OFF-SHORE WIND AND GRID-CONNECTED PV: HIGH PENETRATION PEAK SHAVING FOR NEW YORK CITY

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ABSTRACT

This article presents an experimental evaluation of the combined effective capacity of off-shore wind and PV generation using the city of New York as a test case.

While wind generation is not known as a reliable peaking resource, local offshore generation is an exception because the same heat waves that drive demand peaks also produce enhanced thermal circulations and sea breezes.

The present analysis, based upon one year's worth of hourly site & time-specific data including electrical demand PV and off-shore wind generation, shows that the combination of wind and PV resources results in a markedly stronger capacity credit than each resource alone, particularly as grid penetration increases.

1. INTRODUCTION

The natural synergy between and solar and wind has long been noted as both seasonal and daily production cycles tend to be complementary. A recent study [1] demonstrated this synergy for bulk power generation in New York State and showed that a desired level of grid flexibility can be achieved by combining both resources at a lesser cost of dumping energy than by considering each resource alone.

In the present article we focus our attention on capacity credit: the ability of the considered resource mix to displace conventional peaking resources.

The ability of PV generation to be reliably available at times of peak electrical demand in large cities such as New York is well documented [2]. This effective capacity is achieved because electrical demand is driven by daytime commercial air conditioning (A/C) reaching a maximum during heat waves and because the fuel of heat waves is the sun. In effect, the underlying cause of peak demand is also the source of the energy that can meet the demand.

While the peak-time availability of wind generation is generally not as reliable, on-shore or off-shore generation near large coastal cities may be an exception. This is because the same heat waves that drive demand peaks and insure a reliable solar resource also produce powerful sea breezes and coastal low level jets (LLJs) associated with enhanced thermal circulations [3]. The coastal wind maxima tend to lag the solar cycle by a few hours; hence the combination of dispersed PV and offshore wind generation could be ideally suited to meet the entire peak demand cycle, including the mid-afternoon daytime peak and the evening shoulder peak.

Using the electrical requirements of New York City as a test case, the objective of this study is to quantify the capacity credit of a combined wind-PV resource and to determine their optimum mix as a function of grid penetration.

2. METHODS

The experimental evaluation is based upon the analysis of one year worth of hourly data – 2010 -- including New York City's electrical demand, distributed PV generation, and off-shore wind generation. PV and wind generation data are simulated from actual site and time-specific parameters; hence they represent actual conditions coincident with each hour of electrical demand.

2.2 Experimental Data

Load data: the New York Independent System Operator (NYISO [4]) archives real time load demand data for eleven zones in the state of New York. Zone J corresponds to the five boroughs of New York City that are served by two utilities: Consolidated Edison and the New York Power Authority. NYISO load data are archived on a 5-minute basis and were integrated to an hourly time interval for the present analysis. The 2010 peak demand for zone J occurred on July 6 at 4:30 PM DST topping 11.2 GW.

PV data: PV generation is assumed to be homogeneously distributed through the city. It is further assumed that the predominant PV configuration is optimized for mid-afternoon peaking conditions with an azimuth of 45° West and a tilt of 30°. PV capacity is defined in terms of rated AC output at 20° ambient temperature (PTC rating [5]).

City-wide hourly PV output was simulated using SolarAnywhere standard resolution hourly irradiances, temperatures and wind speed as input and SolarAnywhere's PV simulation capabilities [7]. Note that the ability of satellite-based PV simulations to accurately derive capacity credits has been documented [8].

Wind data: Wind power output is simulated from known turbine power curves and capacity factors (with losses) estimated using observational data from offshore buoys archived at the National Data Buoy Center (NDBC [9]), and validated model output from AWS Truepower's windTrends data set. The accuracy of these models is well documented and is certainly adequate for the present analysis [10, 11[].

Offshore turbines are assumed to have a hub height of 120 meters.

2.2 Quantifying effective capacity

Capacity credit is quantified using two metrics recommended by the utility and the solar industry [12, 13]: the effective load carrying capability [ELCC] and the solar load control metric [SLC].

Both metrics can be estimated directly from the knowledge of load demand and power generation history – in the present case, one year of time-coincident load and generation data.

The ELCC is based on the concept of loss of load probability. Utilities used the ELCC to quantify the capacity of their power generation units before the strengthening of continental/regional interconnectivity. The methodology was still applied at Pacific Gas and Electric [14] as late as the 1980s. As defined by Garver [15], the ELCC of a power plant represents its ability to increase the total generation capacity available on a local grid (e.g., a contiguous utility's service territory) without increasing its loss of load

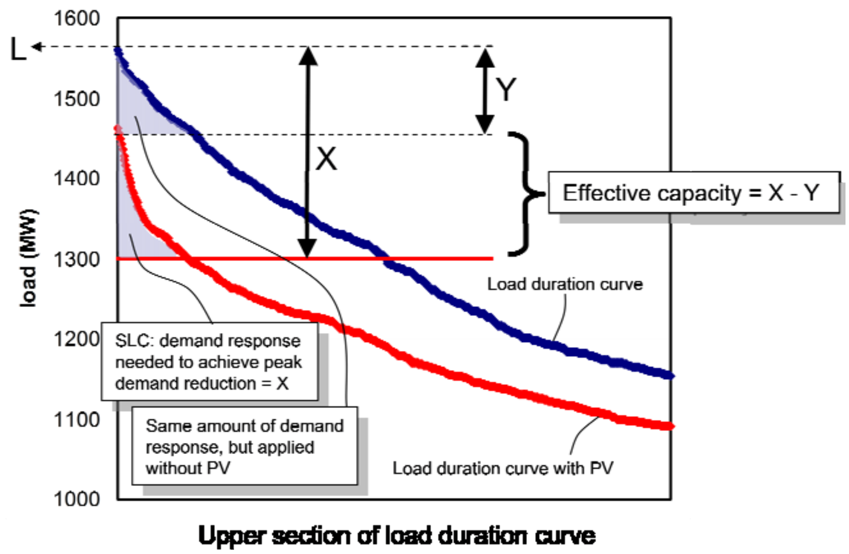

Figure 1: Illustrating the SLC effective capacity metric [11]

probability. This is determined by calculating the loss of load probability of the considered generating resource (here PV and/or wind) and comparing it to an ideal equivalent resource with a constant output.

The SLC is a deterministic metric that quantifies the synergy between short term storage and/or demand response and the considered resource. This metric answers the question: Given a certain amount of cumulative demand response available to a utility, how much more guaranteed load reduction would be possible if PV and/or wind were deployed? This metric is illustrated in Fig. 1, whereby X represents the installed renewable capacity and Y represents the peak reduction achievable without the renewable resource by applying a cumulative amount of load management equal to the load management that would be required to increase the renewable capacity credit to 100% [12]. The SLC metric is a measure of firm achievable capacity, quantifying the capability of resource and load control – from, e.g., demand response, storage or backup – to firmly deliver 100% nameplate capacity.

Both metrics are presented here in relative (percent) terms by dividing the calculated SLC or ELCC capacity by the generating capacity of the considered resource/wind mix.

2.2 Resource penetration scenarios

We explore multiple generation scenarios representing different mixes of solar and wind -- ranging from 100% solar to 100% wind -- and grid penetration levels up to 30% capacity penetration (i.e., up to 3.4 GW of deployed renewable resource).

3. RESULTS

Figs. 2 and 3 respectively compare the ELCC and SLC capacities of PV alone, of wind alone, and of the ideal mix delivering the highest capacity. The ideal Wind PV mix for each capacity metric is reported in Fig. 3 (ELCC) and Fig. 4 (SLC). All PV/wind mix and all penetration scenarios are reported in Tables 1 and 2 in the appendix.

Results show that both capacity metrics are quantitatively consistent, allowing us to make the following observations:

- The effective capacity of the solar-wind mix is higher than each resource's considered alone, indicative of a strong peak shaving synergy between both resources.
- The ideal mix goes from nearly 100% PV at very low penetration to roughly 40% wind - 60% PV at 30% penetration.
- The synergy between the wind and PV resources becomes stronger as grid penetration increases - at 5% penetration, the ideal mix increases the mean individual capacity of PV and wind by a factor of 1.2; while at 30% penetration this factor reaches 2.2.

The synergy between the two renewable resources is qualitatively shown in Fig. 5, comparing the peak demand day availability of each resource alone and ideally combined. The data shown in Fig. 4 correspond to a 20% grid penetration scenario

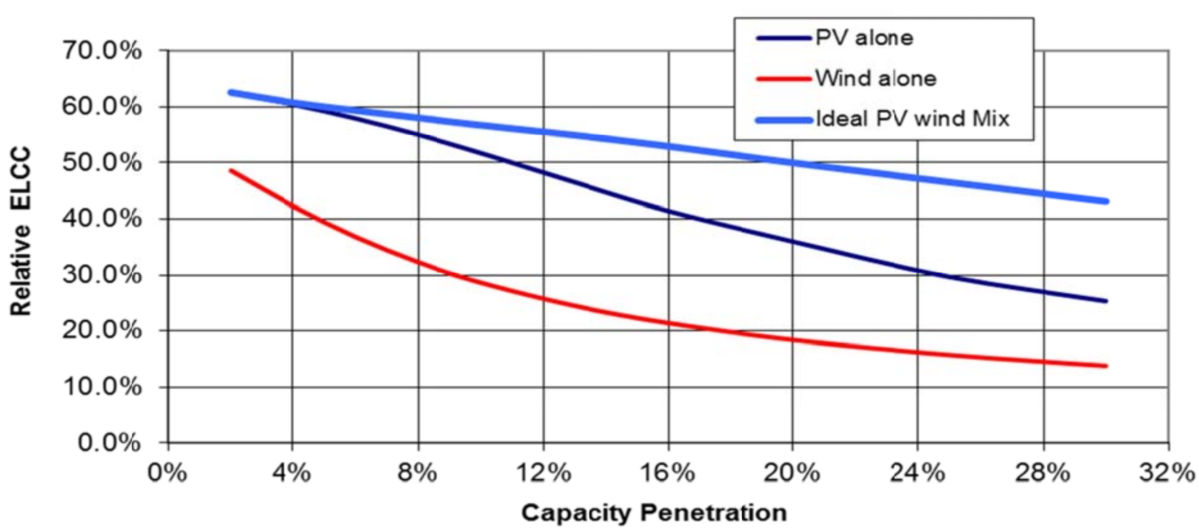

Figure 2: Relative Effective Load Carrying Capability as a function of grid penetration

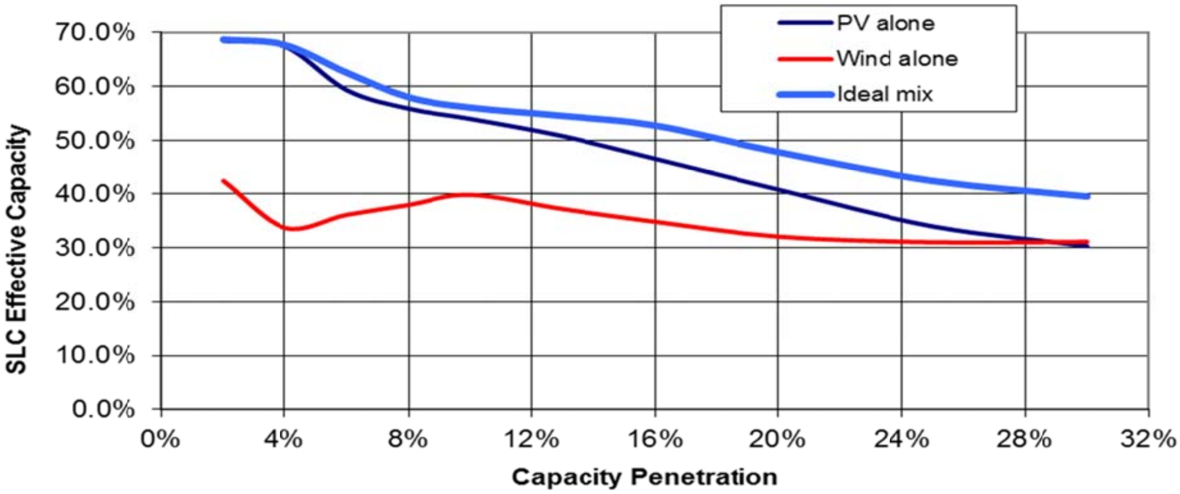

Figure 3: Relative SLC Capacity as a function of grid penetration Figure 3

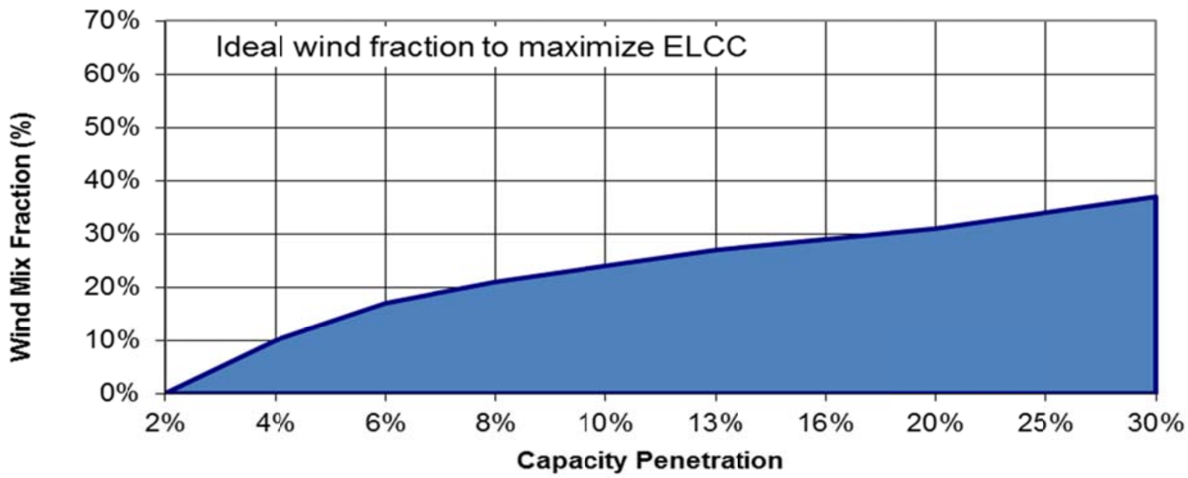

Figure 3: Ideal Wind fraction for the ELCC metric

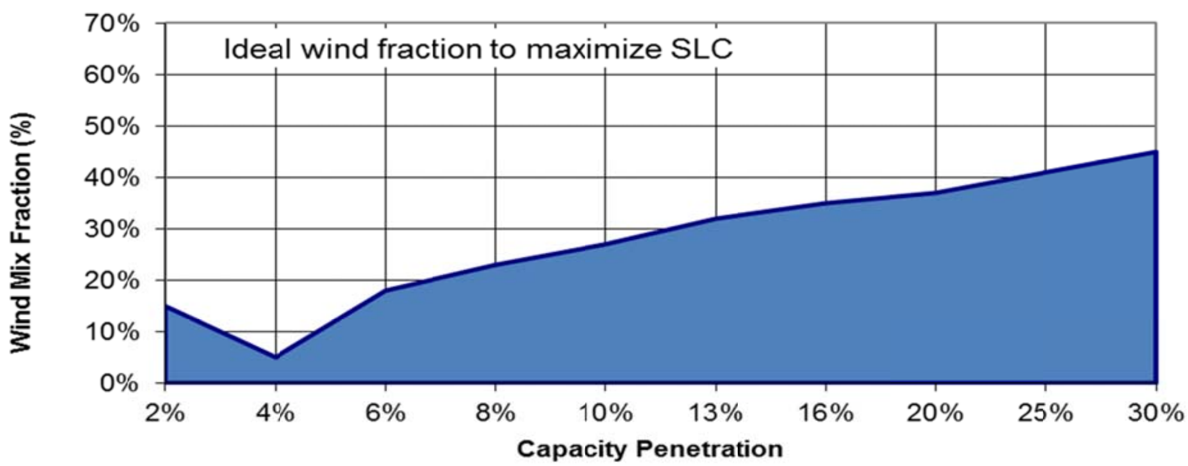

Figure 4: Ideal Wind fraction for the SLV capacity metric

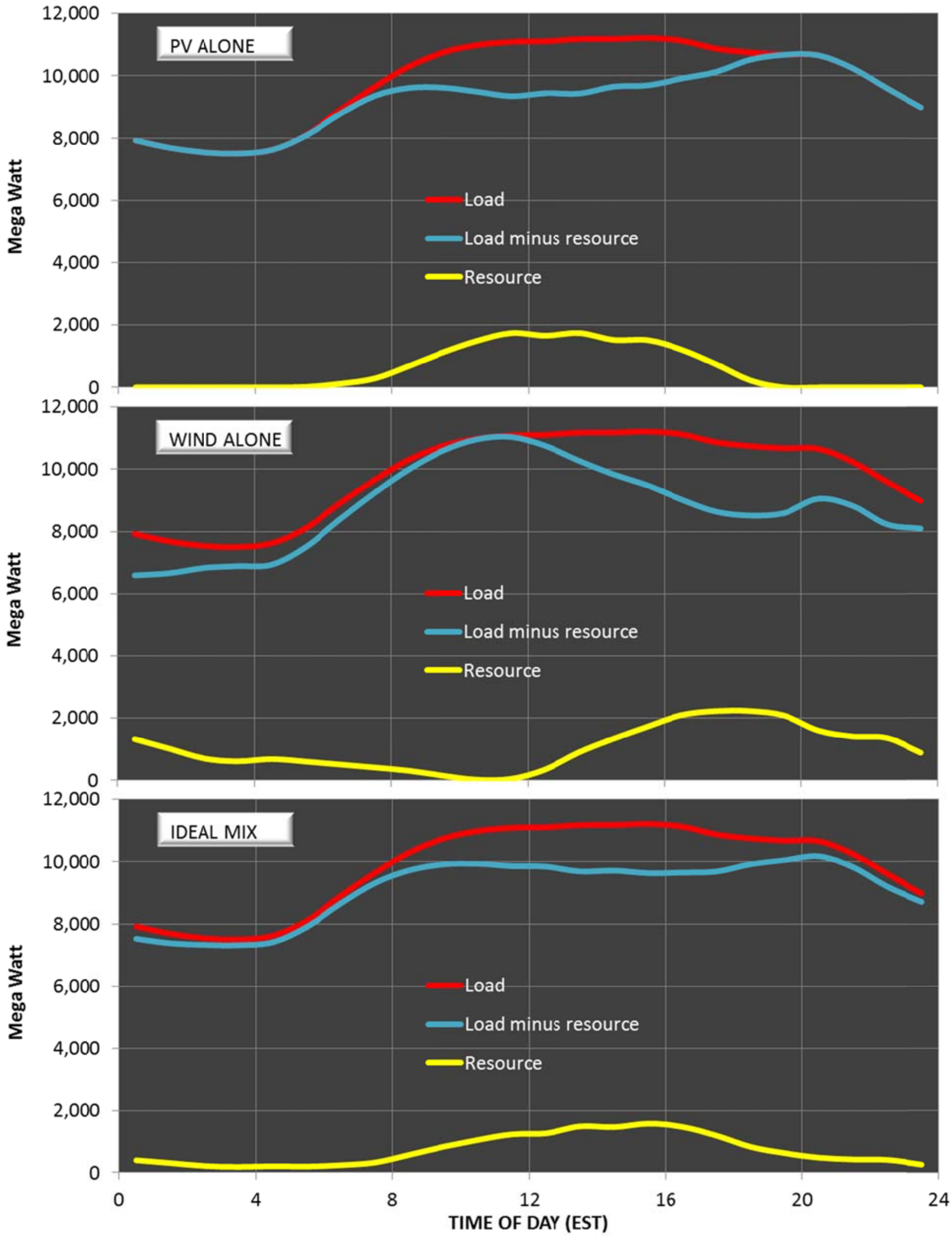

Figure 4: Availability of PV, Wind and the ideal resource mix on peak day (July 6, 2010)

4. DISCUSSION

The experimental evidence analyzed in this article shows that the combination of wind and PV resources results in a markedly stronger capacity credit than each resource's alone.

The optimum mix of wind and solar generation ranges from nearly all solar at very low penetration to 40%/60% wind/solar at 30% penetration.

This peak shaving synergy between both renewable resources increases as grid penetration increases. While the capacity credit of both resources decrease rapidly with penetration, the capacity credit of the ideal mix remains well above 40% at 30% penetration. At this level of penetration, such an ideal mix would consist of ~1.35 GW offshore wind and 2 GW of PV generation.

6. REFERENCES

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APPENDIX

Table 1
Relative ELCC as a function of penetration and wind mix fraction

Wind fraction	Grid Penetration									
	2%	4%	6%	8%	10%	13%	16%	20%	25%	30%
0%	62.6%	60.5%	57.9%	55.0%	51.7%	46.5%	41.4%	36.0%	29.7%	25.3%
10%	62.2%	60.8%	59.1%	57.1%	54.9%	51.1%	47.2%	42.2%	36.8%	32.6%
20%	61.6%	60.6%	59.4%	58.1%	56.6%	54.0%	51.2%	47.3%	42.6%	38.5%
30%	60.8%	59.9%	58.9%	57.9%	56.7%	54.9%	52.9%	50.0%	46.1%	42.2%
40%	59.7%	58.7%	57.6%	56.5%	55.5%	53.8%	52.1%	49.8%	46.5%	43.1%
50%	58.4%	57.0%	55.6%	54.2%	52.9%	51.0%	49.3%	47.0%	44.3%	41.6%
60%	56.9%	54.8%	52.9%	51.0%	49.3%	47.0%	45.0%	42.7%	40.2%	38.1%
70%	55.1%	52.3%	49.6%	47.1%	44.9%	42.1%	39.8%	37.3%	34.9%	33.1%
80%	53.2%	49.3%	45.8%	42.6%	39.9%	36.6%	34.0%	31.5%	28.9%	27.2%
90%	51.0%	46.0%	41.5%	37.6%	34.4%	30.7%	27.8%	25.0%	22.5%	20.6%
100%	48.6%	42.3%	36.8%	32.3%	28.6%	24.5%	21.4%	18.4%	15.7%	13.8%

Table 2
Relative SLC as a function of penetration and wind mix fraction

Wind fraction	Grid Penetration									
	2%	4%	6%	8%	10%	13%	16%	20%	25%	30%
0%	68.5%	67.5%	59.3%	55.9%	54.0%	50.8%	46.6%	40.9%	34.0%	30.3%
10%	68.5%	67.8%	61.3%	57.9%	55.4%	52.9%	49.4%	44.1%	37.5%	33.9%
20%	68.8%	66.0%	62.6%	58.0%	56.0%	54.2%	51.8%	46.7%	40.2%	36.5%
30%	67.5%	63.8%	61.3%	57.1%	56.1%	54.5%	52.8%	47.8%	41.9%	38.3%
40%	65.5%	60.5%	58.2%	56.0%	55.3%	54.2%	52.8%	47.8%	42.5%	39.4%
50%	61.0%	56.3%	54.5%	54.1%	53.9%	53.6%	51.1%	46.6%	42.0%	39.6%
60%	57.0%	51.8%	50.7%	51.3%	51.7%	52.2%	48.5%	44.6%	40.8%	38.8%
70%	52.5%	47.0%	47.0%	47.9%	49.1%	49.4%	45.4%	42.2%	38.8%	37.5%
80%	52.5%	42.5%	43.5%	44.6%	46.5%	45.6%	41.7%	39.4%	36.4%	35.6%
90%	33.0%	38.3%	39.8%	41.3%	43.4%	41.6%	38.3%	36.0%	33.8%	33.5%
100%	42.5%	33.8%	36.2%	38.0%	39.9%	37.2%	34.9%	32.1%	31.0%	31.1%