochastic model, calculate the PLCC using the Usual Recipe, and derive the value of K.
- PacifiCorp used the Top Down Approach.

Careful About Correlations

- The variance of the on-peak generation appears in the main equation:

$$P \approx R - K \cdot \sigma_R{}^2$$

- If you're adding a bunch of resources, the variance term must include the variance of the sum of the added resources.
  - The variance of the sum of the output of two projects is the same as the sum of the individual variances, if the projects are uncorrelated.

Incremental Capacity

» The capacity added to the system from the last resource addition is:

$$P_n \approx R_n - K(\sigma_n^2 + 2\sigma_n \sum_{i=1}^{n-1} r_{i,n}\sigma_i)$$

Where: Pn is the incremental PLCC of the wind project n,
Rn is the expected on-peak generation of wind project n,
σ_i is the standard deviation of hourly generation for project i,
σ_n is the standard deviation of hourly generation for project n,
$r_{i,n}$ is the correlation between projects i and n, and
K is defined as before

Implications (Leaving Math World)

- PLCC for a power plant is the expected on-peak generation minus an amount related to the on-peak variability and the size and reliability of the interconnected power system.
- The PLCC for wind is not fixed:
  - Depends on other projects in the area.
  - Depends on what came before.
- Diminishing returns.
  - The larger the wind project, the smaller the average contribution (as % of nameplate).
  - Diminishing returns can apply to separate wind projects that are in the same general area.
    - ⇒PacifiCorp has seen correlations between fairly widely separated sites (>100 miles) as high as 0.60.

Example– PLCC not fixed for a wind project

Note that the sum of the two projects is the same regardless of order– this is a general result. It is only the relative contribution that depends on order added.

The order of resource addition only matters for correlated projects. Projects that are geographically distant from one another are less likely to be strongly correlated.

» Two projects with correlated on-peak hourly output.

Assumptions		
	Project A	**Project B**
Nameplate (MW)	100	60
Expected On-Pk Gen (MW)	20	12
Std Dev (MW)	18	14
Correlation	0.8	
K (/MW)	0.007	
PLCC Computation		
Result if Unit is Added First (MW)	17.7	10.6
Result if Unit is Added Second (MW)	15.3	8.2
Total of **A** first, then **B** (MW)	25.9	
Total of **B** first, then **A** (MW)	25.9	

» Project A contributes either 18% of nameplate if added first, or 15% if added second. Project B contributes 18% if added first, or 14% if added second.

» **PLCC is not constant, not solely a characteristic of the wind project.**

Example– Diminishing Returns for Build-Outs

- Capacity Contribution as a function of project size
  - Assumes capacity factor constant (30%) over the expansion.

Assumptions						
Nameplate (MW)	100	200	300	400	500	800
On Pk Gen (MW)	30	60	90	120	150	240
Std Dev (MW)	25	50	75	100	125	200
K factor (/MW)			0.003			
Results						
PLCC (MW)	28	53	73	90	103	120
PLCC as % of Nameplate	28%	26%	24%	23%	21%	15%

- The net capacity contribution increases as unit size increases, but decreases as a fraction of nameplate.

Application

The PacifiCorp system already has wind units in the SE WA area, which are correlated with both SE WA and NC OR resource additions.

The build order of NC OR and SE WA does affect the quantities attributed to those projects. The numbers here reflect a build pattern alternating between NC OR (first) and SE WA.

If a SE WA plant is the first added, it would contribute more than the generation stated in the table.

» PacifiCorp applied the methodology to evaluate the PLCC from a wide range of quasi-generic wind projects.

Incremental PLCC Contribution (MW) of the Last 100 MW Plant Added.

Regional Resource Additions (MW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NC OR - 100	1	18	28	17	25	35	37	27	22	14	5	5
-200	0	8	16	7	14	24	28	18	12	5	0	0
-300	0	0	3	0	3	14	19	10	2	0	0	0
-400	0	0	0	0	0	3	10	1	0	0	0	0
SE WA -100	19	14	33	13	13	10	12	7	10	14	16	16
-200	8	2	20	2	1	0	2	0	0	3	5	4
-300	0	0	8	0	0	0	0	0	0	0	0	0
-400	0	0	0	0	0	0	0	0	0	0	0	0
EC NV -100	18	20	32	32	23	28	27	23	21	23	19	28
-200	15	17	29	26	20	24	23	20	17	20	17	24
-300	13	14	25	20	16	20	20	18	13	16	14	21
-400	10	12	21	14	13	17	16	15	9	13	12	17
SE ID -100	26	37	59	35	31	32	25	32	22	32	38	32
-200	20	31	53	29	26	27	21	28	17	26	32	26
-300	14	24	47	24	22	22	17	24	13	21	25	20
-400	8	17	41	18	17	17	13	20	8	16	18	14
WC UT -100	13	10	25	31	35	27	20	26	26	24	20	19
-200	10	9	21	27	31	24	18	22	22	20	17	16

Conclusions

- PLCC can be computed fairly quickly and efficiently.
- Contributions to load carrying capability of wind projects depends on both the characteristics of the wind project and the interconnecting utility (especially its size).
- The contribution is an amount somewhat less than the expected on-peak generation and can be quickly calculated using the mathematics outlined here.
- Even for wind resources with similar characteristics, the peak contribution is not a fixed number, but depends on unit size, and the characteristics of units that were added before it.