esr-duration

Limited Energy Capability Resource Duration Requirement for Participation in PJM Capacity Market

Aramazd Muzhikyan, Laura Walter, Scott Benner, and Anthony Giacomoni

***Abstract*—Federal Energy Regulatory Commission (FERC) Order 841 urges RTOs and ISOs to open their markets to eligible electric storage resources (ESR). The goal of this study is to formulate PJM capacity market participation rules in compliance with this order that treat different types of resources equally. The proposed method of equivalent duration looks at peak-serving from an energy perspective and interprets the capacity of a resource as its ability to serve a certain MW amount of the peak. This allows taking into account specific technical characteristics of ESR, which in turn alleviates constraints on their ability to participate in the capacity market.**

***Index Terms*—FERC Order 841, energy storage resources, PJM capacity market, duration requirement**

I. Introduction

Unlike conventional thermal generation units, certain types of dispatchable resources in PJMs capacity market are limited in their ability to sustain power output equal to their nameplate value for a full operating day. Electric storage resources (ESR), which are defined in FERC Order 841 as "resources capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid," are an example of such resources [1]. ESR can store a finite amount of energy, which limits the duration of their power output at full nameplate value. Demand resources (DR), on the other hand, can sustain the consumption curtailment for the whole duration of their dispatch, but typically can only be invoked within a certain window during the operating day.

In this study, these two types of resources are referred to as limited energy capability resources (LECR). By definition, these resources cannot provide continuous output at the installed capacity (ICAP) value of the unit for an extended period of time. Due to their limited nature, LECR are mainly deployed during the peak hours of the day.

A. Problem Statement

To meet its reliability goals, PJM sets a duration requirement for eligible LECR participating in the capacity market. Determination of this duration requirement is the primary goal of this study. Another question related to the duration requirement is how the capacity of LECR should be calculated while maintaining fairness between different types of resources. Additionally, given their limited nature, the system is likely able to accommodate LECR capacity within a certain limited range while maintaining reliable operations. Determination of this range for LECR ICAP is another goal of this study. Thus, the following research questions are formulated:

- *What should the duration requirement be for LECR participating in the capacity market?*
- *How should the capacity of LECR be calculated for participation in the capacity market?*
- *What is a reasonable range for LECR capacity the system can accommodate?*

The goal is to formulate capacity market participation rules that treat different types of resources equally while allowing them to participate where technically feasible. In front of the meter (FTM) solar and wind resources are not considered here as they have their distinct rules for the capacity market participation [2].

B. Duration Status Quo

For status quo, the current 10-hour duration requirement was developed prior to the creation of the Reliability Pricing Model (RPM) capacity construct in PJM. In May 2010, the "Demand Resource Saturation Analysis" study conducted by Resource Adequacy Planning Department at PJM provided a methodology towards defining a duration requirement for DR. The status quo 10-hour duration requirement was supported by analyzing how much DR curtailment capacity can be provided while still maintaining the required loss of load expectation (LOLE) and not invoking the DR more than 10 times during the summer period. The analysis showed that DR curtailment capacity should not exceed 8.5% of the annual peak, which yielded the 10-hour duration requirement. However, there are several assumptions made in this study that do not necessarily hold when extended to ESR:

- While the use of DR replacing generation capacity was limited to maximum of 10 times during the summer period, ESR does not have such limitation and can be invoked as many times as needed with varying levels of power output.
- DR are assumed to maintain constant curtailment during the whole duration of their dispatch. While such assumption does not limit the performance of DR due

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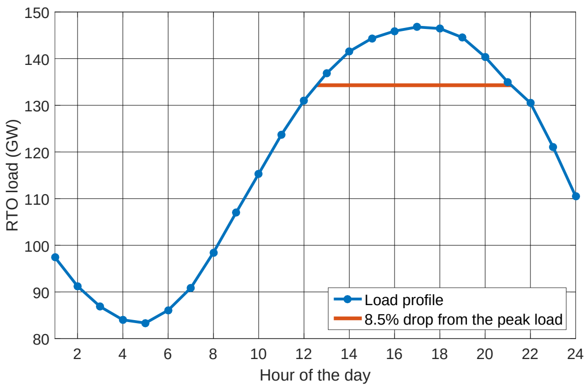

Fig. 1. The hourly unconstrained load for July 19, 2017

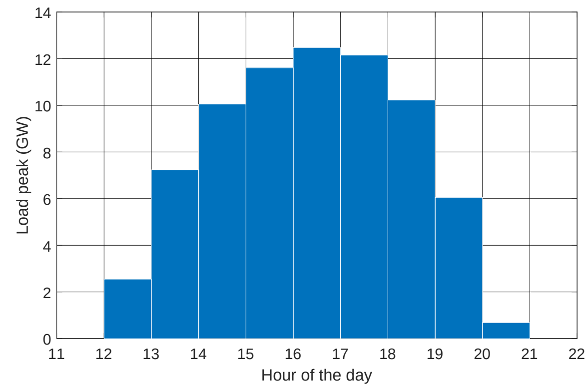

Fig. 2. The total energy under the peak that needs to be displaced

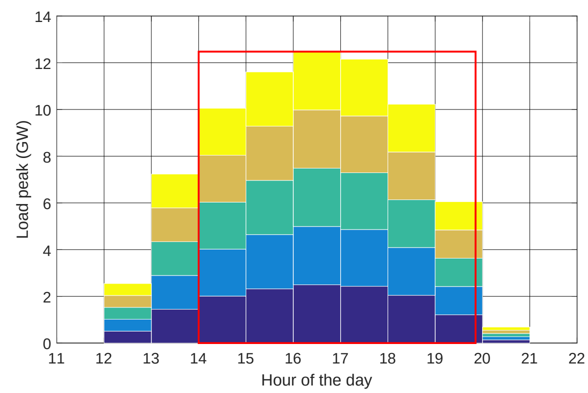

Fig. 3. The geometrically similar strips of the peak

to them being "power" resources, ESR capabilities may be better utilized when they are viewed from an "energy" perspective and the technical requirements are defined by the actual goal of serving the energy in the peak.

The proposed duration calculation method is described in the following section.

II. The Method of Equivalent Duration

The first step is to establish the criteria that are used to define the capacity of a resource. From the perspective of peak-serving, the capacity of a resource can be defined as its ability to serve a certain MW amount of the peak. This is a fair description, as it does not discriminate against any type of resource as long as it is able to fulfill the stated goal.

A. The Energy in the Peak

The proposed method is demonstrated on the example of the hourly unconstrained (not including the effects of DR deployment and pumped hydro generation) load profile for July 19, 2017, shown in Fig. 1. Lets assume that the system has procured LECR capacity equal to 8.5% of the peak (this number is chosen to match the 2010 DR study). This means that LECR should be able to serve 8.5% of the peak, represented by the red line.

In other words, the goal of LECR is to displace the energy in the peak, represented in Fig. 2 as a bar plot with a duration of 9 hours. The conventional wisdom therefore suggests that, for this particular example of the 2017 peak summer day, resources participating in the capacity market should at least meet a 9-hour duration requirement to effectively serve the peak. However, while such approach is reasonable in terms of engineering practicality, it ignores unique attributes of ESR and limits the use of their full potential.

This point becomes apparent when considering the fact that the peak shape is not a rectangle, as illustrated in Fig. 2. Instead, the power value varies with time and has a maximum of 12.47 GW. Thus, imposing a 9-hour duration requirement would require LECR with 12.47x9 = 112.23 GWh energy capacity, while the total energy in the peak is only 73.03 GWh. Thus, such an approach puts higher requirements on LECR than necessary and, therefore, artificially constrains their ability to participate in the capacity market.

B. The Equivalent Duration of the Peak

The method of equivalent duration seeks to establish nondiscriminatory rules for capacity market participation by setting identical requirements for all types of resources. The idea behind this method is demonstrated in Fig. 3. The peak is sliced into geometrically similar strips, where individual pieces follow the same shape but have different heights. Eligible resources are required to have sufficient energy to follow the shape of individual strips for the entire duration of the peak. They can de-rate their capacity to meet this requirement. The capacity compensation each resource receives is defined by the maximum power it provides while following the required shape. This approach is in agreement with the statement above that the capacity of a resource is ultimately its ability to serve a certain MW amount of the peak. Fig. 3 shows that, when stacked together, each individual strip reduces the peak by the amount of its maximum power output. This creates an equal playing field for all resources as they have identical responsibilities in serving the peak.

Conventionally, when speaking about duration requirement, the eligible resources are expected to be able to sustain their constant output during that interval. Since this study departs from such requirement, the notion of duration also becomes generally irrelevant. However, the concept of equivalent duration can be defined for eligible resources as the amount of energy under its individual strip divided by capacity rating it received in the capacity market, i.e., its maximum power output as shown in Fig. 3. Since all strips are geometrically similar, the equivalent durations obtained for each strip or for the overall shape of the peak are identical. For the example in Fig. 3, the total energy under the peak is about 73.03 GWh and its highest power value is about 12.47 GW. Thus, the equivalent duration for this example is 73 GWh/12.5 GW $\approx$ 5.85 h, which can be rounded to 6 hours.

Essentially, the equivalent duration is the time the resource is able to sustain its output while generating at its maximum power level. While this sounds similar to the conventional definition of duration requirement, these two have different purposes and different meanings. The purpose of equivalent duration defined this way is to allow determination of LECR capacity compensation in the capacity market by dividing the energy content of the resource by the equivalent duration. Also, while the conventional duration requirement for the curve in Fig. 3 would be 9 hours, the equivalent duration is derived to be less than 6 hours.

C. The Impact of Behind the Meter Solar

As mentioned above, in front of the meter (FTM) solar and wind resources are not considered in this study as they have their distinct rules for capacity market participation. However, behind the meter (BTM) solar generation should be included in the calculations as a part of the net load.

This study is interested in how the presence of BTM solar changes the shape and the duration of the peak. To that end, Fig. 4 compares the unconstrained load profile to the net load profile with BTM solar generation corresponding to 2028 ICAP projections. This comparison shows that adding the BTM solar data "shaves" the left slope of the peak, moving the overall shape to the right and reducing its maximum MW value. As a result, the same 8.5% drop from the peak corresponds to a lower MW value. These effects are amplified as more BTM solar capacity is integrated into the calculations.

III. The Data Used for This Study

The method of equivalent duration was demonstrated in the previous section in the example of the load shape from July 19, 2017, with LECR capacity equal to 8.5% of the peak. However, in order to obtain results with higher statistical confidence, a wider range of data should be considered. This section describes the set of historical load profiles and BTM solar ICAP projections used in this study. Also, the reasonable range of LECR capacity values considered in this study is discussed.

A. Historical Load Profiles

To define the scope of historical load profiles relevant to this study, equivalent durations for the top 120 summer days of

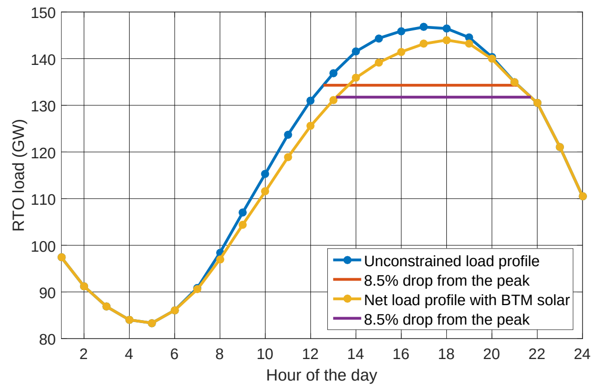

Fig. 4. The effect of BTM solar on the peak shape and duration

2017 are calculated. The historical load profiles are collected via the Power Meter application as described in [3]. This study omits winter days since PJM is a summer peaking system. Capacity procurement is based on the forecasted load peak for the delivery year, and summer peaks have historically been consistently higher than winter peaks.

Since equivalent duration of a peak is only defined by its shape and not its absolute MW value, the peaks for individual days are normalized to the same value and are viewed as potential occurrences of the annual peak. Therefore, LECR percentage for each day is scaled according to the peak of that day. The validity of this assumption will be evident from the results of the analysis.

Fig. 5 shows obtained equivalent durations sorted by the peak of the day, where the first point corresponds to the highest summer peak day, the second point to the second highest summer peak day, etc. The trend of the graph shows that the days with lower peak load generally have longer equivalent duration. This is explained by the fact that the peaks for lower days are generally wider, resulting in longer equivalent durations. Thus, the assumption made above about each individual day being a potential occurrence of the annual peak is only valid for the top days of the year, and therefore the number of days considered for each year should be limited to a certain number.

Since only the top peak summer days are relevant when estimating the capacity requirement, the durations associated with lower peak days can be safely ignored. This study limits its scope to top 20 summer days of each year. The data pool is also expanded by including load data from the last 10 years of 2008–2017. Thus, a total of 20x10=200 daily load profiles are used in this study.

B. Behind the Meter Solar ICAP Projections

While the current total BTM solar ICAP is reported at about 4,500 MW, its projected to double in the next four years and continue growing afterwards [4]. This study limits the time horizon of the solar data projections to 10 years into the future. Hourly solar profiles corresponding to ICAP projections are calculated using their hourly average summer

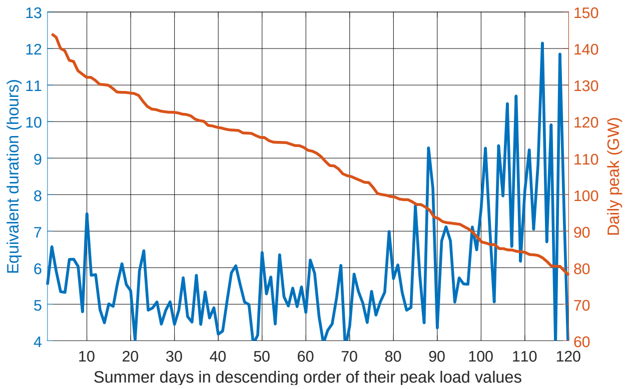

Fig. 5. Equivalent durations for top 120 summer days of 2017

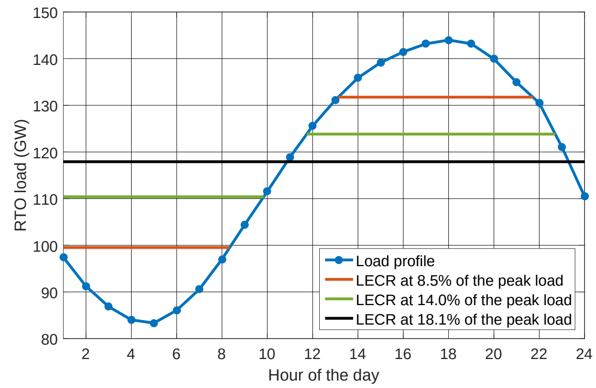

Fig. 6. LECR capacity range calculation

capacity factors obtained from AWS Truepower [5]. For a given zone, multiplication of the hourly capacity factor by the corresponding ICAP projection gives the hourly MW profile for that zone. Thus, the total solar generation hourly profile P_t for a particular year is calculated as:

$$P_t = \sum_i c_{it} \cdot ICAP_i \tag{1}$$

where i is the zone index, $ICAP_i$ is the projected ICAP for that zone and c_it is the capacity factor hourly profile for that zone. This study uses 2028 ICAP projections, the highest capacity values in the considered time horizon. Once the solar profile P_t is obtained, the net load profile is calculated by subtracting P_t from the unconstrained load profile.

C. The Range of LECR Capacity Values

One of the main resources constituting LECR are ESR, defined in FERC Order 841 as resources capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid. By this definition, ESR require time for charging before they are ready to inject the energy back during the peak. The red lines in Fig. 6 show the intervals during which the ESR potentially charges and discharges for an 8.5% penetration case. Economically, ESR would charge during the off-peak period (at the beginning of the operating day) and increase the minimum “valley” demand. If the area of the filled valley is equal to the area served on-peak (with consideration of the resource efficiency), the resource has enough energy stored to serve the peak.

As the amount of LECR in the system increases, the corresponding peak and valley widen as shown in Fig. 6. At some point, the two consecutive intervals of charging and discharging occupy the whole operating day, represented by the single black line in Fig. 6. LECR capacity added beyond this point will remain largely unutilized, which also defines the reasonable range of LECR capacity for this particular day. It is important to mention that ESR with lower efficiency require a longer charging period to store an equivalent amount of energy. Thus, lower efficiency also means a lower estimate of LECR capacity range. Given the variety of ESR technologies

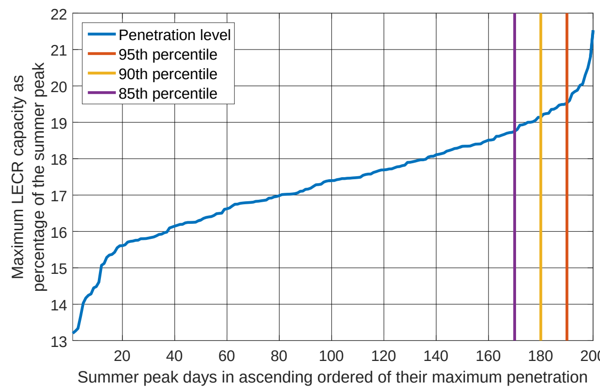

Fig. 7. LECR capacity range estimates from 20 summer peak days of 2008–2017

with different efficiencies, this study uses a conservative 85% efficiency for calculations.

Such calculations of capacity ranges are performed for the available 200 summer peak days and displayed in an ascending order in Fig. 7. The graph shows that the system can economically accommodate up to about 20% of LECR. Beyond that point, the probability of using the additional capacity is less than 5%. This establishes the LECR capacity range considered in this study at 20% of the annual peak.

IV. Calculation of the Equivalent Duration Requirement

Equivalent durations obtained for the available 200 summer peak days with 8.5% LECR capacity are plotted in ascending order in Fig. 8. Such plots give a good understanding of the equivalent duration median value and its different percentiles. For instance, if we want to know what equivalent duration requirement a resource should satisfy to be able to serve the peak for 95% of instances, the red vertical line at 95^{th} percentile indicates that it is about 7 hours for this example. The equivalent durations for 90^{th} and 85^{th} percentiles are also shown.

Next, the same graph is produced for LECR penetration levels within the range established above, i.e., up to 20% of

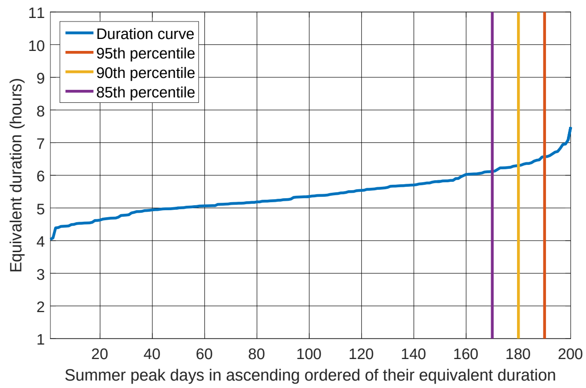

Fig. 8. Equivalent durations from 20 summer peak days of 2008–2017

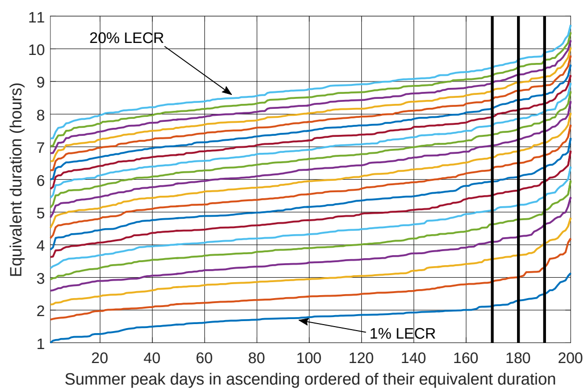

Fig. 9. Equivalent duration curves for different LECR penetration levels

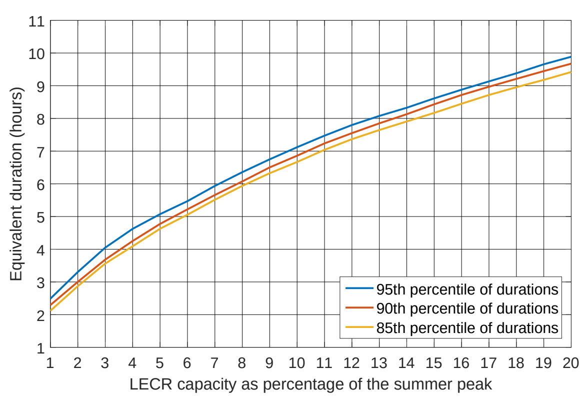

Fig. 10. Equivalent durations for different LECR penetration levels

the annual peak load with 1% increment as shown in Fig. 9. The vertical lines represent the percentiles as in Fig. 8. Based on the curves in Fig. 9, the equivalent durations are plotted in Fig. 10 as function of the LECR penetration levels. The plots show that when the storage penetration reaches 20%, the equivalent duration is about 10 hours. Varying the percentile from 85% to 95% does not alter the equivalent duration estimate significantly.

Conclusions and Future Work

This study seeks to formulate capacity market participation rules that are nondiscriminatory towards different resource types. To achieve that, the method of equivalent duration is proposed that looks at peak-serving from an energy perspective and interprets the capacity of a resource as its ability to serve a certain MW amount of the peak. This allows taking into account specific technical characteristics of ESR, which in turn alleviates constraints on their ability to participate in the capacity market introduced by the conventionally defined duration requirement.

The results show that the equivalent duration requirement increases with increase of LECR capacity in the system. An analysis based on historical load profiles from 2008–2017 and BTM solar ICAP projections for 2028 shows that for 20% LECR penetration, the eligible resources should meet a 10-hour equivalent duration requirement. On the other hand, a 4-hour equivalent duration requirement limits LECR presence in the system to about 3% of the annual peak.

While the system can use a lower equivalent duration requirement at low LECR penetration levels, as the penetration increases, the duration requirement needs to increase as well. This may create a potential for stranded assets, as the early adopters with lower total storage capacity may no longer qualify for the increased participation requirements. Thus, a 10-hour equivalent duration requirement is recommended for the PJM capacity market.

The future work will need to consider the peak start and end times for DR. While the 20% LECR capacity range estimated above does assume no restrictions on the availability of the resources during the day, DR currently have availability restrictions that should be respected. Capacity Performance (CP) DR, by their definition, are available for an unlimited number of interruptions during the delivery year, and must be capable of maintaining each such interruption between the hours of 10:00AM and 10:00PM in the summer. Since increasing the LECR capacity widens the peak, its start and end hours should also be taken into account in the context of the DR availability window when estimating the LECR capacity range.

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