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# Capacity Value of PV and Wind Generation in the NV Energy System

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September 2012



**Pacific Northwest**  
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# Capacity Value of PV and Wind Generation in the NV Energy System

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P. Etingov

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Richland, Washington 99352



## **Abstract**

Calculation of photovoltaic (PV) and wind power capacity values is important for estimating additional load that can be served by new PV or wind installations in the electrical power system. It also is the basis for assigning capacity credit payments in systems with markets. Because of variability in solar and wind resources, PV and wind generation contribute to power system resource adequacy differently from conventional generation. Many different approaches to calculating PV and wind generation capacity values have been used by utilities and transmission operators. Using the NV Energy system as a study case, this report applies peak-period capacity factor (PPCF) and effective load carrying capability (ELCC) methods to calculate capacity values for renewable energy sources. We show the connection between the PPCF and ELCC methods in the process of deriving a simplified approach that approximates the ELCC method. This simplified approach does not require generation fleet data and provides the theoretical basis for a quick check on capacity value results of PV and wind generation. The diminishing return of capacity benefit as renewable generation increases is conveniently explained using the simplified capacity value approach.

## **Acknowledgement**

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# 1.0 Introduction

The adequacy of power generation resources is very important in the areas of system planning and secure operations. It is influenced by the availability of generation resources and the effects of bulk transmission and distribution systems. Factors affecting generation resource availability include forced outages, scheduled maintenance, derating, and other reasons. Load forecast uncertainty also can affect resource adequacy and needs to be considered in generation planning studies.

The calculation of photovoltaic (PV) and wind power capacity values is important for estimating additional load that can be served by new PV or wind installations in the electrical power system. It also is the basis for assigning capacity credit payments in systems with markets. Because of their variability PV and wind generation contribute to system resource adequacy in ways that are different from conventional generators. Calculation of capacity values for these variable resources is, therefore, treated differently from conventional generators.

Many methods have been used by different utilities and transmission operators in the United States [1] [2]. These various methods often result in different values even when based on the same data set. Among these methods, the effective load carrying capability (ELCC) method, which is based on loss of load expectation (LOLE), is considered the most accurate; however, it also requires complicated calculations and large amount of generator and load data [1] [3]. The peak-period capacity factor (PPCF) method uses average capacity factors (or capacity factors with an exceedance level) calculated over certain peak load periods to estimate the capacity value. The PPCF method is clear and simple in concept; however, it seemingly lacks the rigor and the link to the reliability metric of LOLE.

This report uses the NV Energy system as a study case, and applies the PPCF and ELCC methods to calculate capacity values for PV and wind generation. The connection between these two methods is shown by deriving a simplified approach that approximates the ELCC method. This approximation does not require the generation fleet data and provides the theoretical basis for a quick check of PV and wind generation capacity values. The diminishing return of capacity benefit as renewable generation increases is conveniently explained using the simplified capacity value approach.

The report is organized as follows. In Chapter 2, the PPCF method is described, and results from its use are shown for various PV penetration cases. In Chapter 3, the ELCC method for computing capacity values of variable renewable resources is described, and results for PV cases are presented. In Chapter 4, the capacity value of wind resources in the NV Energy system is calculated using the ELCC method. A simplified approach that approximates the ELCC method is discussed in Chapter 5. This simplified method is tested using the same study cases, and a comparison is made between the simplified method and the ELCC method. The diminishing return of the renewable resources capacity value also is explained in this chapter. Finally, conclusions are discussed in Chapter 6.

## 2.0 Peak-Period Capacity Factor Method

### 2.1 Methodology Description

Integration of variable renewable generation sources into a power system raises issues about how to quantify the capacity value of these sources. Different approaches have been developed to assess the capacity value of PV and wind sources. References [1-3] provide overviews for these different approaches. In this chapter, the PPCF method, based on the capacity factor of PV generation during a certain percentile of peak load period, is applied to the NV Energy system.

The system load duration curve is divided into nine bins, including 0.05%, 0.1%, 1%, 5%, 10%, 25%, 50%, 75%, and 100%. These bins correspond to the 4, 8, 88, etc., hours with highest load out of 8760 hours of a year, respectively. The average capacity factor of PV generation during each peak load period is calculated using Equation (2.1) and assigned the capacity value of PV. The correlation between PV generation and load is maintained in the calculation.

$$\text{Average Capacity Factor} = \frac{\sum \text{Solar Power of Selected Peak Load Hours}}{\text{Installed Solar Capacity} \times \text{Total Number of Selected Peak Load Hours}} \quad (2.1)$$

Based on the distribution of capacity factors during peak load hours, PV capacity values with a certain confidence level also can be calculated. For example, a capacity value with 90% confidence means the number is smaller than the actual PV capacity factor 90% of the time.

$$\text{Confidence Level} = \text{Probability}(\text{Capacity Factor in Selected Peak Hours} \geq \text{Capacity Value}) \quad (2.2)$$

Results of the NV Energy PV capacity value based on the approach described above are shown in Section 2.2.1. The analysis uses simulated PV generation data in 2007 produced by Sandia National Laboratories (PV Case 1).

A variation of the above approach is used by the California Independent Services Operator (CAISO) to calculate the capacity value (termed “qualifying capacity” or “QC”) of combined PV and wind generation [4]. In the CAISO approach, a daily peak load period of 5 hours is defined for each calendar month. A capacity value corresponding to a chosen confidence level (termed the “exceedence factor” in the CAISO approach) then are determined for each month based on the defined daily peak period rather than the peak load periods of the entire year. A capacity value assessment similar to that used in CAISO was implemented for comparison, and the results of that assessment are shown in Section 2.2.2. The capacity value was calculated for the entire year instead of on a monthly basis in the NV Energy study. The CAISO-type approach contains mainly two steps, which are described below:

1. First, calculate the daily average capacity factor during the defined daily peak load period:

$$\text{Average Capacity Factor in Daily Peak Load Period} = \frac{\sum \text{Solar Power of Daily Peak Load Period}}{\text{Installed Solar Capacity} \times \text{Number of Hours in Daily Peak Load Period}} \quad (2.3)$$

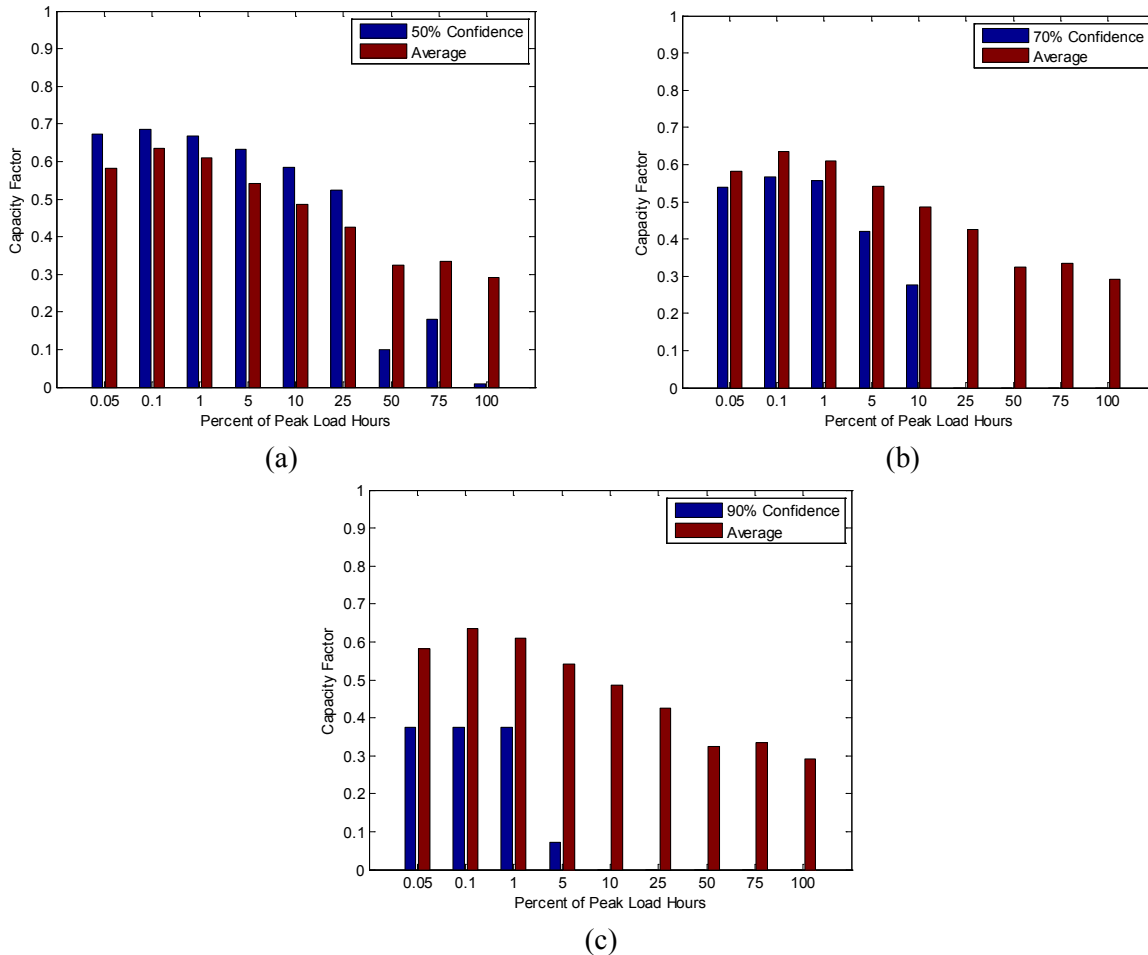
2. Second, find the capacity value at a certain confidence level,  $P$ , which is equal to the  $P^{\text{th}}$  percentile of the daily average capacity factor during peak load period of the whole year:

$$\text{Confidence Level} = \text{Probability}(\text{Daily Average Capacity Factor in Peak Load Period} \geq \text{Capacity Value}) \quad (2.4)$$

## 2.2 Simulation Results

### 2.2.1 Yearly PPCF Approach

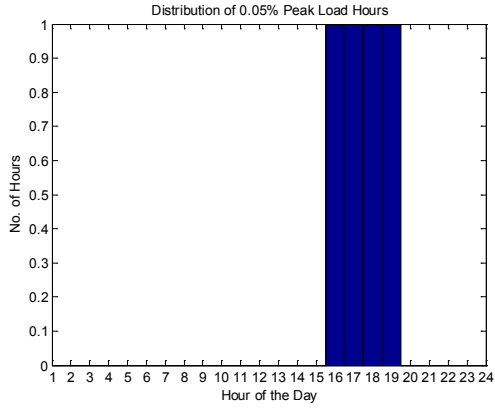
The NV Energy PV capacity value based on yearly peak period capacity factors is presented in this section. The PV capacity factor in the NV Energy system is calculated using the total name plate value of 149.5 MW, as defined in large PV Case1 data set. The capacity factors calculated with respect to different percentages of peak load hours are shown in Figure 2-1. The detailed capacity factors displayed in Figure 2-1 are further tabulated in Table 2-1. Note that, for the 0.05% and 0.1% peak load hours, because the total number of hours is small, rounding up or down could make a significant difference when calculating the capacity value at a certain confidence. The results shown here were rounded toward the more conservative direction (i.e., a lower capacity value). In Figure 2-2, the distribution of system load during a certain percentage of peak load hours is provided to help interpret the results. Similarly, the distribution of the PV capacity factors during peak load periods is shown in Figure 2-3.



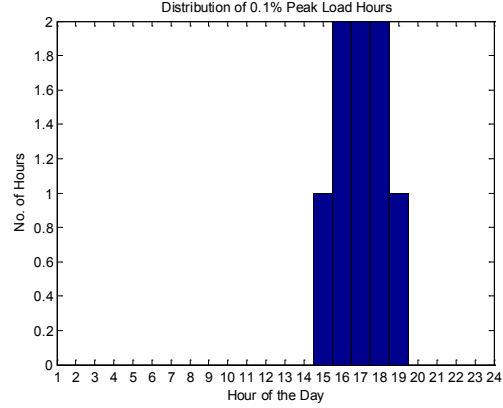
**Figure 2-1.** Capacity Factor with Respect to the Percentage of Peak Load Hours

**Table 2-1.** PV Capacity Factor during Peak Load Hours during a Year

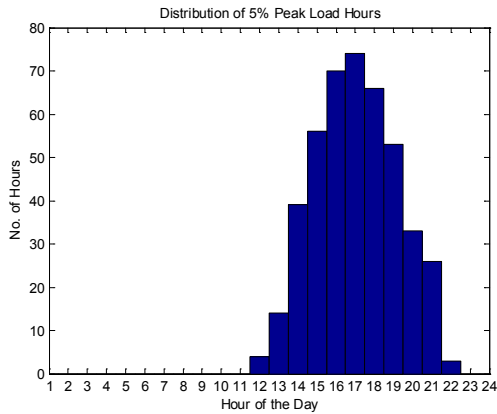
% of Peak Load Hours	0.05	0.1	1	5	10	25	50	75	100
50% Confidence	0.6724	0.6856	0.6676	0.6324	0.5835	0.5230	0.0999	0.1800	0.0083
70% Confidence	0.5383	0.5665	0.5562	0.4214	0.2757	0	0	0	0
90% Confidence	0.3762	0.3762	0.3762	0.0717	0	0	0	0	0
Average	0.5814	0.6358	0.6105	0.5404	0.4849	0.4246	0.3247	0.3356	0.2926



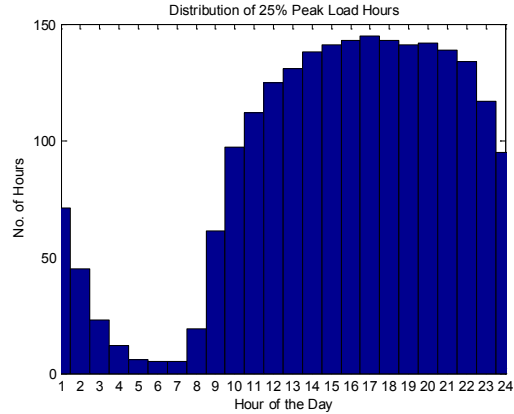
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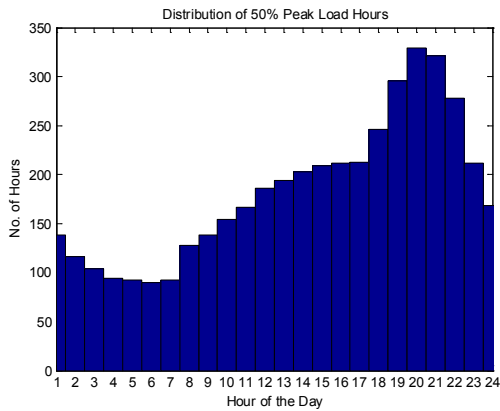
(b)



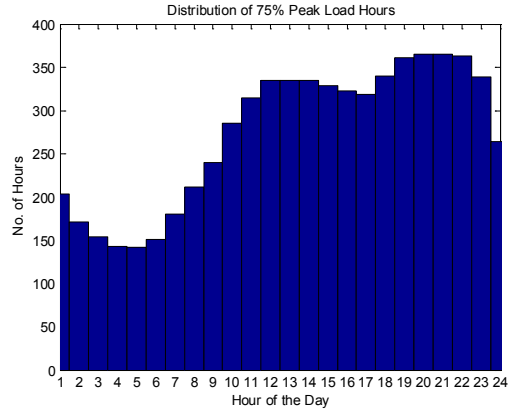
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(d)

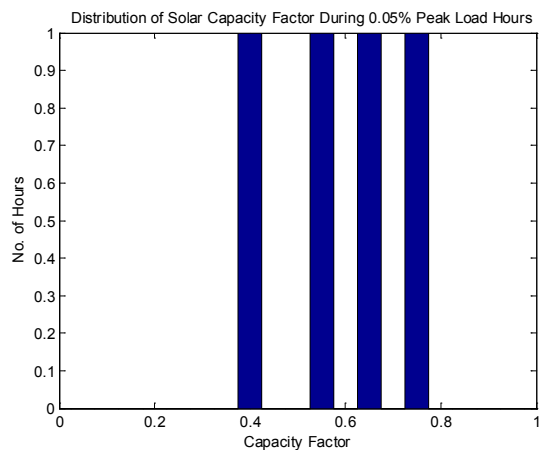


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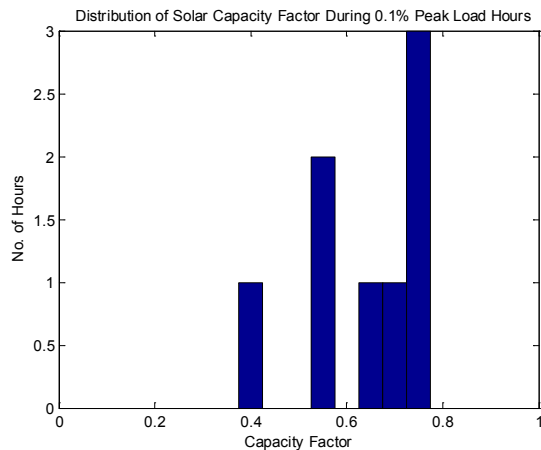


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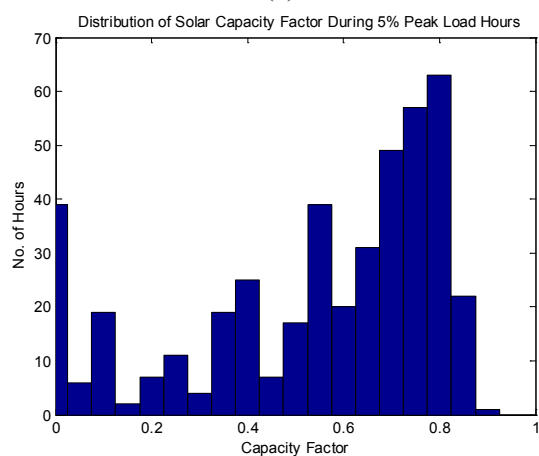
**Figure 2-2.** Distribution of Certain Percentage Levels of Peak Load Hours



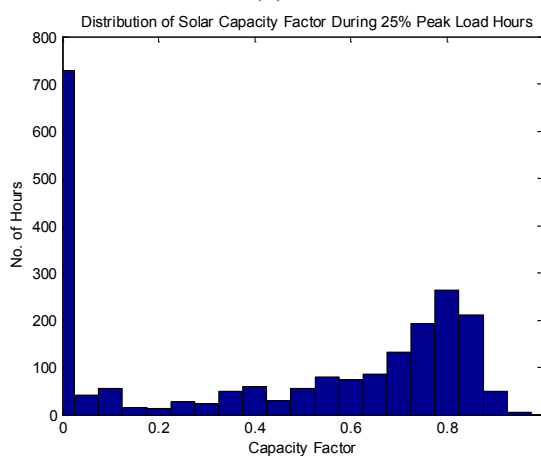
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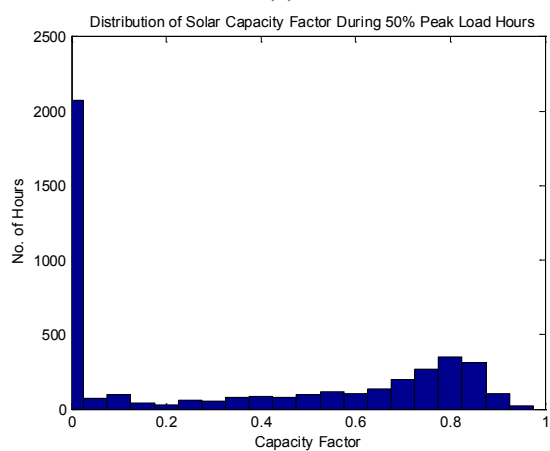
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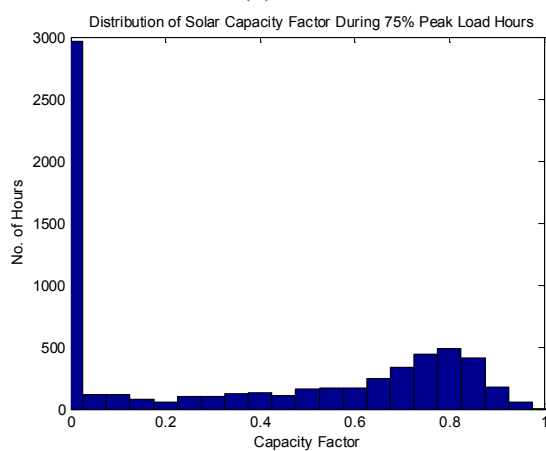
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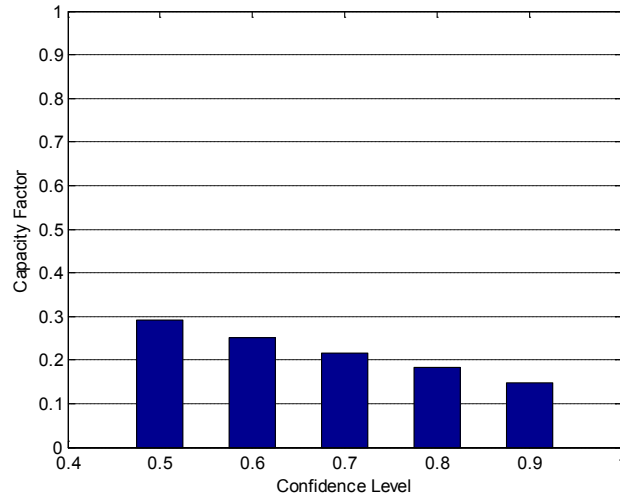


(f)

**Figure 2-3.** Distribution of PV Capacity during Certain Percentage of Peak Load Hours

### 2.2.2. Daily PPCF Approach

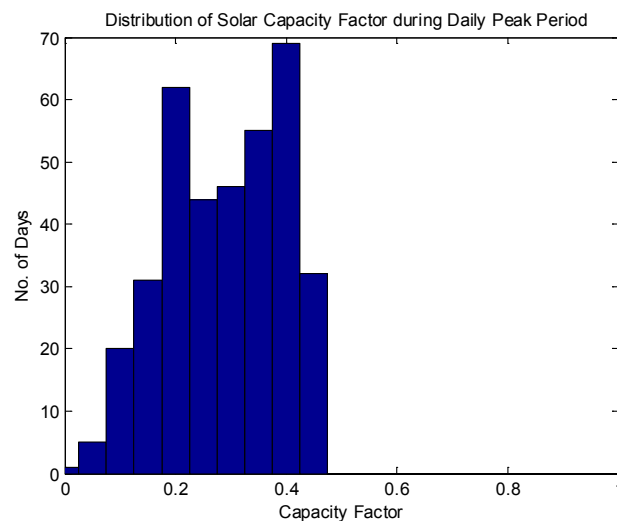
The PV capacity value based on capacity factors during the daily peak load period also is calculated for the same study case. The results are shown in Figure 2-4. This approach is similar to the CAISO QC calculation [4]. In this study, the peak hours are defined to be in the period from 16:00 to 21:00. The values of the capacity factors shown in Figure 2-4 are listed in Table 2-2. The distribution of PV capacity factor during peak load periods is shown in Figure 2-5.



**Figure 2-4.** Capacity Factor Calculated for Peak Load Hours

**Table 2-2.** PV Capacity Value based on the Capacity Factor during the Daily Peak Period

Confidence Level	50%	60%	70%	80%	90%
Capacity Value	0.2923	0.2523	0.2154	0.1824	0.1467



**Figure 2-5.** Distribution of Solar Capacity Factors during the Daily Peak Load Period



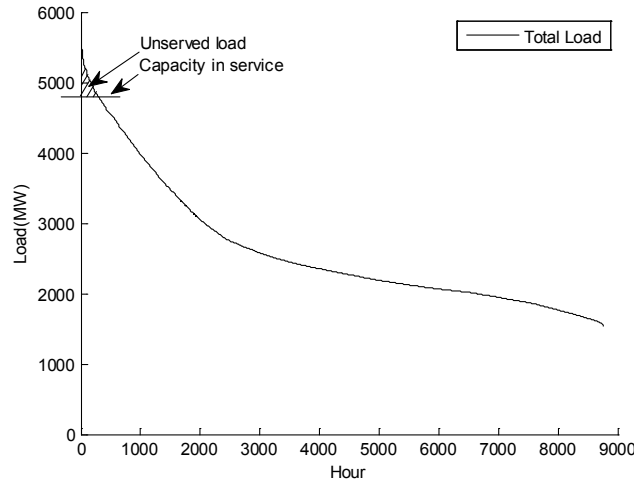
## 3.0 Effective Load Carrying Capability Method

### 3.1 Methodology Description

In this section, we describe the ELCC method used to quantify the capacity value of variable renewable resources. ELCC is identified as the most preferred method in determining PV capacity value by a Solar Electric Power Association workshop [1], and also recommended by the IEEE Power and Energy Society Task Force on the Capacity Value of Wind Power [3].

System reliability can be measured by loss of load probability (LOLP), which is the probability that load is higher than available generation at a given time or LOLE, which is the expected time during which load is higher than available generation. The concept of LOLP, shown in Figure 3-1, can be expressed in Equation (3.1). Figure 3-2 provides an example of the LOLP of the NV Energy southern system generation fleet. For time interval  $t$ , the LOLP is:

$$LOLP(t) = P_t(C_{in\ service} < d_t) \quad (3.1)$$



**Figure 3-1.** NV Energy Southern System Load Duration Curve

The system LOLE can be calculated using Equation (3.2) if the length of time interval  $T$  is 1 hour.

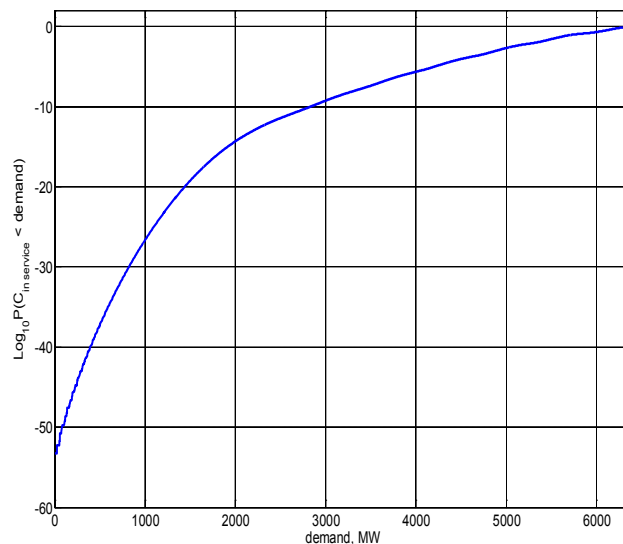
$$LOLE_{year} = \sum_{t=1}^{8760} T * P_t(C_{in\ service} < d_t) = \sum_{t=1}^{8760} P_t(C_{in\ service} < d_t) \quad (3.2)$$

Note that the common industry practice for the calculation of LOLP and LOLE is performed hourly and therefore, only considers meeting the total energy demand in each hour, and does not include the capacity and ramp requirements for catching up with load ramps and intra-hour variability of load. The later, usually taken care of by balancing reserves, may deserve special attention in generation adequacy assessment in a high renewable penetration environment. However, this is outside the scope of this report and will be investigated separately.

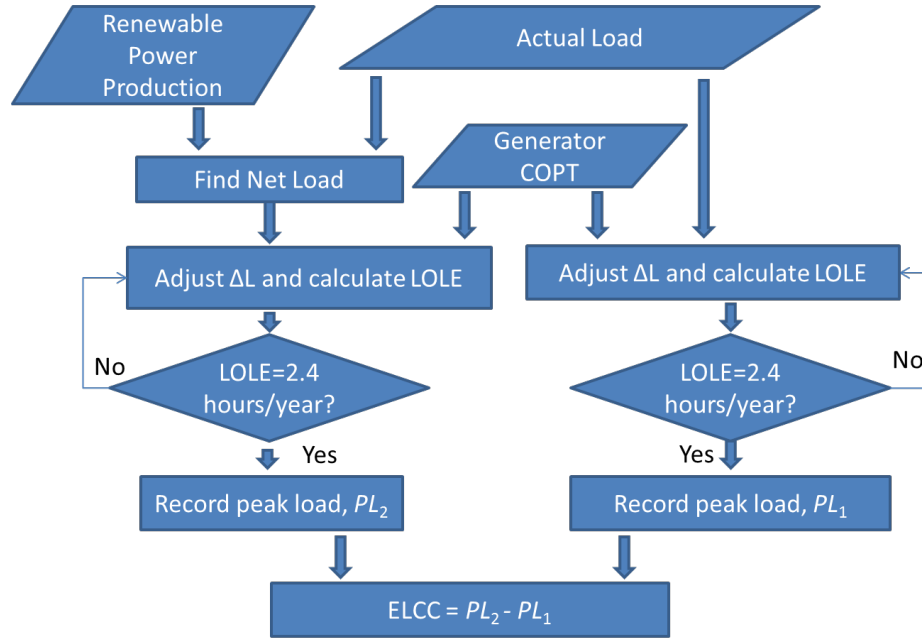
For conventional generators, LOLE is an effective metric for quantifying generation adequacy to meet system load. It is affected by various factors including generation availability such as forced outage, derating, maintenance, and transmission and distribution system availability. In the ELCC method, the

capacity value of renewable generation is calculated as the additional load that can be served as a result of the generation addition while maintaining the same level of reliability. A description of the procedure follows. A flow chart describing these steps is depicted in Figure 3-3.

1. Prepare a full list of generators with their forced outage rates, which excludes any renewable generator to be evaluated.
2. Calculate the capacity outage probability table by convolution, which contains a certain level of generation and its probability.
3. For a given load series with hourly resolution during a specific period, calculate the hourly LOLP values. *Note that the actual load curve is to be used here without considering any renewable generation.*
4. Calculate the LOLE level based on the LOLP values from the previous step.
5. Adjust load level throughout the entire study period by adding  $\Delta L$  until the LOLE reaches the NERC standard, 2.4 hours/year target. Record the peak load level when  $\text{LOLE} = 2.4$  hours/year,  $PL_1$ .
6. Find the net load curve by subtracting the renewable power output from the actual load.
7. Use this net load curve as input, and calculate the LOLE value. This should be lower than the one calculated using the actual load.
8. Iteratively increase  $\Delta L$  so that the new LOLE value reaches 2.4 hours/year. Record the new peak load value,  $PL_2$ .
9. Thus, the capacity value (or ELCC) of renewable resource is  $PL_2 - PL_1$ .



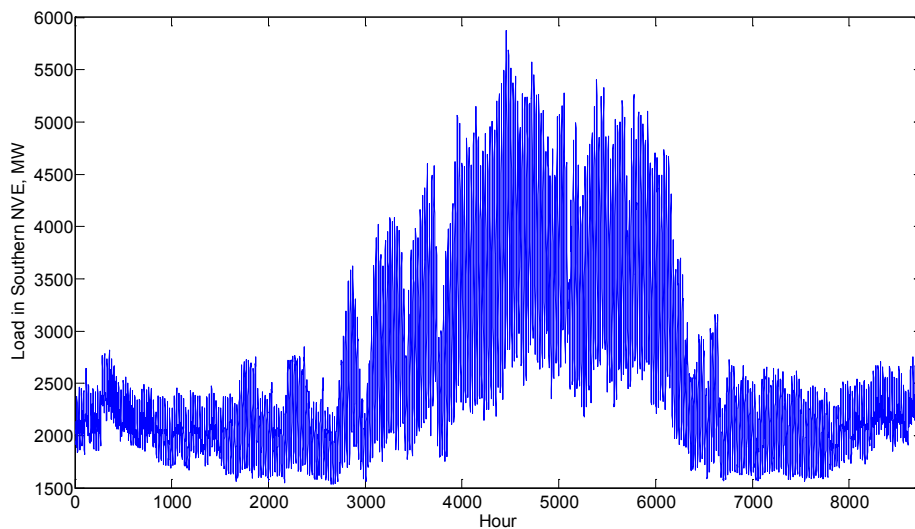
**Figure 3-2.** LOLP of the NV Energy Southern System Generation Fleet



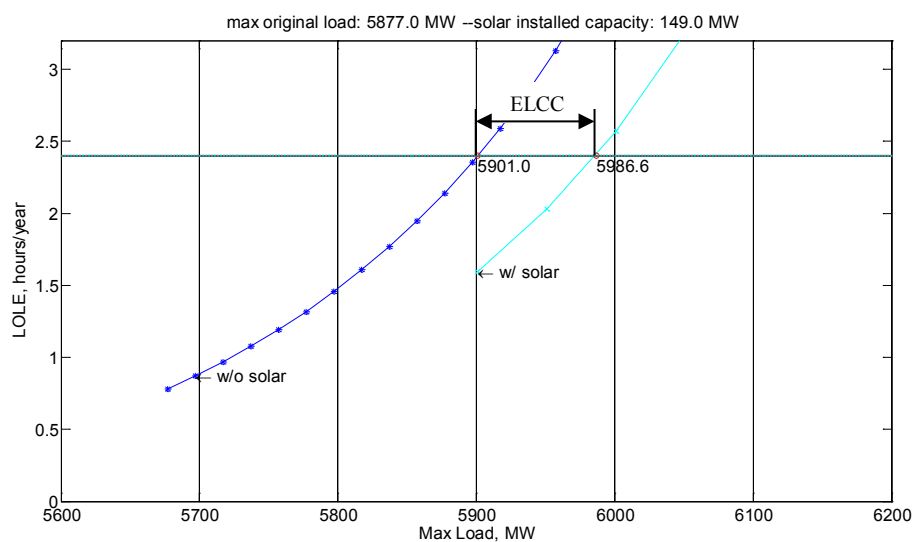
**Figure 3-3.** Flow Chart for Calculating the Capacity Value of a Renewable Resource

## 3.2 Simulation Results

In this section, the ELCC method is applied on the NV Energy southern system for the 2007 study year to calculate the capacity value of PV generation. Data sets including load profile, PV profile, and generator table with FOR are used in the analysis. The load profile in 2007 is shown in Figure 3-4. The generator list with associated FOR values used for LOLE calculations is provided in Appendix A. The ELCC method is tested on five study cases, representing different levels of PV penetration in the NV Energy southern system. The concept of this method of determining the PV capacity value is further illustrated in Figure 3-5. The calculated PV capacity values for different study cases are shown in Table 3-1. The trend plot shown in Figure 3-6 illustrates the impact of increasing PV penetration on the capacity value. It can be observed in Figure 3-6 that the capacity value of PV generation in percentage decreases as the installation capacity increases. The cause of this diminishing benefit is explained in Chapter 5 with the derivation of a simplified capacity value approach approximating the ELCC method.



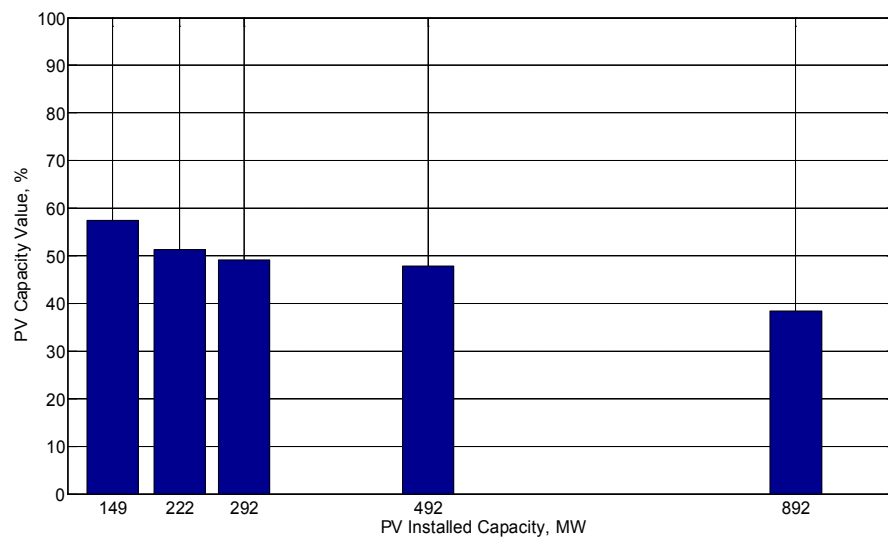
**Figure 3-4.** Hourly Load Profile in the NV Energy Southern System, 2007



**Figure 3-5.** Concept for Determining PV Capacity using the ELCC Method

**Table 3-1.** PV Capacity Value with Respect to Installed Capacity

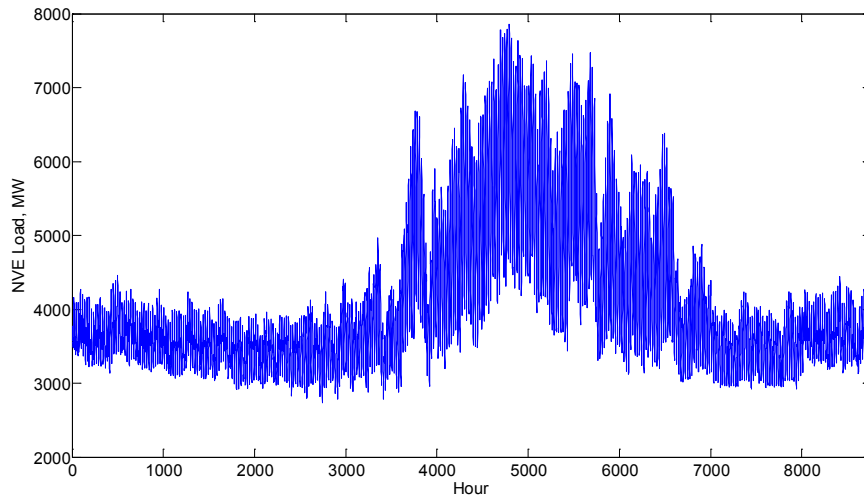
Cases	Installed Capacity, MW	PV Capacity Value, MW	PV Capacity Value, Percentage
1	149	85.55	57.41%
2	222	113.87	51.29%
3	292	143.36	49.10%
4	492	235.55	47.88%
5	892	343.16	38.47%



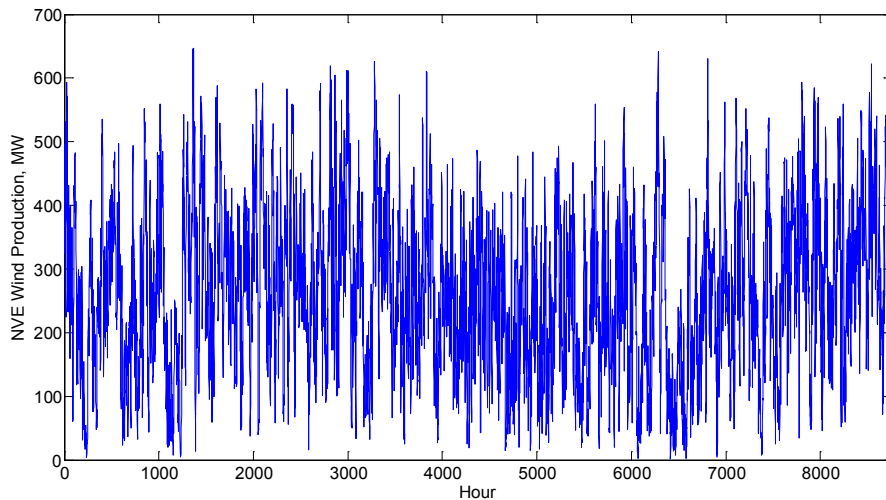
**Figure 3-6.** Impact of Increased PV Penetration on Capacity Value

## 4.0 Wind Generation Capacity Value

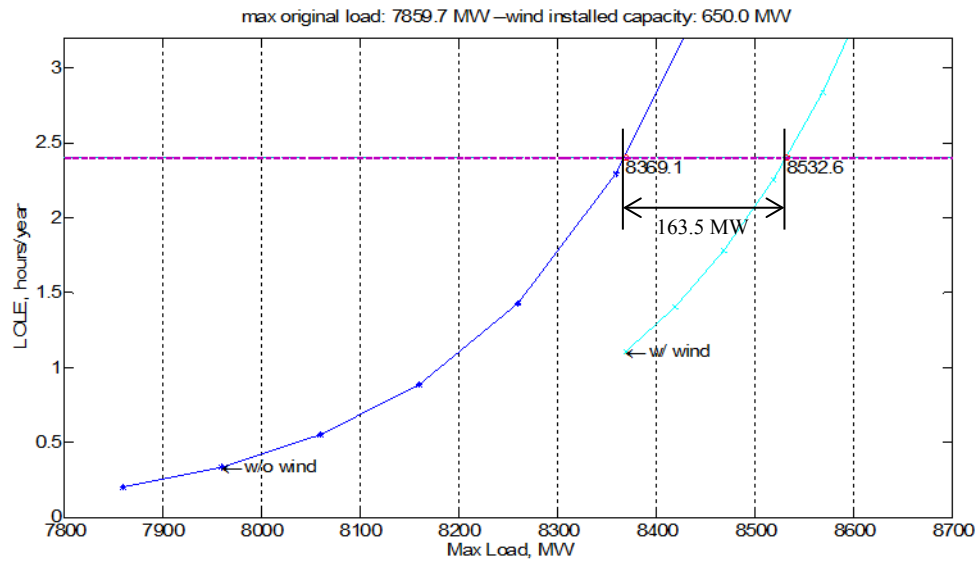
In this chapter, the same ELCC method described in Chapter 3 is implemented to evaluate the capacity value of wind resource in the NV Energy system. Based on the data available, this study is performed for the year 2010, for both the northern and southern parts of the NV Energy system. As shown in Figure 4-1, the peak hourly load of 7859.66 MW occurred on July 2010. The hourly wind production curve containing the outputs from four wind farms is shown in Figure 4-2. The generators with their FOR values used for LOLE calculation are listed in Appendix B. The total installed wind capacity in the analysis is 650 MW. The calculated wind capacity value is 163.5 MW as shown in Figure 4-3, which is 25.2% of the installed capacity.



**Figure 4-1.** Hourly Load Profile in the Entire NV Energy System, 2010



**Figure 4-2.** Hourly Wind Profile of Four Wind Farms in the Entire NV Energy System, 2010



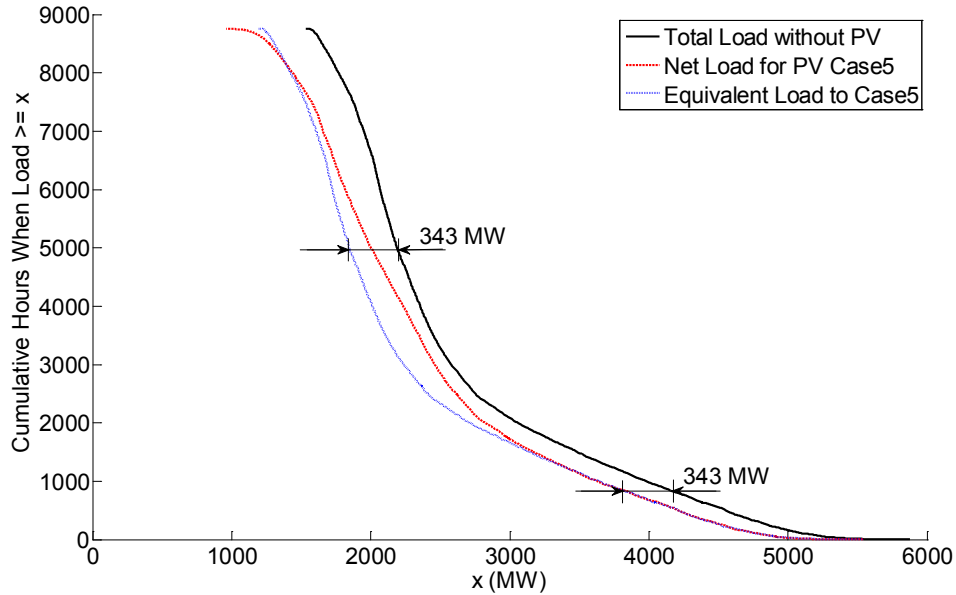
**Figure 4-3.** Wind Generation Capacity Value in the Entire NV Energy System, 2010

## 5.0 A Simplified Capacity Value Approach

### 5.1 Development of a Simplified Approach

Usually, the ELCC approach described in Chapter 3 is considered to provide accurate calculations of PV or wind capacity values. This approach requires large amount of data and complicated calculations, and it is difficult to apply in many situations. This section describes the derivation of a simplified approach that approximates the ELCC method, eliminates the need for conventional generation data, and can be performed very quickly. Based on this simplified approach, the diminishing return of renewable generation capacity value can be conveniently explained, as will be discussed in Section 5.2.

The ELCC method defines capacity value as the equivalent perfectly reliable generation capacity that, when used to replace PV or wind generation, the system can achieve the same LOLE as with the renewable resources being replaced. Figure 5-1 shows the load duration curve (the horizontal and vertical axes are transposed for the convenience of discussions later on) for the base case without PV, net load in PV Case 5, and the equivalent load to PV Case 5 (shifted left from the base case curve, which has the same LOLE as PV Case 5). The y axis in Figure 5-1 represents the cumulative hours through the entire year when load is less or equal to x. The calculated capacity value for PV in Case 5 is 343 MW. Again, as noted in Section 3.1, the LOLE calculation does not consider balancing requirements caused by the uncertainty and variability of load and PV generation.



**Figure 5-1.** Load Duration Curve for PV Case 5 and its PV Capacity Value

The LOLP for load in any particular hour  $t$  of the year is the probability of generation capacity in service ( $C_{in\ service}$ ) being less than the demand in hour  $t$  ( $d_t$ ):

$$LOLP(t) = P_t(C_{in\ service} < d_t) \quad (5.1)$$

The LOLE for hour  $t$  is therefore:

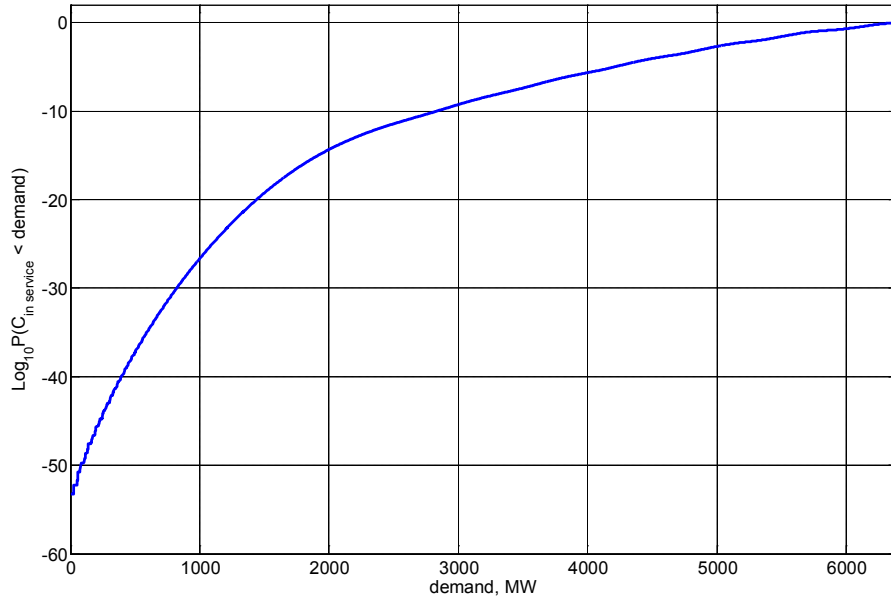


$$LOLE(t) = T * P_t(C_{in\ service} < d_t) \quad (5.2)$$

$T$  is one hour. For convenience,  $T$  will be omitted in the equations that follow. The LOLE for the entire year is calculated as:

$$LOLE_{year} = \sum_{t=1}^{8760} T * P_t(C_{in\ service} < d_t) = \sum_{t=1}^{8760} P_t(C_{in\ service} < d_t) \quad (5.3)$$

To be absolutely accurate, we would need to calculate the LOLP for each hour of the year to get the LOLE of the year. However, when the demand is very low compared to installation capacity of the generation fleet, the LOLP in low demand hours is negligible. This can be observed in Figure 5-2, which shows the LOLP of the NV Energy southern system at different demand levels.



**Figure 5-2.** LOLP of NV Energy Southern System Generation Fleet (probability of in-service capacity being less than specific demand values)

In Figure 5-2, we can see that, even if we ignore the LOLP in those hours in which demand is less than 3000 MW, the LOLE result will probably not be affected much. Next, we will discuss more quantitatively under which demand levels we can ignore the LOLPs.

First, we set the error tolerance of LOLE as 1% of the largest LOLP among all hours of the year, which occurs during the hour with the highest demand:

$$Tol = \frac{1}{100} \max(LOLP(t)) = \frac{1}{100} P(C_{in\ service} < d_{max}) \quad (5.4)$$

Comparing Equations (5.3) and (5.4), we can see that:

$$Tol \leq \frac{1}{100} LOLE_{year} \quad (5.5)$$

Second, we define a set of hours (i.e., “Low Demand Hours”) when demand is less than a threshold  $d_{lh}$ , and  $d_{lh}$  should satisfy:

$$\sum_{t \in \text{Low Demand Hours}} LOLP(t) = \sum_{t \in \text{Low Demand Hours}} P(C_{in \text{ service}} < d_t) \leq Tol \quad (5.6)$$

From Equation (5.6), we can get:

$$\sum_{t \in \text{Low Demand Hours}} LOLP(t) \leq \sum_{t \in \text{Low Demand Hours}} P(C_{in \text{ service}} < d_{th}) = N * P(C_{in \text{ service}} < d_{th}) \quad (5.7)$$

where N is the number of hours in the “Low Demand Hours” set.

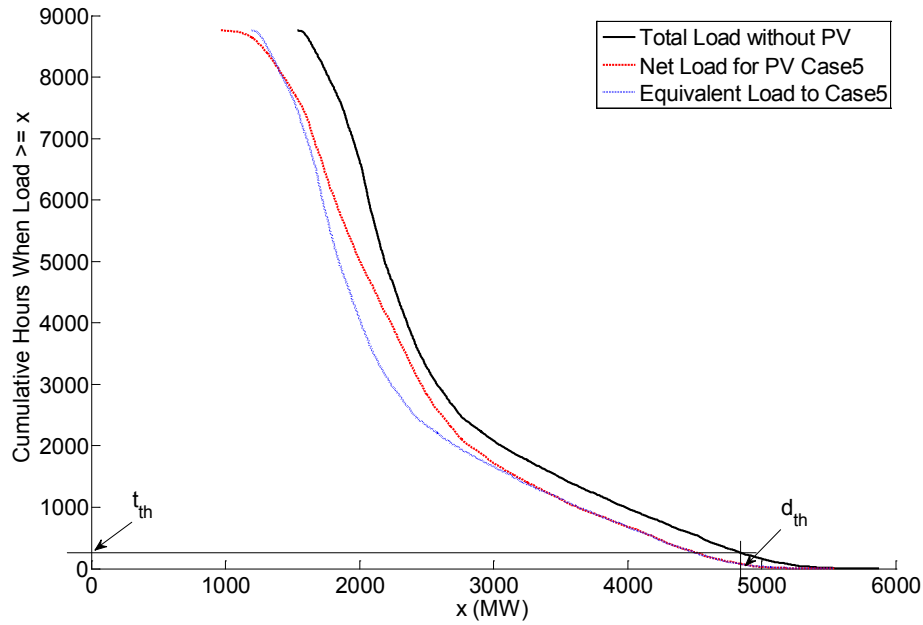
By combining Equations (5.5) and (5.6), we can find  $d_{th}$  by:

$$P(C_{in \text{ service}} < d_{th}) \leq Tol/N \quad (5.8)$$

When calculating the LOLE, we can use Equation (5.9) and ignore the contribution of the LOLP in those hours when demand is lower than  $d_{th}$  with an error of less than 1%.

$$LOLE_{year} \approx \sum_{d_k \in \{d_t | d_t > d_{th}\}} P_k(C_{in \text{ service}} < d_k) \quad (5.9)$$

On the load duration curve shown in Figure 5-1, define hour  $t_{th}$  as the hour with demand  $d_{th}$ . The terms  $t_{th}$  and  $d_{th}$  are indicated on the redraw of the load duration curve in Figure 5-3.



**Figure 5-3.** Load Duration Curves for the NV Energy Southern System with an Indication of the Threshold Demand  $d_{th}$  for Calculating the LOLE

Define  $d'_t$  as the demand on the load duration curve, and Equation (5.9) can be rewritten as:

$$LOLE_{year} \approx \sum_{t \in [0, t_{th}]} P_t(C_{in \text{ service}} < d'_t) \quad (5.10)$$

In the NV Energy southern system, the peak load is 5877 MW in year 2007. The LOLP at the peak load hour is:

$$LOLP(d_{max} = 5877MW) = P(C_{in \text{ service}} < d_{max}) = 0.1398 \quad (5.11)$$

Using Equations (5.4) and (5.8) and the LOLP curve in Figure 5-2, we can determine  $d_{th}$ , which is ~4900 MW. According to the load duration curve for no PV case in Figure 5-1,  $d_{th}$  corresponds to the

lower bound of 2.5% peak load period. In other words, when calculating  $LOLE_{year}$ , we only need to consider the LOLP of those hours in the 2.5% peak load period.

With PV in the system, the LOLE calculation uses the net load duration curve (load – PV generation), which is shown as the red dashed line in Figure 5-3:

$$LOLE_{year\_PV} \approx \sum_{t \in [0, t_{th}]} P_t(C_{in\ service} < nd'_t) \quad (5.12)$$

where  $nd'_t$  is the net load on the net load duration curve.

When calculating the capacity value of PV ( $CV_{PV}$ ), we still adopt Equation (5.10), and  $CV_{PV}$  should satisfy:

$$LOLE_{year\_PV} \approx \sum_{t \in [0, t_{th}]} P_t(C_{in\ service} < d'_t - CV_{PV}) \quad (5.13)$$

which means that with PV in the system, the LOLE is the same as adding a perfectly reliable resource of capacity  $CV_{PV}$ .

Assume that the LOLP function is linear between  $d_{th}$  and  $d_{max}$ , which is approximately true at the upper end of the curve in Figure 5-2. From Equations (5.12) and (5.13), we get:

$$\begin{aligned} \sum_{t \in [0, t_{th}]} P_t(C_{in\ service} < d'_t - CV_{PV}) &= \sum_{t \in [0, t_{th}]} P_t(C_{in\ service} < nd'_t) \\ \sum_{t \in [0, t_{th}]} (d'_t - CV_{PV}) &= \sum_{t \in [0, t_{th}]} nd'_t \\ CV_{PV} &= mean(\sum_{t \in [0, t_{th}]} (d'_t - nd'_t)) \\ &= mean(\sum_{t \in [0, t_{th}]} PV'_t) \end{aligned} \quad (5.14)$$

where  $PV'_t$  is the PV generation corresponding to the peak load period  $[0, t_{th}]$  on the *Net Load* duration curve in Figure 5-3. Once  $d_{th}$  and then  $t_{th}$  are determined, Equation (5.14) can be conveniently used to calculate the capacity value of PV, which is a variation of the peak-period capacity factor method. It should be noted that the PPCF method normally uses renewable generation data during the peak load period to calculate the capacity value rather than the peak *net load* period as in Equation (5.14).

In the NV Energy southern system, using the 2.5% peak load period calculated above as the  $t_{th}$ , capacity values for each PV case calculated by Equation (5.14) and by the accurate ELCC approach are compared in Table 5-1. Similar comparison is shown for wind capacity value results in Table 5-2.

**Table 5-1.** PV Capacity Value Calculation Results Comparison

PV Cases	Case 1	Case 2	Case 3	Case 4	Case 5
PV Installed Capacity (MW)	149	222	292	492	892
Capacity value in MW	Equation (5.14)	86	115	145	235
	ELCC approach	86	114	143	236
Capacity value in %	Equation (5.14)	57	52	50	48
	ELCC approach	57	51	49	48

**Table 5-2.** Wind Capacity Value Calculation Results Comparison

Wind Installed Capacity (MW)		650
Capacity value in MW	Equation (5.14)	165
	ELCC approach	164
Capacity value in %	Equation (5.14)	25
	ELCC approach	25

Table 5-1 and Table 5-2 show close matches between the results from the simplified approach and the accurate ELCC approach. When generator data such as forced outage rate, derating, and maintenance schedules are not available, or a software program following the accurate calculation of LOLE is too time consuming, Equation (5.14) can be used to calculate the capacity value of renewable resources.

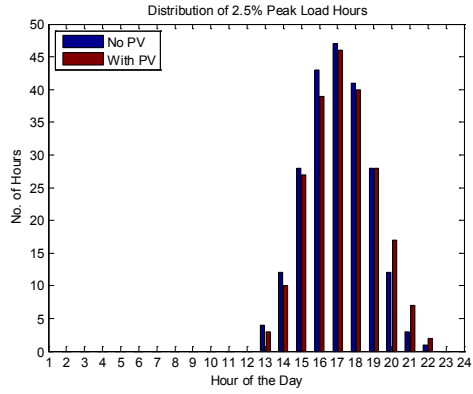
The discussion in this section establishes the connection between the peak-period capacity factor method and the effective load carrying capability method. When the peak load period  $[0, t_{th}]$  is carefully selected, it shows that the PPCF method provides a good approximation of ELCC. However, we need to recognize the assumption is that the LOLP function is linear between  $d_{th}$  and  $d_{max}$  (load corresponding to  $t_{th}$  and 0 on the load duration curve). If  $t_{th}$  is too large, this assumption will not be valid; on the other hand, if  $t_{th}$  is too small, LOLPs neglected in Equation (5.9) will be large. For a particular system, Equations (5.4) to (5.8) can be used to find the appropriate value of  $t_{th}$ .

## 5.2 Capacity Value Diminishing Return Explained

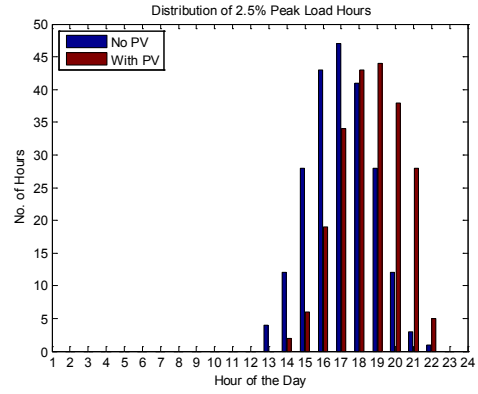
We observed from the results in Chapter 3 and also in Table 5-1 that the capacity values of PV generation in the NV Energy southern system decrease from 57% at 149 MW to 38% at 892 MW. This diminishing capacity benefit can be conveniently explained using the simplified capacity value approach developed in Section 5.1.

Figure 5-4 shows the distribution of 2.5% peak load hours in Case 1 and Case 5, in comparison with the No-PV case. Because of the significant amount of PV generation in Case 5, the center of the peak load period shifts nearly two hours from 17:00 to 19:00, while there is almost no change in the peak load period in Case 1. Consequently, the capacity factor of PV generation during the peak period decreases substantially in Case 5 when compared to Case 1. This significant change is shown in Figure 5-5. In Figure 5-5, the “No PV” data set uses *load* duration curves to find the 2.5% peak load hours and displays the distribution of PV capacity factor in each PV case in these hours. The “With PV” data set uses *net load* duration curve to find the same percentage of peak hours.

In summary, the peak period of net load shifts toward those hours when PV generation has lower capacity factors, as PV penetration increases. In Section 5.1, we showed that the PV output in these peak (net) load hours matters the most and approximately determine the capacity value, according to Equation (5.14). Therefore, the PV capacity value tends to decrease in percentage as its installation capacity increases. In principle, this phenomenon and explanation applies to all variable generation sources including wind.

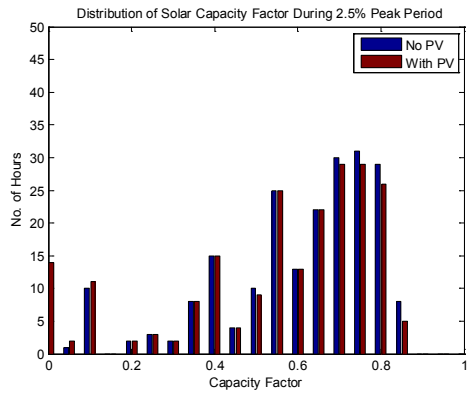


(a) Case 1

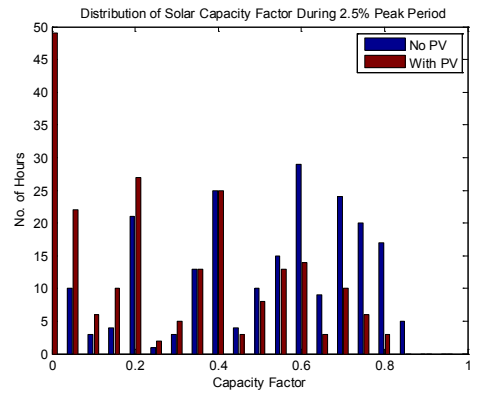


(b) Case 5

**Figure 5-4.** Distribution of Peak Load Hours at Different PV Penetration Levels



(a) Case 1



(b) Case 5

**Figure 5-5.** Distribution of PV Capacity Factor during Peak Load Hours

## **6.0 Conclusions**

In this report, several approaches are applied for computing the capacity values of PV and wind generation in the NV Energy system, including the PPCF and ELCC methods and a new simplified method. Several study cases for the NV Energy southern system were analyzed to investigate the capacity values of PV generation under different penetration levels. The ELCC method was tested on the wind generation data for the entire NV Energy system. Our simplified capacity value approach does not require generation fleet data and provides the theoretical basis for a quick check on PV and wind generation capacity value results. The diminishing return of capacity benefit as renewable generation increases is conveniently explained using our simplified approach.

## 7.0 References

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## Appendix A

**Table A.1.** Generator List in the NV Energy Southern System, 2007

No.	Generator Name	Capacity, MW	FOR
1	REID GDR-1	100	0.12
2	REID GDR-2	100	0.12
3	REID GDR-3	100	0.12
4	REID GDR-4	24	0.09
5	NAVAJO-1	85	0.03
6	NAVAJO-2	85	0.03
7	NAVAJO-3	85	0.03
8	Silverhawk 2x1	599	0.01
9	Lenzie 1_2x1	601	0.02
10	Lenzie 2_2x1	601	0.02
11	Higgins 2x1	600	0.01
12	Harry Allen 2x1	524	0.03
13	CLARK-9	250	0.04
14	CLARK-10	57	0.03
15	ALLEN CT-3	84	0.11
16	ALLEN CT-4	84	0.11
17	SUNRISE-2	81	0.0449
18	SUNPEAK-3	78	0.05
19	SUNPEAK-4	78	0.043
20	SUNPEAK-5	78	0.07
21	CLARK-4	63	0.25
22	CLARK-11	57	0.05
23	CLARK-12	57	0.05
24	CLARK-13	57	0.05
25	CLARK-14	57	0.05
26	CLARK-15	57	0.05
27	CLARK-16	57	0.05
28	CLARK-17	57	0.05
29	CLARK-18	57	0.05
30	CLARK-19	57	0.05
31	CLARK-20	57	0.05
32	CLARK-21	57	0.05
33	CLARK-22	57	0.05
34	SAGUARO-1	90	0.055
35	NCA 1-1	85	0.11
36	NCA 2-1	85	0.11
37	LvCogen-1	50	0.04
38	LVC-1	118	0.05
39	LVC-2	118	0.05
40	GRIF7x24-1	570	0.03
41	RG4CDWR-4	233	0.09



## Appendix B

Table B.1. Generator List with FOR Values for the Entire NV Energy System, 2010

No.	Generator Name	Capacity, MW	FOR
1	CLARK MT-3	72	0.06
2	CLARK MT-4	72	0.04
3	PINON CC-1 (80 MW CT +30 M steamer)	108	0.03
4		541	0.05
5		53	0.01
6	TRACY-2	83	0.01
7	TRACY-3	108	0.03
8	CLARK-10	57	0.03
9	CLARK-11	57	0.05
10	CLARK-12	57	0.05
11	CLARK-13	57	0.05
12	CLARK-14	57	0.05
13	CLARK-15	57	0.05
14	CLARK-16	57	0.05
15	CLARK-17	57	0.05
16	CLARK-18	57	0.05
17	CLARK-19	57	0.05
18	CLARK-20	57	0.05
19	CLARK-21	57	0.05
20	CLARK-22	57	0.05
21	CLARK-4	63	0.25
22	CLARK-9	250	0.04
23	FT CH-1	113	0.02
24	FT CH-2	113	0.05
25	ALLEN CT-3	84	0.11
26	ALLEN CT-4	84	0.11
27	HA_2x1-1	524	0.03
28	HIG_2x1-1	600	0.01
29	Len1_2x1-1	601	0.02
30	Len2_2x1-2	601	0.02
31	Navajo-1	85	0.03
32	Navajo-2	85	0.03
33	Navajo-3	85	0.03
34	REID GDR-1	100	0.12
35	REID GDR-2	100	0.12
36	REID GDR-3	100	0.12
37	REID GDR-4&5	257	0.09
38	SHW1_2x1-1	599	0.01
39	SUNPEAK-3	78	0.05
40	SUNPEAK-4	78	0.043
41	SUNPEAK-5	78	0.07
42	VALMY-1	127	0.06

No.	Generator Name	Capacity, MW	FOR
43	VALMY-2	134	0.06
44	Beowawe	17.7	0.01
45	Brady	24	0.0076
46	Desert Peak 2	25	0.01
47	Faulkner 1	49.5	0.01
48	Galena 2	13	0.01
49	Galena 3	26.5	0.01
50	Homestretch	2.1	0.0076
51	Jersey Valley	22.5	0.01
52	Richard Burdette	26	0.01
53	Salt Wells	23.6	0.01
54	San Emidio (Amor 2)	3.8	0.01
55	Soda Lake I & II	23.1	0.01
56	Steamboat Hills	14.6	0.01
57	Steamboat IA	2	0.01
58	Steamboat II	13.4	0.01
59	Steamboat III	13.4	0.01
60	Stillwater	47.2	0.01
61	LVC-1	118	0.05
62	LVC-2	118	0.05
63	LyCogen-1(older unit)	50	0.04
64	RG4CDWR-4	233	0.09
65	TOLL15_1-1	525	0.01
66	NCA 1-1	85	0.11
67	NCA 2-1	85	0.11
68	GRIF7x24	570	0.03
69	SAGUARO-1	90	0.09
70	NMTblk12-1	168	0.06
71	NMTblk3-1	41	0.06
72	WINN GT-1	17	0.03



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