

## Section 5: PJM Effective Load Carrying Capability Analysis

### 5.1 Overview

The Effective Load Carrying Capability (ELCC) analysis provides key parameters to the determination of the Accredited UCAP value of ELCC Resources. The model employed to perform the ELCC analysis is probabilistic and requires inputs associated with load uncertainty and resource performance uncertainty. The model calculates hourly loss of load probability (LOLP) so that the 1-day-in-10-years loss of load expectation (LOLE) criterion is met. The output of the model is the Portfolio UCAP. A heuristic is then performed to allocate the Portfolio UCAP to each ELCC Class, determining the Class UCAPs and the Class Ratings.

### 5.2 Load Model

The first input into the ELCC analysis is the Load Model. The Load Model is intended to capture a wide range of load scenarios, in other words to capture load uncertainty, for an entire future delivery year. Since the ELCC model is hourly, each load scenario in general is a collection of 8,760 values (however, if a specific scenario is constructed with data from a leap year, then such a scenario covers 8,784 hours). The Load Model has the following components:

#### 5.2.1 Hourly Load Shape

Hourly Load Shapes (HLS) are derived consistent with: (i) actual weather experienced during past delivery years; and (ii) the most recent PJM load forecast model. Specifically, the actual hourly weather data during past years is input into the PJM load forecast model to derive a set of HLS for each future target delivery year included in the ELCC analysis. The HLS are derived with weather data from each delivery year in the period 2012/2013 Delivery Year through the most recent past delivery year preceding the timing of the ELCC analysis. Note that the HLS are not actually simulated in the ELCC model; however, they are key to determine the Hourly Load Scenarios (which are effectively simulated in the ELCC model) and the Probability for each Hourly Load Shape (which is used to calculate LOLP).

#### 5.2.2 Probability for each Hourly Load Shape

Each HLS has an associated probability of occurrence (PHLS), which is calculated using the following procedure:

- i. Gather the monthly peak load values produced by the weather scenarios used in the PJM load forecast process.
- ii. Calculate the summer and winter peak loads for each of the weather scenarios, then use a clustering algorithm to group the weather scenarios represented by pairs (summer peak, winter peak) into a limited set of clusters. For example, the result of this step provides information such as: there are X% of the weather scenarios in cluster C that is representative of extreme summer peaks and extreme winter peaks.
- iii. Determine the summer and winter peaks in each HLS. For instance, if there are n HLS, there will be n pairs (summer peak, winter peak).
- iv. For each pair in the previous step, determine the most representative cluster based on the summer and winter peak values. For instance, if year 1 has an HLS with an extreme summer peak and an extreme winter peak, then year 1's HLS is representative of the cluster that contains extreme summer and extreme winter peaks (say, cluster C). The probability assigned to year 1 is P1%, which is the share of weather scenarios in cluster C (out of the total quantity of weather scenarios considered in the most recent PJM Load Forecast).

### 5.2.3 Hourly Load Scenarios

The Hourly Load Scenarios (HLSc) are intended to represent the possible variations around each HLS and therefore, the possible variations representative of the cluster of weather scenarios associated with each HLS. The HLSc derivation process employs the monthly peak load values from the weather scenarios in the representative cluster. For instance, if the HLS for year 1 is representative of cluster C, then the monthly peak load values from the weather scenarios in cluster C are used to derive the HLSc for year 1's HLS. The procedure to derive the HLSc is as follows:

- i. Identify the monthly peaks from the weather scenarios in the cluster that each HLS is representative of.
- ii. Using the 12 monthly peak load values from the weather scenarios in the representative cluster, determine the parameters of a multivariate normal distribution. A multivariate normal distribution is used instead of a normal distribution to account for the correlation between monthly peak loads.
- iii. Using Monte Carlo sampling and the multivariate normal distribution, derive 1,000 HLSc for each of the HLS.

## 5.3 Resource Performance

This is the second key input into the ELCC analysis. Modeling resource performance uncertainty in the ELCC model entails deriving the hourly output of each resource in the ELCC Model associated with each HLSc. The procedure to derive the hourly output differs by resource category and/or resource class.

### 5.3.1 Unlimited Resources

The metrics that are key to model the hourly availability/unavailability patterns of Unlimited Resources are the Effective Equivalent Forced Outage Rate – Demand (EEFORd), the Equivalent Planned Outage Factor (EPOF), and the Equivalent Maintenance Outage Factor (EMOF). Jointly, these metrics capture all the types of outages that Unlimited Resources experience. Two additional metrics that underlie the EEFORD calculation are also derived for each unit: the Mean Time to Failure (MTTF) and the Mean Time to Repair (MTTR). All these metrics are calculated for each unit based on historical Generator Availability Data System (GADS) data from the most recent 5-year period prior to running the ELCC analysis.

Monte Carlo sampling is employed to derive the hourly availability/unavailability patterns related to forced outages (using the MTTF, MTTR and EEFORD metrics) while a deterministic scheduling algorithm is employed to derive the availability/unavailability patterns related to planned and maintenance outages (using the EPOF and EMOF metrics).

### 5.3.2 Variable Resources

The development of the hourly output for variable resources entails producing an Hourly Output Shape (HOS) based on the historical weather years used in the construction of the HLSc. The HOS for an ELCC Class of variable resources (e.g., wind) comprises actual and backcasted output from existing members of the class and backcasted output from planned members of the class. If there are N HLS (and associated HLSc) based on N historical weather years, then there will be N HOS for each ELCC class belonging to the variable resources category. The derivation of HOS based

on a historical weather year H for a future delivery year F is described as follows:

- Calculate hourly actual metered output in MW from all units that were classified as existing in year H and are expected to still be in service in year F.
- Calculate hourly total backcasted output in MW from all units that were classified as planned in year H and are expected to be in service in year F.
- Calculate the hourly total output in MW (by including actual and backcasted outputs from the two steps above) and hourly total MFO for future delivery year F.
- For each hour, divide the hourly total output by the hourly total MFO. The result constitutes the Hourly Output Shape (HOS) based on historical weather year H for future delivery year F.

### 5.3.3 Limited Duration Resources and Combination Resources

The hourly output of Limited Duration Resources and Combination Resources is derived by using a simulated dispatch procedure that takes into account the rest of system conditions (load, other resources' output) simulated in the ELCC model. The simulated dispatch procedure also incorporates the charging or charging-equivalent process whereby Limited Duration Resources and Combination Resources replenish their storage components. Limited Duration Resources and Combination Resource components that have the same impact on LOLE as the same quantity of perfect resource are modeled as perfect resources. The procedure to derive the simulated dispatch for Limited Duration Resources and Combination Resources applied to each hour is the following:

- i. Calculate the Margin Threshold as total available resources prior to dispatching Limited Duration Resources and Combination Resources minus load.
- ii. Calculate the Nameplate Threshold as the total estimated available Effective Nameplate Capacity of Limited Duration Resources and Combination Resources minus the targeted Primary Reserves assumed to be provided by Limited Duration Resources and Combination Resources.
- iii. Calculate the Dispatch Threshold as the absolute value of the Margin Threshold minus the Nameplate Threshold.
- iv. If the Margin Threshold is greater than zero, charging for resources that require charging can proceed. However, the charging can only occur to the extent that the additional load in the system does not cause the Margin Threshold to be less than zero. The charging step recognizes differences between classes within the Limited Duration Resources and Combination Resources category regarding the charging or charging-equivalent process. This entails using hourly streamflow data to replenish the storage component of resources within the Hydropower With Non-Pumped Storage class, charging the storage component in closed-loop solar-storage resources only to the extent that the solar component can support that charging, and reflecting charging constraints on standalone storage resources and storage components in open-loop solar-storage resources.
- v. If the Margin Threshold is less than zero, the Limited Duration Resources and Combination Resources are assigned a targeted dispatch. If the Dispatch Threshold is less than zero, Limited Duration Resources and Combination Resources are assigned to supply load commensurate with the full Margin Threshold. Demand Resources receive no assignment. If the Dispatch Threshold is greater than or equal to zero, Limited Duration Resources and Combination Resources are assigned to supply load commensurate with the Nameplate Threshold. Demand Resources receive an assignment equal to the Margin Threshold minus

Nameplate Threshold (i.e., the portion of the margin that was not assigned to Limited Duration Resources and Combination Resources).

- vi. The previous step determines the load assignment for the entire Limited Duration Resources and Combination Resources category. The load assignment for each ELCC Class within the category is determined based on a ratio which is calculated as that class's estimated available Effective Nameplate Capacity divided by the total estimated available Effective Nameplate Capacity of Limited Duration Resources and Combination Resources.
- vii. If a load assignment cannot be partially or fully supplied by an ELCC Class because of power or energy limitations, Demand Resources will receive the unsupplied portion of the assignment. If all Demand Resources are exhausted, the other ELCC Classes will receive the assignment based on an availability-derived order, from most-available class to less-available class.
- viii. For ELCC Classes that require specific modeling of the individual units in the Simulated Dispatch (e.g., Hydropower With Non-Pumped Storage), the load assignment received by the class will be further allocated to the individual units in the class based on the same logic described in vi and vii (the two immediately preceding steps).

#### 5.3.4 Demand Resources

The simulated dispatch of Demand Resource is governed by steps v and vii described above for the simulated dispatch of Limited Duration Resources and Combination Resources. The amount of Demand Resources available to perform during each hour of the simulation is calculated as Nominated DR Value (a constant value for an entire delivery year) times  $r$ , where  $r$  is defined as the ratio of simulated hourly load (in MW) to 50/50 peak load (in MW).

### 5.4 Loss of Load Expectation (LOLE) Calculation

As indicated in 5.2.3, there are 1,000 HLSc for each HLS. If there are  $N$  HLS, then the total number of HLSc is  $N$  times 1,000. The probability of each HLSc, PHLS<sub>c</sub>, is calculated by using the PHLS described in 5.2.2. For example, if the HLS based on year 1 has PHLS equal to  $P_1$ , then each of the 1,000 HLSc created based on year 1's HLS has a PHLS<sub>c</sub> equal to  $P_1$  divided by 1,000.

In the ELCC analysis, a loss of load occurs when the hourly load is greater than the hourly output of all the resources considered available in the simulation. LOLE is calculated as follows:

- a) For each HLSc, count the number of days in a delivery year that include at least one hour of loss of load.
- b) Multiply the quantities from the previous step by the corresponding PHLS<sub>c</sub>.
- c) Add up all the quantities calculated in the previous step. The result is the LOLE of the simulated system.

### 5.5 Calculation of ELCC Portfolio UCAP

The calculation of the ELCC Portfolio UCAP requires simulating the system twice. The first simulation (PJM Case "Including") includes the ELCC Resources in addition to the Unlimited Resources and Demand Resources. The second simulation (PJM Case "Excluding") excludes the ELCC Resources, but includes Unlimited Resources, Demand Resources, and a variable amount of Perfect Generation (i.e., generation that is assumed to have no outages and no use limitations). The PJM Case "Including" is run until an LOLE of 0.1 days per year is achieved. At that point, the peak load value for

the case is recorded. The PJM Case “Excluding” is then run by inputting the peak load value from the PJM Case “Including” and determining the amount of Perfect Generation necessary to add to the system in order to achieve an LOLE of 0.1 days per year. This added amount of Perfect Generation is the ELCC Portfolio UCAP (i.e. the ELCC of the entire group of ELCC Resources included in the simulation).

## 5.6 Calculation of ELCC Class UCAP and ELCC Class Rating values

The allocation of the ELCC Portfolio UCAP to the ELCC Classes, and ultimately determining the ELCC Class UCAP and ELCC Class Rating values, is performed according to the incremental value of each class measured in the absence of the other ELCC Classes adjusted to reflect the diversity interaction of the ELCC Class with all the other modeled ELCC Classes. The procedure is as follows:

- A. Each ELCC Class has a **representative incremental quantity** whose hourly output is determined consistent with the output of the subject class.
- B. For each ELCC Class, the “**Last-In ELCC UCAP**” (in MW) is defined as the difference between (a) the ELCC Portfolio UCAP of a portfolio that includes all classes and resources in the ELCC model plus the representative incremental quantity of the subject ELCC Class and (b) the ELCC Portfolio UCAP of a portfolio that includes all classes and resources in the ELCC model.
- C. For each ELCC Class, the “**Last-In ELCC Rating**” (in percent) is equal to [Last-In ELCC UCAP]/[Effective Nameplate Capacity of the increment]
- D. For each ELCC Class, the “**First-In ELCC UCAP**” (in MW) is defined as the ELCC Portfolio UCAP of a portfolio consisting solely of the representative incremental quantity of the subject ELCC Class;
- E. For each ELCC Class, the “**First-In ELCC Rating**” (in percent) is equal to [First-In ELCC UCAP]/[Effective Nameplate Capacity of the increment];
- F. For the entire ELCC Portfolio, the “**Portfolio Diversity Interaction**” (in MW) is defined as the difference of (a) the sum across all classes in the model of the product of [the aggregate Effective Nameplate Capacity of the class] times [the First-In ELCC Rating of the class]; minus (b) the ELCC Portfolio UCAP of a portfolio that includes all classes and resources in the ELCC model;
- G. For each ELCC Class, the “**Class Delta Rating**” (in percent) is the Last-In ELCC Rating minus the First-In ELCC Rating.
- H. For each ELCC Class, the “**Class Delta UCAP**” (in MW) is the Class Delta Rating times the aggregate Effective Nameplate Capacity of the class.
- I. For the entire ELCC Portfolio, the “**Total Delta UCAP**” (in MW) is the sum of the Class Delta UCAP values of all classes.
- J. For each ELCC Class, the “**Class Delta Share**” (in percent) is equal to [Class Delta UCAP] divided by [Total Delta UCAP].
- K. For each ELCC Class, the “**Class PDI Share**” (in MW) is the product of the [Portfolio Diversity Interaction] times the [Class Delta Share].
- L. For each ELCC Class, the “**Class Rating Adjustment**” (in percent) is the Class PDI Share divided by the aggregate Effective Nameplate of the class.
- M. For each ELCC Class, the “**ELCC Class Rating**” (in percent) is the First-In ELCC Rating minus the Class Rating Adjustment.



- N. For each ELCC Class, the ELCC Class UCAP is the ELCC Class Rating times the aggregate Effective Nameplate Capacity of the resources in the model that belong to the subject class.