Grid Planning and Operation of Large Loads

ESIG

11/16/24

Goal

Investigate the rapidly changing field of large step loads (such as AI and other data centers, hydrogen, industrial heat electrification, and EV fleet charging) with a focus on grid impacts, challenges, and potential solutions to both streamline deployment and ensure these loads do not negatively impact grid reliability.

Context

Integration of Large Loads poses a new challenge for the electric power industry today. Whether it be utility planners who are struggling to forecast future load[1][2], large loads that don't know where they can interconnect quickly, transmission planners who are struggling to build infrastructure in a timely fashion, system operators who are seeing large loads disconnecting during a fault potentially causing instabilities, or large load owners who want to access real-time prices or provide ancillary services but cannot access wholesale markets, there are many issues that industry needs to address. Today this is being driven by the high data center growth and rapidly increasing requests for data center interconnections but tomorrow this may be driven by requests for GW-scale hydrogen production or large EV fleet charging centers.

Many RTOs and utilities are looking for solutions to these challenges. ERCOT is a leader in this topic with an 800 MW data center in Texas and a market participation model that allows large loads to participate in wholesale markets. However, they are facing a pushback with implementation of interconnection performance requirements for large loads; without performance requirements, these large loads may pose reliability threats to the grid. Large load developers are struggling through the opaque and diverse processes of interconnection and tariffs. They are seeking faster interconnections and are building their own substations in some cases to accelerate interconnection. Without more streamlined interconnection processes and more efficient transmission upgrades, growth and development of their industry (whether it be AI or EV charging, etc.) may slow. ESIG wants to set up a task force in this area and believes there is a win-win in this situation if we can bring together both sides of this issue in a setting outside of formal regulatory or RTO stakeholder proceedings and tackle aspects that benefit both sides. ESIG is not an

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[1] https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

[2] https://www.epri.com/research/products/3002028905

advocate, but rather works collaboratively across industry to provide unbiased technical engineering information. By working at a higher level than a single RTO, we hope that more harmonized practices may emerge and be adopted by different regions.

ESIG Large Loads Task Force is looking to provide a state-of-play of the various challenges, their impact, how they are currently being addressed, and potential solutions and innovations.

Grid impacts of large loads can be broken down into these topical areas covered in more detail further in this document:

1. Data collection on characteristics of AI and other data centers and other large loads.
2. Load forecasting – size, number, location, flexibility of different large load types (such as AI and other data centers, hydrogen, industrial heat electrification, EV fleet charging, manufacturing). Exploratory requests vs actual needs.
3. Interconnection process – how to interconnect large loads; what kind of data do they need to provide; managing speculative requests; potential “flexible interconnections” in which load is not firm
4. Interconnection performance requirements – ride-through requirements for large loads; fast cycling of loads and impact on oscillations; how uninterruptible power supplies may increase load after load reconnects
5. Modeling requirements for interconnection – how to model large loads; models that need to be provided to transmission operators
6. Transmission planning – holistic planning of generation and load; proactive planning of transmission for both generation and load
7. Wholesale market options – allowing load to participate in ancillary services; exposing loads to wholesale market prices; co-location of generation and load
8. Resource adequacy – flexible interconnections; price-sensitive loads

Tasks

1. **<u>Data collection</u>** on characteristics of AI and other data centers and other large loads. Interview large load owner/developers and collect information from academic and business literature. Goal is to have at least the data center portion of this task completed in 8 months. This will be the first in a series of reports on large loads:
    - **a.** What are the size, location, siting considerations, flexibility, timing, load profiles, and other pertinent characteristics of different large load types?

    Break down by use case, e.g., artificial intelligence (AI) vs cloud, as appropriate.
    - **b.** What are the electrical characteristics of the facilities including properly modeling the facilities and performance (e.g. AC/motor loads, power electronics settings, ramping capabilities, multi-facility coordination, etc.) in order to model potential impacts on grid planning and operations of different large load types?
2. **Load forecasting** – leverage and continue existing Long-term Load Forecasting project team on large loads to provide input to this chapter. Coordinate with the interconnection process and other project teams as appropriate; coordinate with EPRI's data center flex initiative and load forecasting initiative.
    - **a.** Collect existing forecasting practices for large loads (location, size, modularity, speed, flexibility, onsite generation);
    - **b.** Explore how to consider speculative requests (loads that are shopping around) and certainty of the projects (project readiness milestones), as well as any lessons learned from the generation interconnection process that could apply to large loads
    - **c.** Develop recommended best practices, in collaboration with the other project teams, to standardize large loads modeling for long-term forecasting, as well as in coordination and collaboration with large load customers to improve forecasting methods
3. **Interconnection process** - coordinate with all other project teams. Coordinate the project team to gather industry best practices, insights, opinions, perspectives, and input on large load interconnection processes. Produce a collective vision with the project team of an ideal large load interconnection process, including differences between generation interconnection processes, process considerations for behind-the-meter generation at the large load facilities, considerations for standalone large load facilities versus large load facilities co-located with generation facilities, and more. Provide potential guidance on how to implement the ideal large load interconnection process, whether at the local/state level or national level (via FERC and/or NERC). Produce a task force report highlighting the lessons learned, findings, and recommendations for the interconnection processes of large loads, particularly to support project developers, generator owners, transmission service providers, and system operators in improving and accelerating the interconnection of large loads.
    - **a.** Current practices collection in the beginning of the project, including surveying the industry as to what is working, what is broken, where can

improvements be made, how big are the interconnection queues, and what are practical recommendations and improvements being considered

   - **b.** Defining various milestones during the interconnection process that could be implemented to help ensure certainty with large load projects, be meaningful for the project developers, and informative to the utilities
   - **c.** Defining what modes and studies are needed during the large load interconnection process
   - **d.** Exploring what processes should be implemented with transmission planning teams if transmission upgrades and system improvements are identified during large load interconnections
   - **e.** Recommendations that can be pulled from the lessons learned with the interconnection of inverter-based resources, including FERC Order 2023 requirements

4. **Interconnection performance requirements** usually refer to technical minimum specifications for grid users (generation, load, transmission assets) that are needed to maintain reliable operation of the bulk power system. The requirements for new technologies normally start from a “do no harm” perspective, to avoid adverse impacts from the grid user to the grid during normal operation and disturbance conditions. Such requirements may apply to disturbance ride-through capabilities, as well as the requirements regarding power quality (e.g. harmonics) and requirements not to excite any new oscillatory modes on the grid. The requirements may evolve further, such that grid users are required or incentivized to provide certain essential reliability services (mandatory or market-based). This is dictated by grid transformation and proliferation of new grid users with new characteristics, combined with retirements of existing resources that were previously providing these services. In developing the requirements, transmission system owners or operators usually need to understand technical capabilities of the equipment and capabilities that can be reasonably achieved through supplemental devices, e.g. reactive power compensation, etc. In this workflow, we’ll investigate system reliability needs related to connection of large loads and how these needs can be translated into minimum technical performance requirements:
   - **a.** Understand transmission system minimum reliability needs as related to large grid user connections. Which of these needs can potentially be served by adding new devices on the transmission side and which need to be served by grid users?
   - **b.** Use the existing generation interconnection requirements as a framework, but separate essential needs for grid reliability from services that generators are required to provide to improve grid reliability.

    c. Analyze load connection requirements that already exist globally, e.g. Europe's ENTSO-E Network Code on Demand Connection, including newly proposed modifications and national-level implementations. How is conformity/compliance with these requirements assessed during the connection process and lifetime of the asset?
    d. Are there examples where inadequate large load performance led to reliability risks?
    e. Work with large load developers/owners to understand equipment characteristics and capabilities/performance that can be achieved by the load. How do these capabilities vary based on the type of load (including load profiles) and size? Can required capabilities be partially or fully achieved with supplemental devices based on available technologies (e.g. static synchronous compensators, battery energy storage systems, co-located existing or new generation plants). If data and time permits, comparison of cost and efforts vs benefits of each solution could be of interest here. As a proof of concept and to bound the scope of work we may focus on one or two load types first (such as AI and other data centers) and then expand this to other types of loads in the future.
    f. Develop recommended set of large load connection requirements and some guidelines for conformity assessment with these requirements.
5. **Modeling requirements for interconnection** is a related topic and usually is a part of interconnection requirements to study the impacts that new and existing grid users have on the grid. These simulations are used by transmission owners/operators/planners. The simulation model includes all connected grid devices (including generation, loads and transmission assets). For different studies, different types of models of grid devices are used (e.g. power flow models, phasor-domain transient models, electromagnetic transient (EMT) models, short circuit models etc.). Models for synchronous (fossil fueled and hydro) generators are well understood and standardized. Models for inverter-based resources (wind, solar, battery storage) have been developed in the past 20-25 years and achieved some level of maturity, although this is still an ongoing area of further research and development. Load models historically have lagged due to lack of data, and the fact that impacts were generally more localized due to generally high overall grid strength. Today, increasing numbers and sizes of power electronics-interfaced loads and a weaker transmission system (due to proliferation of inverter-based resources and retirements of synchronous generation) make accurate load modeling more critical. In this workflow, we'll systematically investigate:

    a. Understand types of studies currently carried out by transmission owners/operators and modeling needs for large loads to be accurately represented in these studies. For each study type it is important to understand and document aspects of the load model that may have significant impacts on the study results.
    b. Are there existing modeling requirements for large loads globally, are there any best practices that can be identified?
    c. Are there examples where inadequate large load modeling led to reliability risks?
    d. Work with large load developers and owners to understand characteristics of various load types, what can be reasonably achieved in terms of modeling, can typical/generic models be developed e.g. to be used for scoping or planning studies.
    e. Develop recommendations for modeling requirements, including model validation and model quality testing guidelines.
6. **Transmission planning** – is critical in facilitating the integration of large loads, the necessary generating resources, and managing their impacts on the grid. However, our current transmission planning processes are suboptimal and fail to provide for the infrastructure solutions that would allow for sufficiently timely, flexible, and cost-effective integration of large load and the associated generation. Proactive, holistic, scenario-based planning for both generation and load, as prescribed by FERC Order 1920 for long-term planning processes, is a best-practice framework to achieve more cost-effective and least-regrets outcomes. To address the pressing needs for large loads, such proactive and holistic planning processes will need to be applied to both near-term and long-term timeframes and include generation interconnection-related needs. In coordination with the other workstreams, we'll systematically:
    a. Investigate and document existing processes for transmission planning, load interconnection, and generation interconnection
    b. Document best practices for proactive and holistic grid planning frameworks (with North American and International examples)
    c. Discuss how scenario-based, value-based, least-regrets planning can be used to identify the most cost-effective solutions (with highest benefit-cost ratios) that can, in both the short- and long-term, most flexibly address the typically wide range of uncertain future needs
    d. Discuss the role of grid-enhancing technologies and opportunities to expand the transmission capability of existing lines and rights-of-way play in cost-effectively interconnecting large loads and generation in a timely fashion

  - **e.** Develop recommendations on how to improve existing planning processes to achieve the benefits of more proactive and holistic planning.

7. **Wholesale market options** – This task addresses various market issues for large loads including:
   - **a.** Co-location of generation and load – Address co-location from a services perspective: What services do stand-alone loads and co-located loads receive from the grid? What are the options for load configuration (e.g. with behind-the-meter [BTM] generation, or co-located campuses)? What are the challenges associated with the different configurations? What are the wholesale market options considering different load configurations?
     - i. For some large loads, such as AI and other data centers, backup BTM generation is built to maintain reliability. Typically, these BTM generators cannot be accessed by wholesale markets except in cases of emergency. Emissions rules may also prevent use of these generators. How can this BTM generation be designed and encouraged to provide more grid services?
   - **b.** Wholesale market participation models – what kind of wholesale market participation model is needed for large loads to participate in ancillary service markets? Discuss examples such as ERCOT's Controllable Load Resource that can be used as a framework for loads to participate. How can we better expose large loads to wholesale market prices, and treat large loads similarly to generators in the wholesale markets? This is one way to incentivize large loads to provide flexibility when the grid needs it. It is also one way to help the viability of large loads with low price points (e.g. industrial heat electrification).
     - i. For each ISO/RTO, discuss their market participation models for price responsive demand and how these may be improved.
   - **c.** Demand response – how to consider demand response options for large loads, including baselining, net benefits test.

   This task is linked the resource adequacy task and how capacity obligations are determined for loads. To respect the valuable time of common task force members, this project team and the resource adequacy project team are likely to be combined into a single monthly meeting.

8. **Resource adequacy** - The Resource Adequacy (RA) Task Force will address the evolving challenges associated with integrating large loads into the power system, evaluating how these loads impact system reliability and determining the required flexibility to maintain resource adequacy standards. Leveraging the expertise of the

Task Force, this scope of work will involve in-depth assessments on how to model large loads in RA studies, understanding their flexibility options, and ensuring adequate capacity to meet a one-day-in-10-year Loss of Load Expectation (LOLE). This task will conduct the tasks below. This work will be conducted by reviewing industry resource adequacy studies (where applicable), discussions with the task force and large loads, data analysis of existing pricing and load data, and inspection of data from resource adequacy studies that have already been conducted.

- **a.** Consider how large load forecast uncertainty effects capacity requirements in future integrated resource plans and capacity markets.
- **b.** Review of historical operating data to assess the elasticity of large loads during high price events, focusing on how these loads respond under grid stress conditions. This will require operating data from large loads, system operators, and/or utilities if available.
- **c.** Segment large loads based on their operating characteristics, such as hourly and seasonal demand profiles, price sensitivity, and flexibility options. This segmentation will inform tailored approaches to resource adequacy that account for variations in load behavior.
- **d.** Make recommendations on how to model different large loads in resource adequacy assessments, including operating profiles and flexibility options.
- **e.** Consider new metrics to quantify the incremental resource adequacy contributions (or requirements) introduced by large loads, akin to an inverse ELCC used for generating resources.
- **f.** Review of existing resource adequacy assessments to consider the frequency and frequency and nature of tight margin events to determine the flexibility of large loads that would be required, aiming to balance reliability with efficient load utilization use.
- **g.** Explore how interconnection agreements may be crafted to support accelerated and interconnection capacity in exchange for load flexibility commitments.
- **h.** Consider the potential for on-site generation of large loads to reduce system-wide capacity needs.
- **i.** Evaluate how large load contracting strategies, such as Power Purchase Agreements (PPAs) with renewable sources and 24/7 load matching can either contribute to, or detract from resource adequacy.

Deliverables

1. Establishment of the Large Load Task Force and project teams on each of the above tasks with members from RTO/ISOs, utilities, large load owner/developers, transmission owners, researchers, consultants and other appropriate industry representatives. The project teams focusing on each task will meet separately on regular basis. Where relevant for better coordination and efficiency of participation, the project teams will hold joint meetings. – 16 months
2. Workshops on Integration of Large Loads into Grid Planning and Operations – 12 months
3. Reports/guides summarizing challenges and solutions to integrating large loads into planning and operations produced within each project teams – 16 months