How Effective Load Carrying Capability ("ELCC") Accreditation Works

Andrew Levitt
Market Design and Economics Dep't
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PJM ELCC

- **Function:** creates a “class rating” that sets the amount of capacity a resource can provide

- **Approach**: Accreditation based on class rating with unit-specific performance adjustment.
- ELCC results change when the resource mix and/or load shape changes.
- Model and accreditations updated annually with a four-year-forward horizon *(plus six more years of indicative values)*

- **Proposed launch**: 2023/2024 Delivery Year *(first auction scheduled for December 2021)*

- **Scope**: ELCC applies to all renewables *(wind, solar, hydro, landfill gas)* and storage-type resources *(pumped hydro, batteries, hybrids, generic limited-duration resources)*

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Preliminary ELCC Results for 2023 Compared to Status Quo

	Preliminary for 2023	Status Quo	Delta
Onshore Wind	13%	14.7%	-1.7%
Solar Fixed	29%	38%	-9%
Solar Tracking	54%	60%	-6%
4-hr Storage	79%	40%*	+39%
8-hr Storage	95%	80%*	+15%
Hydro Intermittent	44%	100%*	-56%
Landfill Gas	62%	100%*	-38%

** Derated by (1-EFORd)*

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Preliminary ELCC Results for 2023 vs. 2028

	Preliminary ELCC Class Rating 2023	Preliminary ELCC Class Rating 2028
Onshore Wind	13%	11%
Offshore Wind	27%	21%
Solar Fixed	29%	18%
Solar Tracking	54%	31%
4-hr Storage	79%	79%
8-hr Storage	95%	93%
Solar Hybrid Open Loop – Storage Component	80%	76%
Solar Hybrid Closed Loop – Storage Component	79%	76%
Hydro Intermittent	44%	46%
Landfill Gas	62%	61%

- Preliminary results are for estimated actual ELCC ratings, not the floors. Floor values for 2023 and 2028 will be lower.
- ELCC model not expected to significantly change for final results.
- Final results will change vs. preliminary due to updates to a variety of inputs.
- Offshore wind uses early preliminary hourly profiles – results may change significantly with more precise profiles.
- “Open loop” hybrids can charge from the grid; “closed loop” hybrids cannot.
- Hybrids modeled as 100 percent max facility output, 100 percent tracking solar nameplate, 25 percent four-hour storage nameplate.

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ELCC: More Details

1 ELCC uses Loss of Load Expectation analysis (consistent with today's Installed Reserve Margin study) to precisely quantify the resource adequacy contribution of a resource.

2 ELCC uses historical load shapes and weather data to compare future expected load shapes to future expected resource output. Resources that consistently produce during times of expected shortage get a higher ELCC.

3 ELCC is sensitive to a small number (e.g., 200) high-risk hours over 10+ years.

4 ELCC is sensitive to load shapes and the resource mix (e.g., with more solar, risk windows shift.)

5 It was originally developed in the 1960s to quantify the resource adequacy impact of carrying very large plants in a fairly small balancing area.

6 It was later applied to variable resources.

7 It can theoretically be applied to zones or subzones, but it does NOT capture the local reliability benefits of a resource.

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Under high deployment of variable resources and limited-duration resources, periods of high risk of load shed can shift.

E.g., with high solar deployment displacing unlimited resources, summer risk shifts later in the afternoon and evening.

By comparing a resource or class to load and other resources, ELCC accounts for:

1. Hourly and seasonal trends
2. Consistency of output during high-risk periods
3. The effect of limited energy and limited-duration capability of storage-type resources
4. The effect of a changing resource mix, including interactions among different resource classes
5. Impacts due to load shape changes

ELCC is therefore a useful tool for quantifying resource adequacy value of resources under high deployment of renewables and storage.

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Variable Resource Classes

- Tracking solar
- Fixed-tilt solar
- Onshore wind
- Offshore wind
- Landfill gas units that cannot run consistently at ICAP levels for 24 or more hours
- Intermittent run-of-river hydropower

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Storage and Hybrid Classes

- **Energy storage resources** of four-hour, six-hour, eight-hour and 10-hour duration, or longer duration as required to secure a 100 percent ELCC rating. Such classes include pumped-storage hydropower.
- **Generic limited-duration resources** of four-hour, six-hour, eight-hour and 10-hour duration, or longer duration as required to secure a 100 percent ELCC rating.
- **Hybrids** that are combinations of one of the above generation types plus an energy storage resource of four-hour, six-hour, eight-hour or 10-hour duration.
- **Hybrids** that are combinations of one of the above generation types plus generic limited-duration resource of four-hour, six-hour, eight-hour or 10-hour duration.
- **Hydropower** with non-pumped storage (i.e., pondage or reservoirs, but no pumps)

An energy storage resource of "X"-hours duration is capable of running continuously at its effective nameplate capacity power level for X hours starting with a full state of charge under conditions of highest risk of shortage on the PJM system, provided that such calculation excludes any megawatt hours reserved for Black Start Service or for other firm commitments, and that such resource is capable of fully recharging in a similar amount of time.

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Interaction of CIRs & ELCC

1. ELCC assesses a unit's physical capability to provide capacity → **UCAP**.
2. Capacity Interconnection Rights (**CIRs**) are the amount of firm deliverability a generator has reserved on the transmission network.
3. A unit can provide only the capacity it is capable of producing (UCAP), and also must have enough firm deliverability (CIRs) to support such UCAP.
4. **For resources to deliver full output, CIRs must generally be greater than UCAP.**

   E.g., a 100 MW gas plant with a 10 percent outage rate has a 90 MW UCAP and needs 100 MW CIRs.

CIRs are distinct from ELCC/UCAP. ELCC and CIR rules need to be integrated with matching principles. *To meet FERC's deadline, PJM deferred CIR changes vs. the ELCC proposal.*

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Accredited UCAP

- "Accredited UCAP" is a measure of the physical capability of an ELCC Resource (i.e., renewables and storage).
- An ELCC Resource can provide Capacity up to the lesser of its Accredited UCAP and its CIRs.
- Accredited UCAP is calculated differently for different ELCC Resource categories, but is generally derived from:

$$EffectiveNameplateCapacity \ X \ ELCCClassRating \ X \ ELCCResourcePerformanceAdjustment$$

- "ELCC Class Rating" is an output of the ELCC model.

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How the ELCC Model Works: **Class Rating**

- The ELCC model compares hourly load to hourly supply across a simulated year. ELCC Class Rating values depend on the relative output of a class of resources (wind, solar, etc) during hours in which demand exceeds or nearly meets supply ("shortage hours").
  - In fact, the metric is derived from Loss of Load Expectation analysis comparing scenarios with and without ELCC Resources.
- If resources consistently perform well during shortage hours, the Class Rating is high.
- If resources sometimes perform well and sometimes perform poorly, the Class Rating is lower.
- If resources consistently perform poorly, the Class Rating is lowest.
- Simulated shortage hours are often but not always summer afternoons.

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Examples of How the ELCC Model Works: **Class Rating**

1. Theoretically: an ELCC Class that always produces power at 30% of it's nameplate power rating will get an ELCC Class Rating of ~30%.
2. Theoretically: an ELCC Class that produces power at 100% at midnight but 30% other hours will get an ELCC Class Rating of ~30%.
   - *Because in the simulated scenarios midnight is never at risk of shortage*
3. Theoretically: an ELCC Class that produces power at 60% on even-numbered dates but 0% on odd-numbered dates will get an ELCC Class Rating of ~30%.
   - *There are a variety of shortage-type events on different days and seasons, and ELCC ratings are sensitive to performance on all of them.* ***Output that is well above the ELCC Accredited UCAP value in certain hours can contribute to that value.***

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How the ELCC Model Works: **Class Rating**

- For Variable Resources (e.g., wind, solar, intermittent hydro), actual historical output is used as the hourly profile in the ELCC model.
  - *This includes any actual curtailment.*
  - *For Planned Resources or resources that entered service after June 1, 2012, a backcast is used to develop an hourly shape from such units to develop output shapes for all years back to 2012.*
  - *Historical output will exceed Accredited UCAP in many hours, including potentially shortage hours.*
- For storage-type resources (e.g., dispatchable hydro, batteries), a simulated output profile is developed.
  - *Simulated output could exceed Accredited UCAP in many hours, especially for shorter-duration storage-type resources whose inventory is exhausted during some shortage events.*
- The ELCC model uses output in all hours towards accreditation, without regard for CIRs or potential curtailment on the transmission network.
  - *Actual curtailment of Variable Resources is included in the ELCC analysis.*

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How the ELCC Model Works: **Performance Adjustment**

- The ELCC Model analyzes aggregate classes to produce a Class Rating. Individual units may perform better or worse than the class.
- For Variable Resources:
  - *A metric called "200CPx2" compares performance of a unit to performance of the overall class—if it is the same, the Performance Adjustment is 100%. Better performance is above 100% (can be 150% or higher), and vice versa.*
- For storage-type resources: perfect availability is assumed in the ELCC model, which simulates dispatched output from such resources.
  - *1-EFORd is used as a Performance Adjustment to further derate such units based on actual unavailability.*
- For hybrid variable+storage resources:
  - *The variable component uses the same performance adjustment as its standalone equivalent; the storage component uses 1-EFORd.*
- Again, CIRs are not considered in these calculations. Some resources might have relatively higher or lower CIRs, but that does not change Performance Adjustment except to the extent it actually impacts hourly output in important hours (Variable Resources) or EFORd (storage-type resources).

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Variable Resource Performance Adjustments

Variable resources have a performance adjustment based on their output during:

The 200 coincident peak "gross load" hours of the last ten years

The 200 coincident peak "putative net load" hours of the last ten years

- The putative net load is the gross load minus the estimated historical output of the target resource mix, including the existing resources as well as expected incoming resources.
- A given resource's performance adjustment is the ratio of their performance metric to the weighted average performance metric across their entire class.

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Effective Nameplate Capacity

- Effective Nameplate Capacity is a relative measure of resource size.
- For Variable Resources: ENC is Maximum Facility Output.
- For storage-type resources: ENC similar to Installed Capacity, i.e. the lesser of:
  - Maximum Facility Output
  - Highest of last three summer tests
  - Level of output the resource can maintain for X continuous hours during peak conditions, where X is e.g., 4 hours, 6 hours, etc., depending on the characteristic duration of the class.
- ENC is not sensitive to CIRs.

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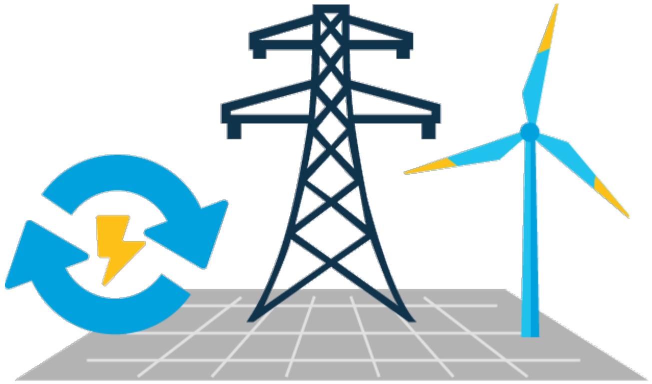
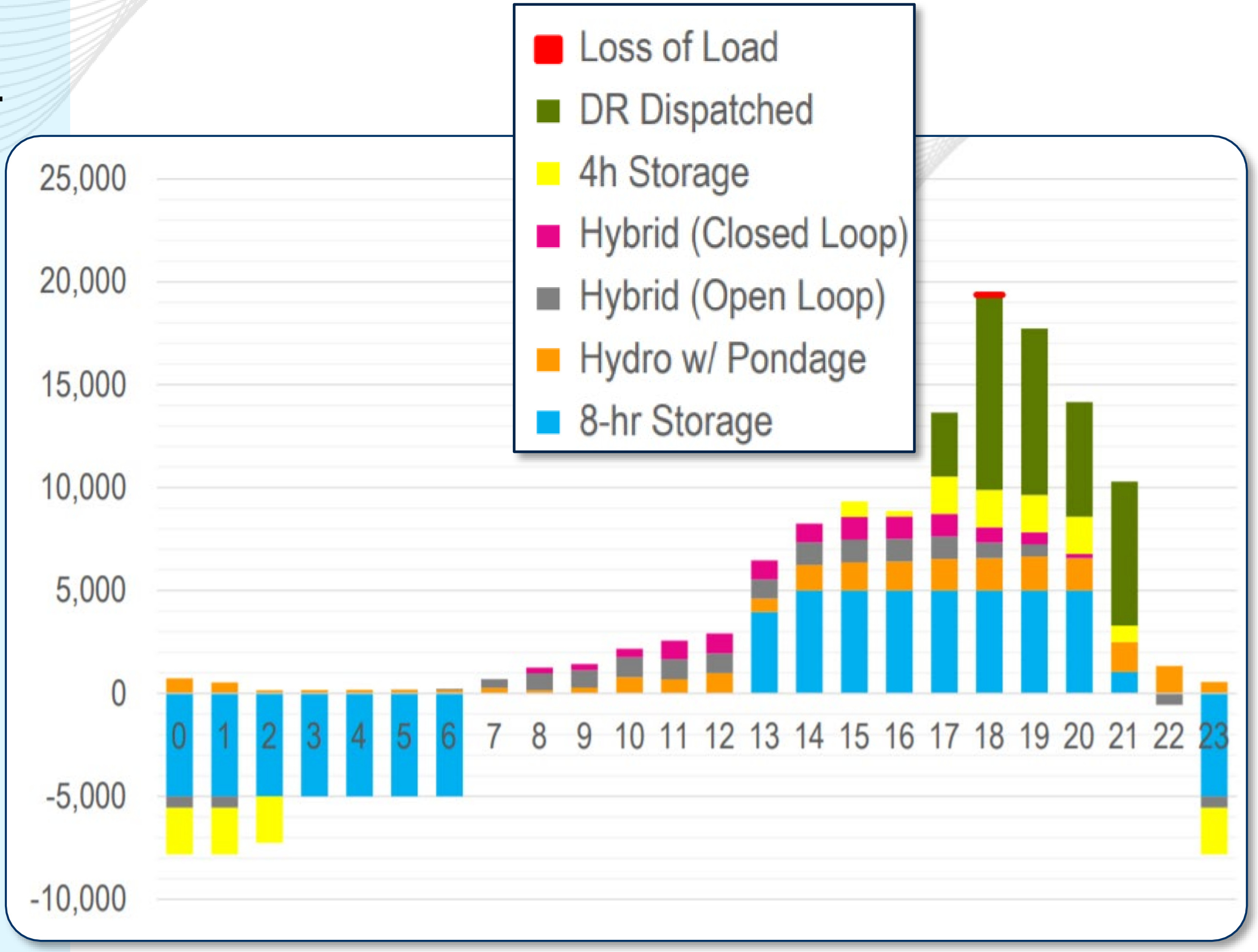
Appendix: General Treatment of Storage-Type Resources

- The hourly output shape of storage-type resources is based on simulated response to hourly conditions inside the model, rather than historical output.
- The simulated output requires parameters: maximum power, energy storage capability, etc.
- Otherwise, the ELCC analysis is the same for storage as it is for variable resources.
- All storage resources with identical parameters are assumed to perform the same.
- Downstream of the ELCC model, specific resource accredited UCAP values of storage-type resources are adjusted by (1-EFORd) to account for varying performance.



Appendix: Principles for Simulated Storage Dispatch

1. All else equal, maximizing reliability value of storage.
2. Consistency with the status quo for dispatching economic resources relative to demand resources (i.e., load management). In particular:
   a) Exhaust all economic resources prior to deploying load management
   b) Deploy load management in order to maintain primary reserves (currently 2,450 MW)
   c) Do not shed load in order to maintain primary reserves
3. Takes account of the effect of imperfect foresight of load, intermittent resource output and thermal outages, as well as diverse approaches to scheduling and bidding limited-duration resources.



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Appendix: ELCC Model Mechanism

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ELCC

- Introduced by Garver in 1966, ELCC provides a way to assess the capacity value (or reliability contribution) of a resource (or a set of resources) that is tied to the loss-of-load probability concept
- Can be defined as a measure of the additional load that the system can supply with a particular generator of interest, with no net change in reliability.
  - ELCC can be based on any reliability metric (LOLE, LOLH, EUE)
  - Since PJM uses LOLE to set up the requirement in the capacity market, the rest of this presentation will use LOLE

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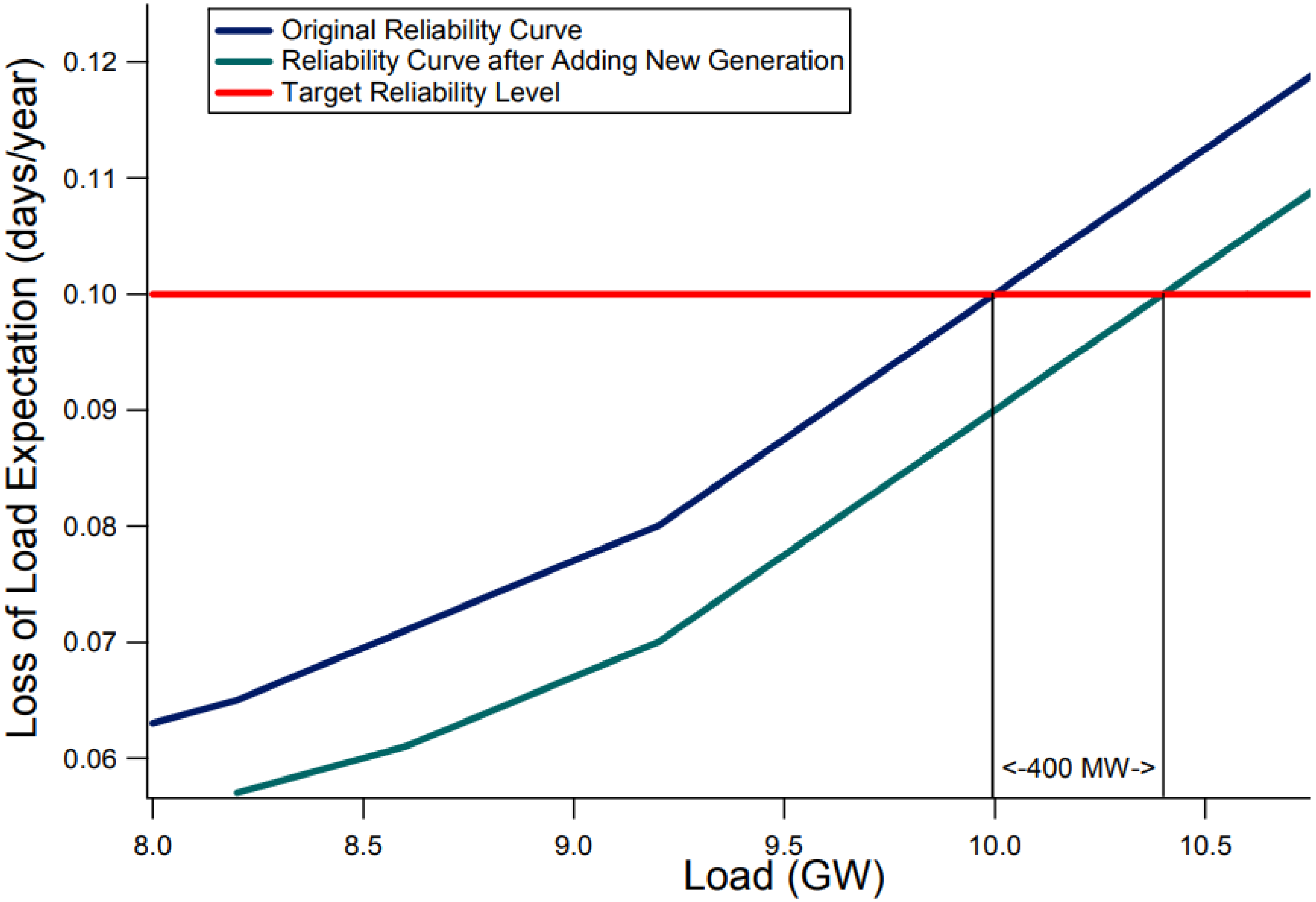

Figure 4. ELCC is the vertical distance between the reliability curves, measured at the target reliability level (400 MW at 1d/10y).

- Prospective analysis; based on inputs for a future target year
- LOLE is driven by the timing of high loss-of-load probability (LOLP) hours. Therefore, ELCC is driven by the timing of high LOLP hours
- A resource that contributes a significant level of capacity during high-risk hours will have a higher capacity value (ELCC) than a resource that delivers the same capacity only during low-risk hours

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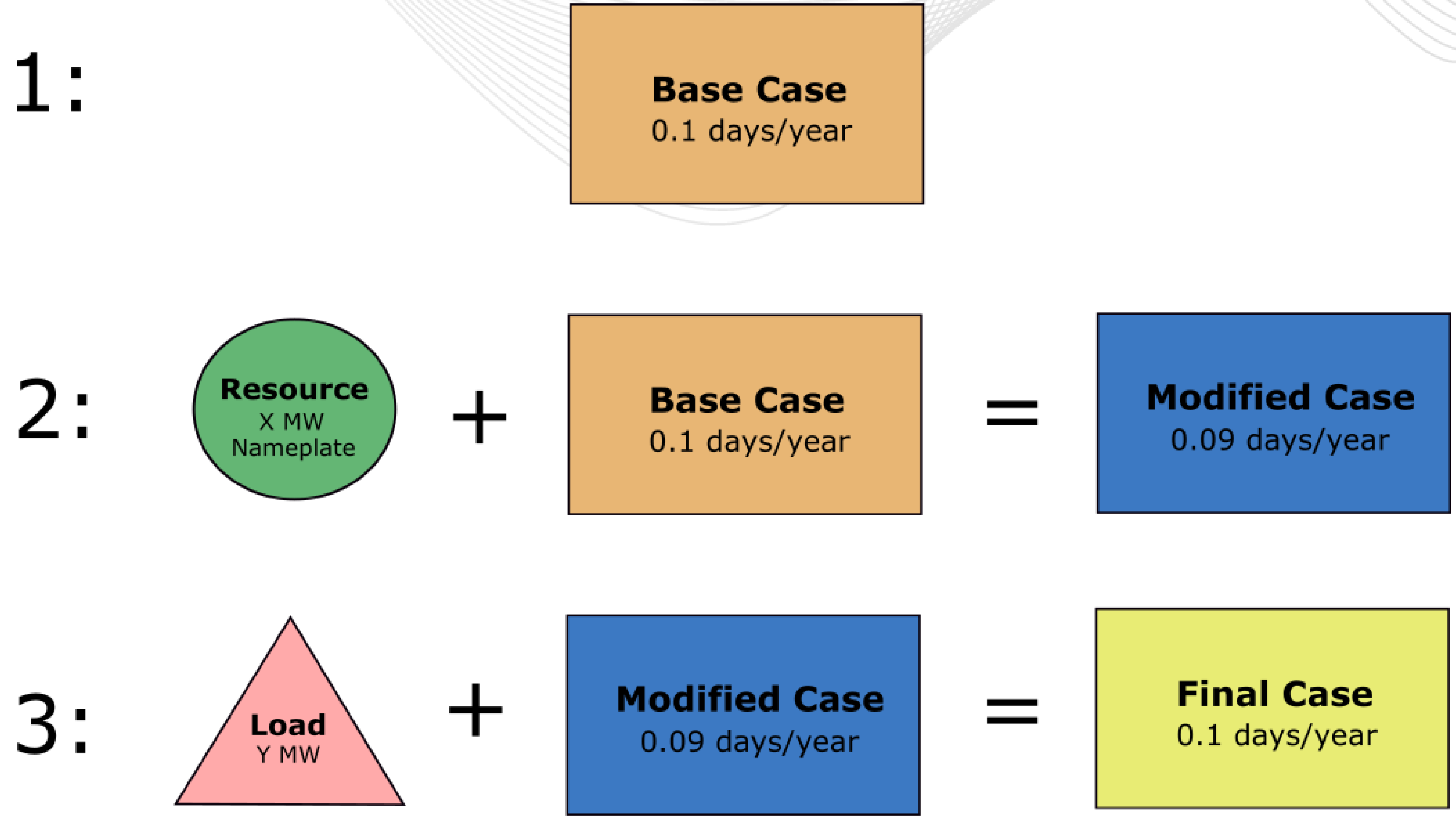
ELCC Approaches – "Load Approach"



**The ELCC of the Resource added in Step 2 is the amount of Load added in Step 3 (Y MW).
It can be expressed as percent of the Resource's nameplate (i.e., Y / X)**

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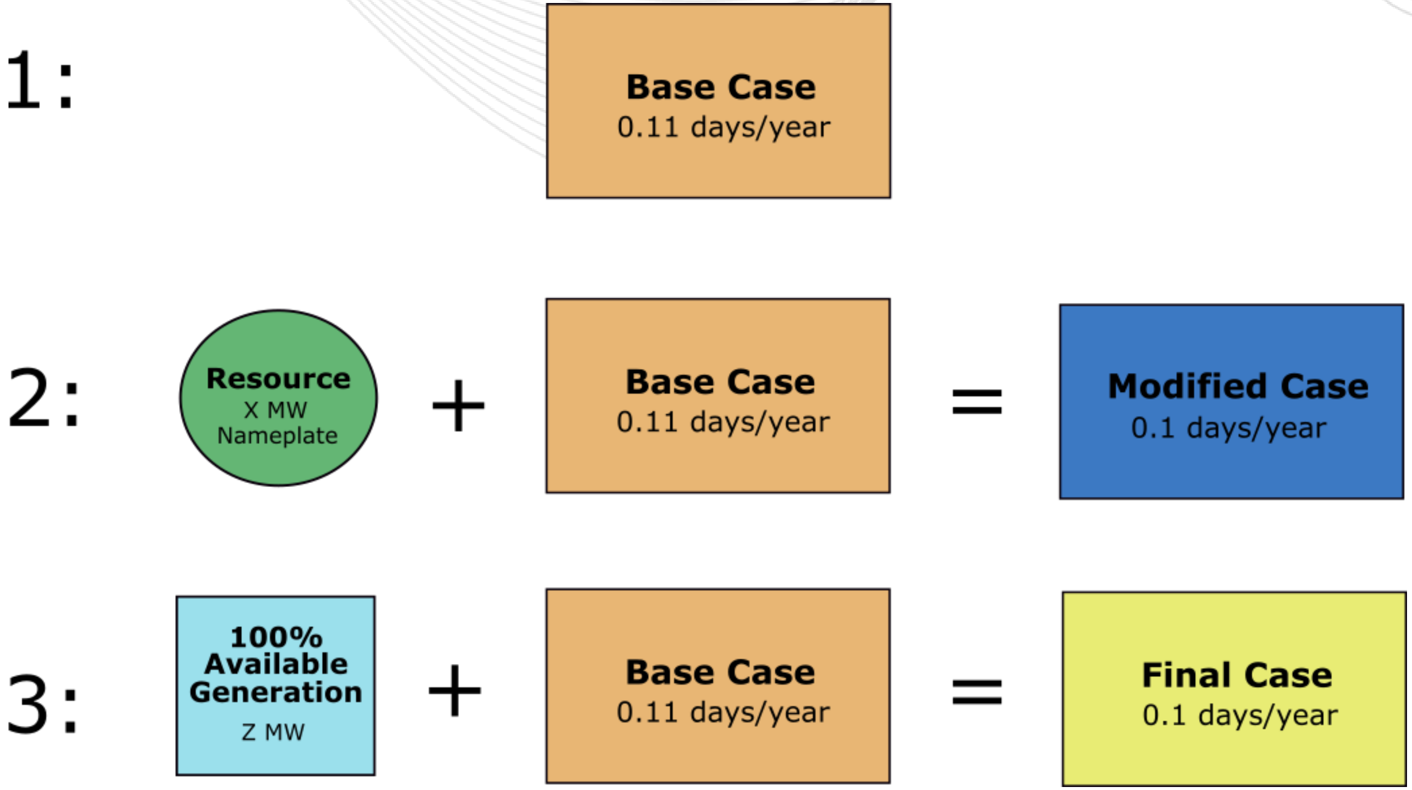
ELCC Approaches – “Generation Approach”



The ELCC of the Resource added in Step 2 is the amount of 100% Available Generation added in Step 3 (Z MW). It can be expressed as percent of the Resource’s nameplate (i.e., Z / X)

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- Period to analyze: 48 hours (2 days)
- Peak occurs at Hour 14
- No load uncertainty (for ease of exposition)
- Performance uncertainty on thermal generation (included but not shown in slides)
- Performance of limited resource:
  - From Hours 12 to 17 of Day 1, the resource provides 30% of Nameplate (NP)
  - Rest of the hours, the resource produces 0 MW
- Three nameplate penetration levels are examined: 1,000 MW, 10,000 MW and 30,000 MW
- For ease of exposition, the Load Approach is used to run ELCC

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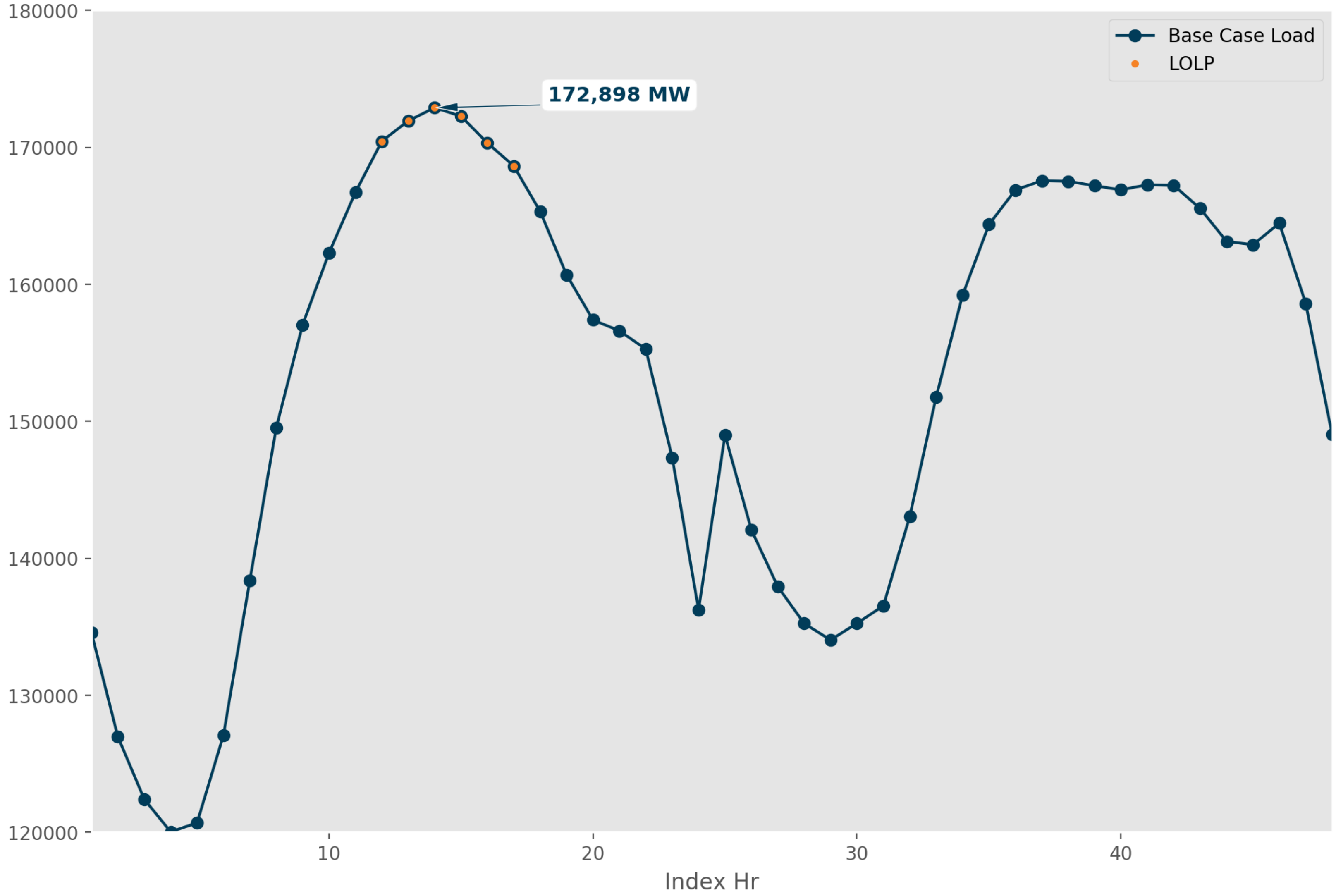
Example - Base Case



LOLE = 0.1 days/year

A peak of 172,898 MW can be served

Hours 12-17 are the only hours with LOLP greater than 0.

Only thermal resources

Limited resource is not included

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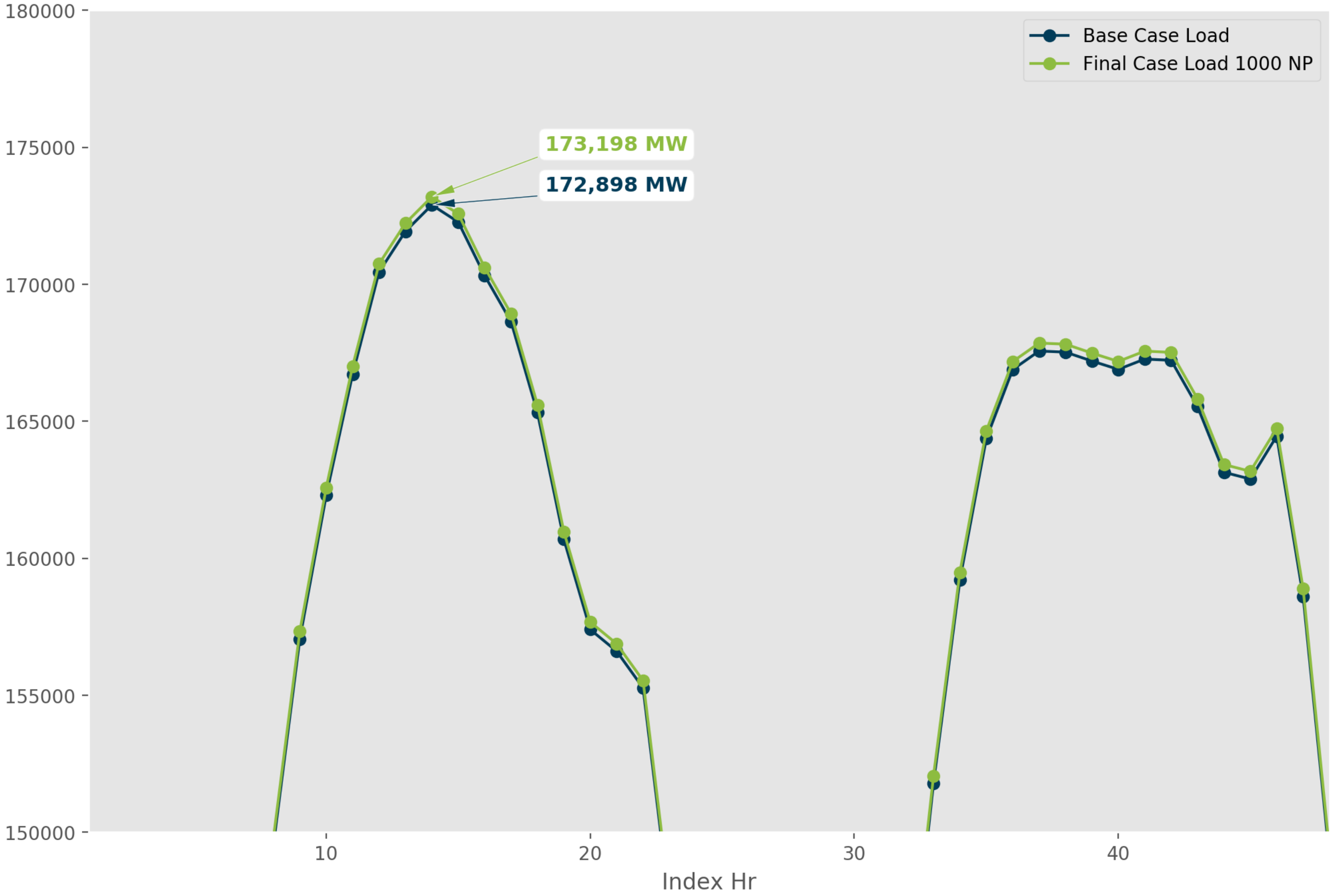
Example – Final Case - 1,000 MW Limited Resource



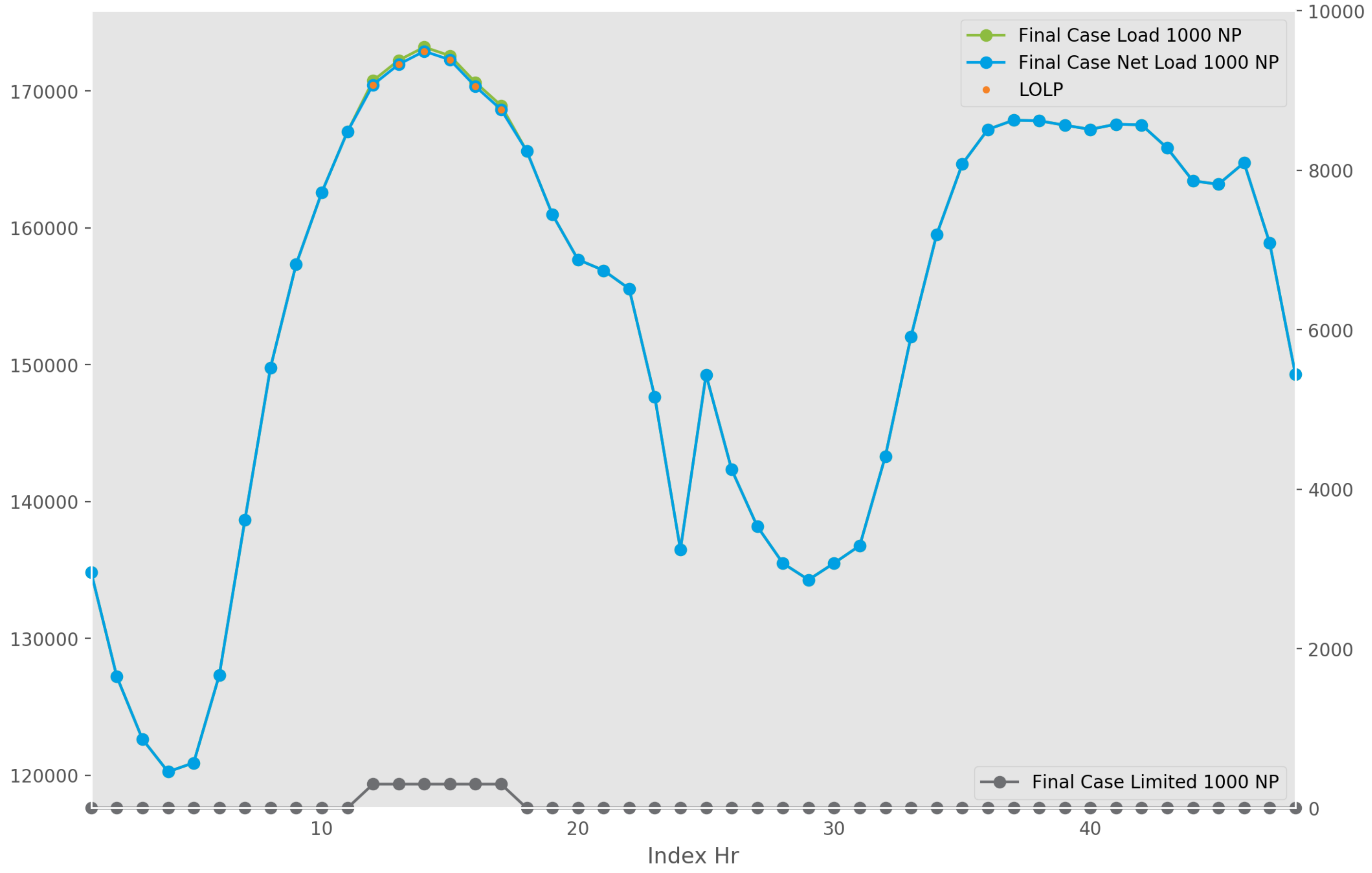
LOLE = 0.1 days/year

By adding the Limited Resource, which performs at 30% of NP during hours 12-17, the system can now serve a peak of 173,198 MW maintaining the same reliability

ELCC = 173,198 – 172,898
= 300 MW

ELCC (%) = 300 / 1,000 = 30%

Example – Final Case - 1,000 MW Limited Resource



All lines except for the gray line (performance of Limited Resource) are drawn based on the left y-axis

The Load Shape and the Net Load Shape in the Final Case almost overlap, except between hours 12-17 where the Limited Resource produces energy.

As in the Base Case, hours 12-17 continue to be the only hours with LOLP greater than 0. These hours coincide with the hours where the Limited Resource performs

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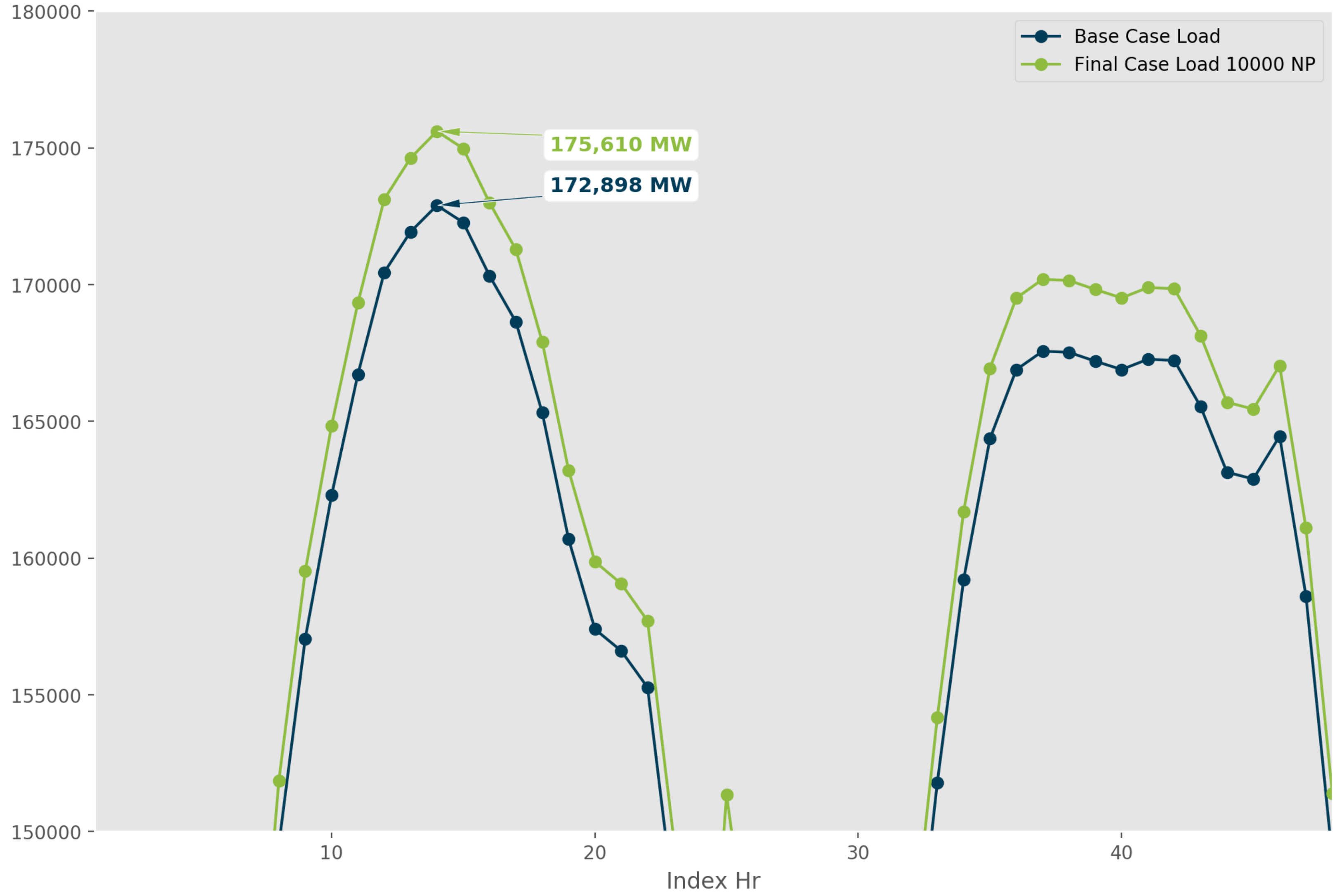
Example – Final Case - 10,000 MW Limited Resource



LOLE = 0.1 days/year

By adding the Limited Resource, which performs at 30% of NP during hours 12-17, the system can now serve a peak of 175,610 MW maintaining the same reliability

ELCC = 175,610 – 172,898
= 2,712 MW

ELCC (%) = 2,712 / 10,000
= 27.12%

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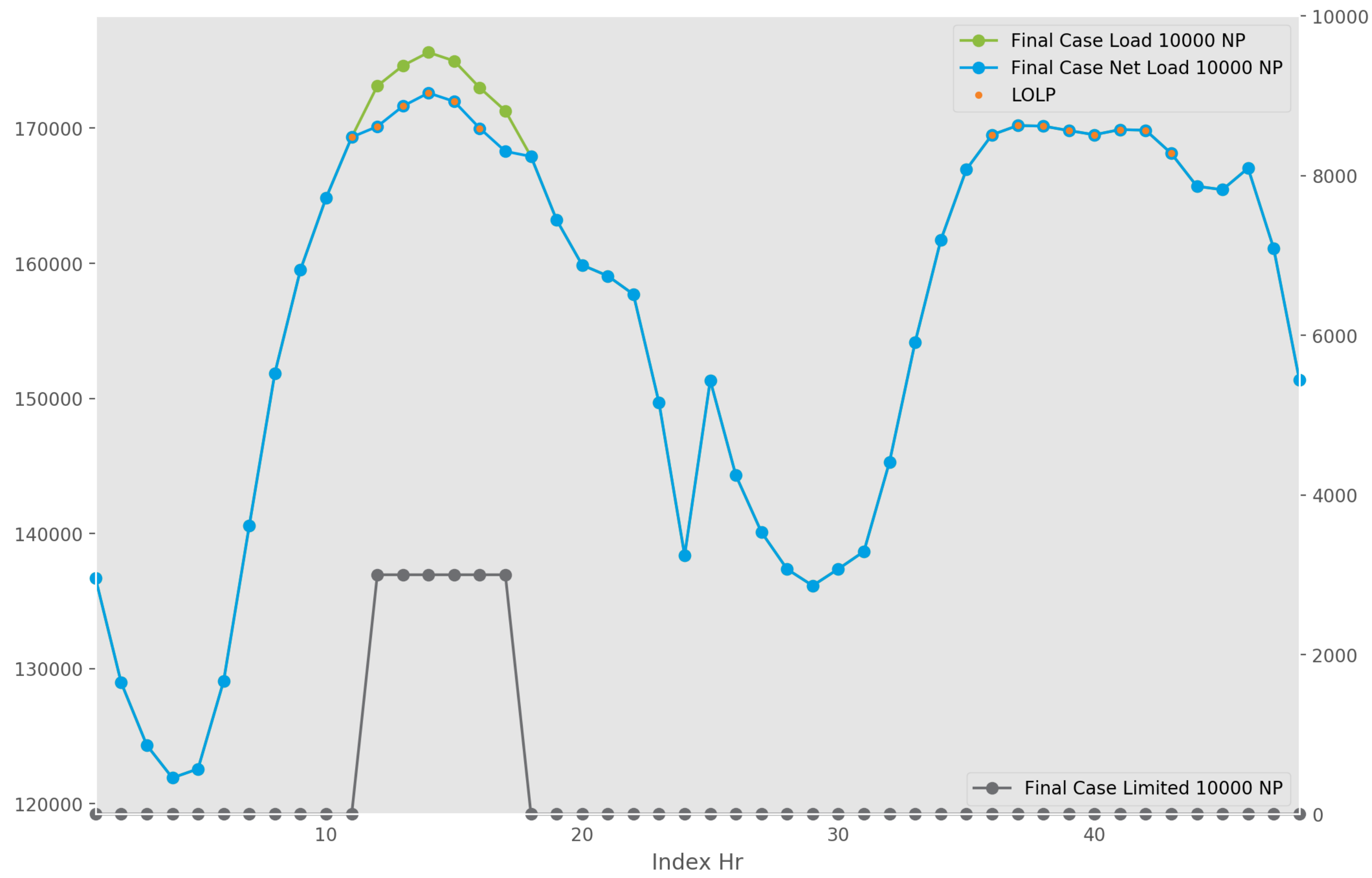
Example – Final Case - 10,000 MW Limited Resource



All lines except for the gray line (performance of Limited Resource) are drawn based on the left y-axis

The Load Shape and the Net Load Shape in the Final Case almost overlap, except between hours 12-17 where the Limited Resource produces energy.

Compared to the Base Case, there are many more hours with LOLP greater than 0. In fact, there are some hours in Day 2 with LOLP > 0 (hours 36-43).

However, 81% of the risk is still concentrated during hours 12-17. This is why the ELCC is still close to 30% (27%)

Example – Final Case - 30,000 MW Limited Resource

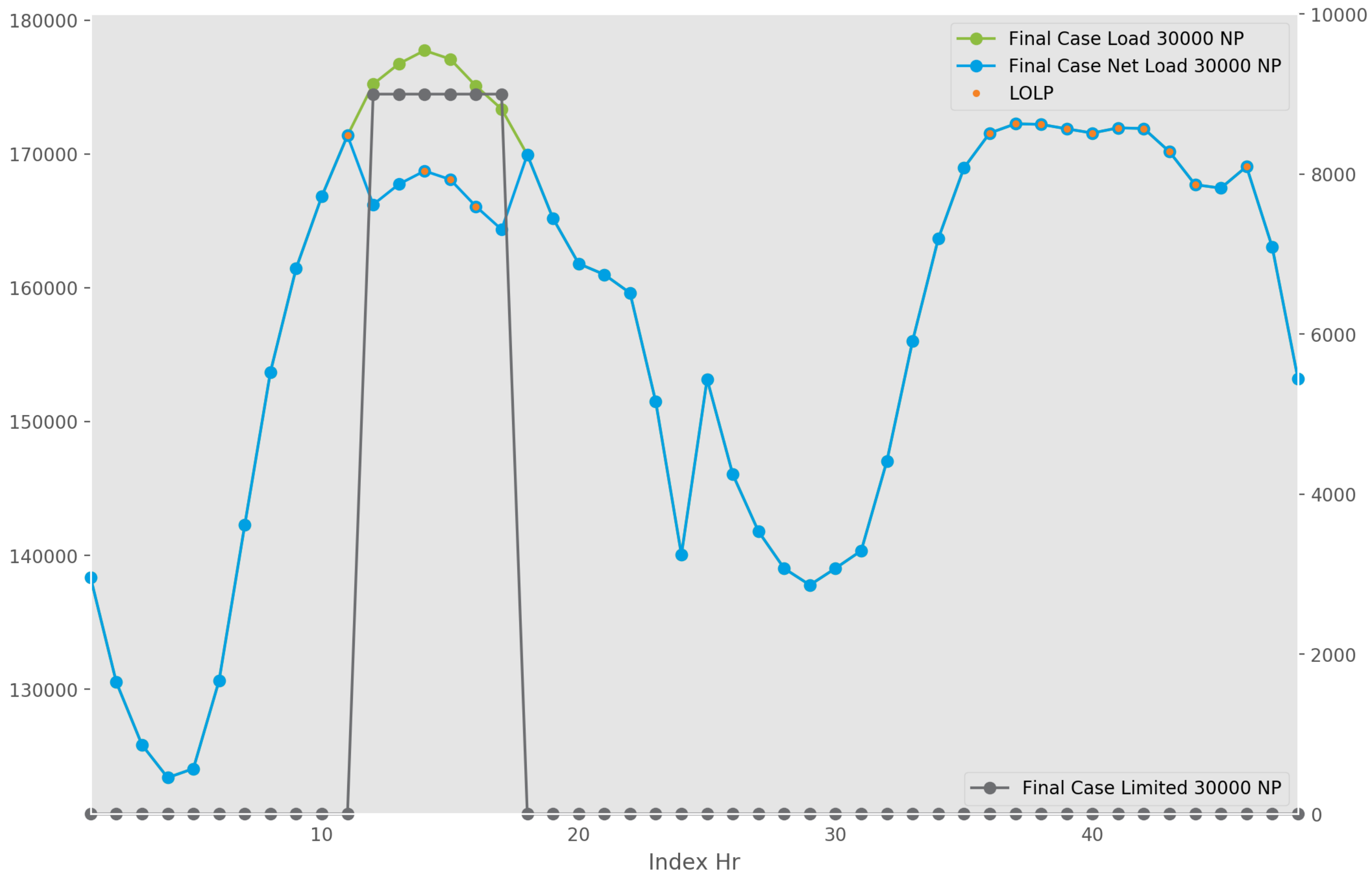
LOLE = 0.1 days/year

By adding the Limited Resource, which performs at 30% of NP during hours 12-17, the system can now serve a peak of 177,726 MW maintaining the same reliability

ELCC = 177,726 – 172,898
= 4,828 MW

ELCC (%) = 4,828 / 30,000
= 16.09%

Example – Final Case - 30,000 MW Limited Resource



All lines except for the gray line (performance of Limited Resource) are drawn based on the left y-axis

The Load Shape and the Net Load Shape in the Final Case almost overlap, except between hours 12-17 where the Limited Resource produces energy.

Compared to the Base Case, the hours with LOLP greater than 0 have mostly shifted. There are several hours in Day 2 with LOLP > 0 (hours 36-44 and 46).

Most of the risk is now in Day 2 (74%). This is why the ELCC drops significantly to 16%

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Contact

Facilitator:
Brian Chmielewski
Brian.Chmielewski@pjm.com

Secretary:
Daniel Bennett
Daniel.Bennett@pjm.com

SME/Presenter:
Andrew Levitt,
Andrew.Levitt@pjm.com

How Effective Load Carrying Capability ("ELCC") Accreditation Works

Member Hotline

(610) 666 – 8980

(866) 400 – 8980

custsvc@pjm.com

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