Integrated Distribution System Planning Approach

Eversource System Planning

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FIGURES

1. INTRODUCTION

The electric power industry is undergoing significant change with increasing customer expectations for reliability and resiliency; widespread adoption of new, often disruptive, technologies; and a rapidly evolving regulatory landscape. These changes and other advancements have not altered the basic mission of the distribution system, but have impacted the way we way approach planning, the data sources and study methods, scenarios and simulation cases, and the range of possible solutions considered for mitigation.

The Company's traditional system-planning analysis to develop annual and long-term plans for load customers necessarily involves a holistic view of engineering needs across the distribution system, focused on the goal of providing safe and reliable service. Eversource's integrated distribution planning process now includes not only traditional planning considerations for expanding the system to avoid capacity, voltage, and reliability violations but also advanced planning concepts related to Non-Wires Alternative (NWA) Solutions, Battery Energy Storage Systems (BESS) and other DER applications, and integrated load/DER forecasting with EV adoption.

One of the key drivers of the integrated planning concept is high DER penetration especially at saturated stations. This has required Electric Distribution Companies (EDCs) to develop a comprehensive, holistic approach to system planning considering the integrated impacts of both load growth (including electric vehicle (EV) adoption, energy efficiency, demand response, sector conversion, etc.), as well as DER adoption, rather than looking at these two dynamics as separate and independent activities. Therefore, any assessment of long-term system planning needs should identify upgrades that provide a broader benefit and can accommodate various types of load growth, as well as high penetration of DER. Not doing so may result in upgrades constructed that are either sized inadequately or would need to be upgraded prematurely.

Naturally there are synergies and overlaps in the upgrades and activities undertaken to integrate DER safely and reliably and the planning activities to accommodate new load types and provide reliable, resilient service to customers. Integrated system planning drives the most optimal infrastructure solution set that yields value to not just DER enablement but, simultaneously, much broader benefits for many more customers.

To enable this integrated planning approach, Eversource has developed a probabilistic scenario-based DER adoption rate and load forecast methodology to evaluate the system's performance and assess the need for substation capacity upgrades over the ten-year planning horizon. Using a Scenario Planning approach, Eversource seeks to build on scenarios starting with the base need to reasonably forecast load growth and DER and build on that base scenario by also projecting EV growth and gas-to-electric sector conversion. Running multiple scenarios provides system planners with the full scope of system needs to inform sizing of infrastructure upgrades appropriately.

Eversource's ten-year integrated distribution assessment considers short-term and long-term upgrades to the electric power system (EPS) that will meet the capacity, reliability, and operational flexibility required to serve all customers. However, Eversource also considers demand projections beyond the ten-year planning horizon, driven, for example, by electrification policies, and uses these demand assessments to inform the sizing of the solution.

One of Eversource's key planning objectives is to provide the same level of safe, reliable service to DER customers that we provide to our load customers. This implies that the EPS should preserve the safety and reliability under normal conditions, emergency conditions, and scheduled maintenance conditions. Consequently, the integrated assessment includes the following general steps:

1. **Define and establish planning scenarios**, sub regions or study areas, modeling assumptions and the scope and drivers for system expansion, applying Eversource planning criteria.
2. **Forecast future demand** including load growth, EV, heating conversion, and deployment of large- and small-scale DER, in alignment with trends and the Commonwealth's clean energy and climate objectives.
3. **Assess impact of future demand** on the bulk substations and distribution feeders applying Eversource planning criteria as well as impacts on the transmission system applying NERC, NPCC and Eversource transmission planning criteria. This analysis leverages the same advanced models, planning tools and methodologies for steady-state and transient analyses of load and DER, to assess system deficiencies and needs for providing adequate capacity, reliability, voltage, and power quality to all customers.
4. **Determine transmission and distribution upgrades** required to reliably integrate existing and future load and DER while maintaining safe, reliable operation. This includes upgrades that benefit more than one interconnecting facility or distribution customers at large.
5. **Define and allocate system capacity** (as needed) between DER customers and distribution customers in proportion to upgrades that provide operational flexibility and reliability benefits.

2. INTEGRATED PLANNING SCENARIOS

With the growth of distributed generation (DG), evolving customer needs and interests, and the increasing influence of clean energy and climate policy objectives on system investment decisions, it is important to consider integrated planning needs when assessing resilient and sustainable solutions for meeting future demand for load and DG facilities. The scope of the integrated analysis includes DG interconnecting at a station or a group of stations (DER Study Group) that are electrically dependent such that during a single contingency (N-1) event at the station, transfers can be made to prevent loss of load or DG output during the event. This section will describe the methodology for defining the Planning Scenarios involving a DER Study Group.

Infrastructure upgrades allow the Company to preserve and maintain safe, reliable operation of the EPS for all customers with high penetration levels of potentially disruptive DG, particularly solar PV, while also enabling renewable energy to fully support the Commonwealth's climate goals. The key to maintaining safe, reliable operation is preserving operational flexibility under all scenarios for which the system is planned and designed to accommodate. As systems become more saturated with DG, it becomes increasingly difficult for the Company to preserve reliability and operational flexibility under all scenarios. EDCs' policies and programs need to keep pace and be consistent with State policies and programs to send the appropriate message to MA stakeholders. The capacity enabled by EPS upgrades allows the Company to maintain its operational standards despite the challenges presented by high DG penetration. The examples below from actual substation areas with various levels of saturation will illustrate this point. The Company utilizes its advanced forecasting capabilities (described in the Eversource Forecasting and Electric Demand Assessment Methodology Document) to identify areas on the EPS that are projected to have high adoption propensities.

Low DER Saturation Area

In areas of low DER penetration, substations and circuits can typically be analyzed independently and not as part of an interconnected, inter-dependent group. This is because, even though substations might still have N-1 dependency, the DER penetration has not reached the critical point of affecting the reliability and operational flexibility of the larger EPS. Individual and nearby substations are not saturated to the point of restricting permanent, emergency, and planned system reconfigurations. The low DER penetration scenario is illustrated in Figure 1 below. In this scenario, line 1 provides transfer capability between substations A and C, line 2 provides transfer capability between substations C and D, and line 3 provides transfer capability between substations B and D. Line 4 provides transfer capability to offload circuit 1 and circuit 3. In this scenario, reliability and operational flexibility are not affected because system reconfigurations under contingency conditions do not result in adverse conditions (thermal issues, steady-state or transient voltage violations) at individual substations or adjacent substations. Moreover, each substation can be analyzed independently to determine the trigger points for upgrades required to accommodate future DER, i.e., cost causation can be easily determined when looking at individual substations within this static system.

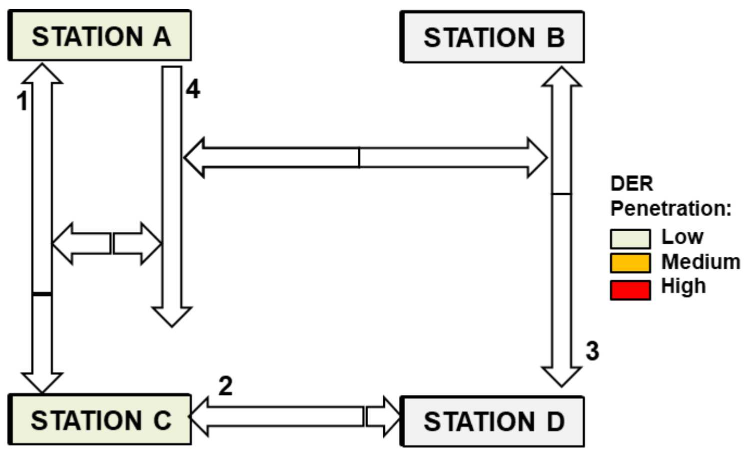


Figure 1. Low DER Penetration Scenario

Medium/High DER Saturation Area

A high DER penetration scenario is depicted in Figure 2 below. In this scenario both Substations B and C are expected to have high DER penetration (or saturation) which affects the system reconfiguration capability between substations A-C, A-B, C-D and B-D. Moreover, reconfiguration options that were previously available between circuits 1-4 and 4-3 could also be limited depending on the amount and location of new DER connected to the circuits. Not only are Substations B and C saturated, but this condition may also result in saturation at Substations A and D since transfer capability that was previously available via circuits 1, 4, and 3 is now limited due to saturation at Substations B and C. This is because under scheduled or forced outage conditions, the station tie-lines that traditionally help boost station load carrying capability (LCC), serve as conduits to transfer additional DER (in excess of load) to neighboring stations.

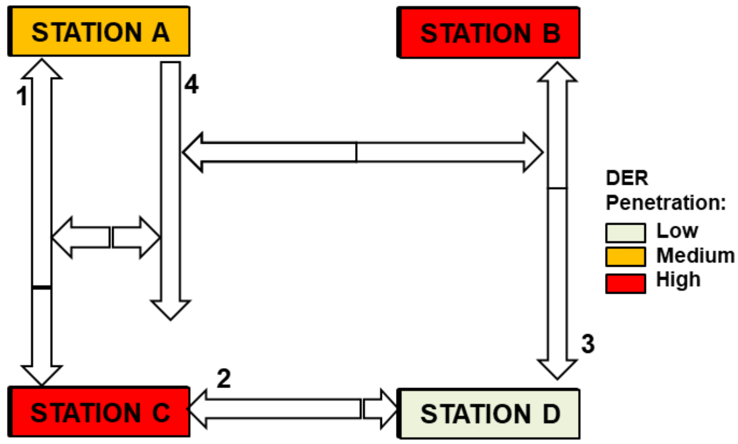


Figure 2. Medium to High DER Penetration Scenario

In areas of medium to high DER penetration, the substations must be analyzed as a group to find the most cost-effective solution that integrates new DER while maintaining the current level of reliability and operational flexibility for the EPS. In this scenario, the standard approach of analyzing individual substations used for areas of low DER penetration, has the potential of increasing cost, reducing reliability, and limiting operational flexibility. For example, even if upgrades are completed at Substation B and C to reduce the negative effects of increased DER penetration at those stations, this could still result in saturation at Substation A and D by limiting the transfer capability between A-C, D-C, and B-C, and lines 4-3. A Group Study approach analyzes the group holistically to determine the most cost-effective solution for all stations in the group, and to evaluate the need to reserve or build capacity to maintain safe, reliable operation of the EPS.

Similarly, Figure 3 below, illustrates some of the operational challenges that can result at the distribution feeder level in areas of medium to high DER penetration. The left side graphic shows the existing "as is" system under normal (N-0) conditions where 3 of the 4 substations are already at medium-level DER saturation.

The right side shows a potential scenario in which Substation A saturates as a result of reliability improvement work at the distribution feeder level. The work could consist of transferring a section of a circuit from Line 3 to Line 4, a common practice used to balance load or customer count between the two circuits or substations or to reduce exposure for customers on a poor performing circuit. In this scenario, depending on the ratio of DER to load on the section, transferring both load and DER from Line 3 to Line 4 might be constrained unless a significant amount of reinforcement work is completed on both Circuit 4 and Substation A. This “constrained” condition that results from having a system at high saturation levels limits the flexibility of operators during normal and emergency conditions.

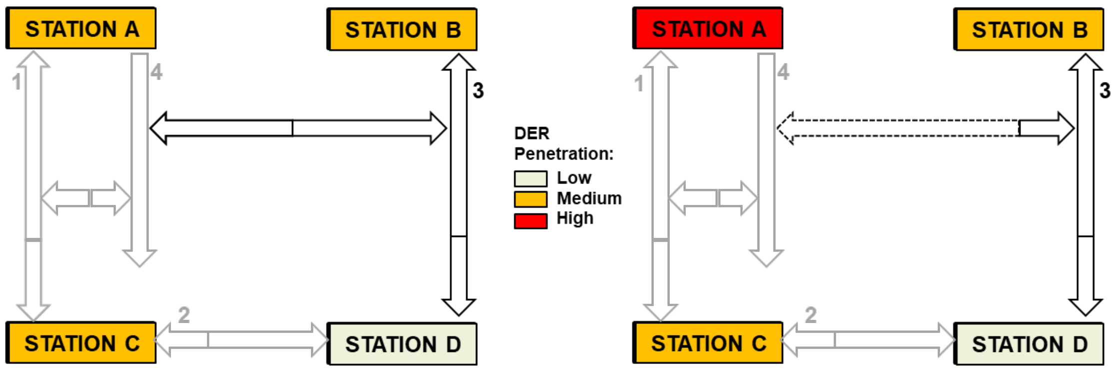


Figure 3. Operational Challenges at Distribution Feeder Level

Moreover, the constrained condition also limits the ability of planners and engineers to propose system design changes that will improve the performance of the EPS and enhance service to existing distribution customers. Utilities faced with significant DER growth, without the ability to address these types of conditions, could experience reliability deficiencies in the near-term when low DER saturation areas progress to medium or high saturation. DERs could be forced offline for long periods to facilitate any scheduled work at these stations as well as under forced (unplanned) bulk substation outage scenarios.

In addition to the substation reliability benefits to all customers, new distribution lines and line upgrades driven by DER growth are likely to create opportunities to rebalance feeders, reduce exposure and transfer load, which would lead to improved reliability and voltage quality for distribution customers.

Once the existing and future DER are determined for each DER study group/substation, the next step is to determine the upgrades required to accommodate the existing and future DER interconnections. Future transmission, substation and distribution line reinforcements are determined after completion of detailed load flow, dynamic and transient analyses that account for equipment firm capacity and emergency transfer capabilities. Final reinforcements would result from detailed analyses accounting for capacity, stability, voltage, and reliability constrained conditions that could result from DER saturation.

3. SYSTEM ANALYSIS

Eversource has developed a comprehensive Distribution System Planning Guide to provide a consistent, uniform approach to designing an efficient and reliable EPS that ensures the quality of service expected by our customers. The Distribution System Planning Guide aligns with applicable safety codes, regulatory requirements, and industry standards. It establishes uniform criteria and design standards across the Company's Service territory for all aspects of the System Planning Process, including goals for system performance and identification of suitable design solutions, including non-wires alternative (NWA) solutions to meet those goals. In alignment with the Distribution System Planning Guide, the Company has developed a DER Planning Guide that documents the study approach, processes and technologies required safely and reliably integrate DER into the Company's EPS. The Company has also developed an NWA Framework to provide a standardized and expedited process to screen an NWA solution's technical and economic feasibility to meet a need at a specific location identified in accordance with the distribution planning criteria. The Distribution System Planning Guide, the DER Planning Guide and the NWA Framework are essential components of our comprehensive approach to integrated distribution planning and assessment of systems with high DER penetration.

The Distribution System Planning Guide describes a common planning model and study methodology for both distribution and DER planning, as well comprehensive solution development to comprehensively address system needs. This approach to system planning will increase efficiencies and provide lower cost solutions through better coordination of capital projects. The fundamental processes outlined in the Distribution System Planning Guide form the basis of the comprehensive system assessment described below.

Model Development

Historically, EDCs focused primarily on maximum (peak) load analysis as the driver for system design changes. Peak load analysis is focused on a specific time during a peak day when the system experiences the highest net demand, typically occurring during periods of high load and low distributed generation (DG) output. With the introduction of large quantities of DG, potentially leading to reverse flow during low load periods, this paradigm has shifted, and minimum load models have become just as important, depending on the amount of installed DG.

- **Maximum Load Model**: For the maximum load model, system planning considers current worst-case loading conditions on the system in combination with low DG output projections to ensure that the system can reliably supply loads. These are typically hot, humid, cloudy summer days which can lead to increased equipment loading and sub-standard (under-) voltages. When developing maximum load models, EDCs use 90/10 weather-normalized load forecasts, ensuring that any design decisions made will adequately address the most demanding scenarios. Construction of the maximum load models typically begins each year after the peak load season. For summer peaking areas, this is typically around the September to October timeframe.
- **Minimum Load Model**: The minimum load model has become more relevant with the integration of large quantities of DG on the distribution system. During low load conditions, typically spring or fall months, DG output can significantly offset load, or even surpass it, causing what is commonly referred to as reverse power flow. This can lead to increased equipment loading and power quality concerns, such as elevated (over-)voltages. Construction of the minimum load models typically starts later than the maximum models, ensuring low load fall months can be captured in the model.

Because the interaction of load and DG is weather and time dependent, the analysis has shifted from a peak load analysis to an 8760 load-flow model that accounts for all hours of the year.

As part of the minimum load model evaluation and development process, Eversource determines system upgrades required for safe, reliable integration of groups of DER at various stations. The minimum load model is significantly driven by the adoption propensity of DG at these stations, which part of Eversource's advanced forecasting process, as outlined in the Eversource Forecasting and Electric Demand Assessment Methodology Document.

The first step in analyzing distribution and transmission level upgrades is to identify geographic areas experiencing high DER growth that are expected to saturate due to existing, in queue, and future projected DER. Distribution bulk substations in these areas are assigned to a study group based on physical location, topology, load transfer capability, reliability, and capacity dependency with nearby substations. Using the following process (as illustrated Figure 4 below) the critical system condition (low load model) for the group study is determined.

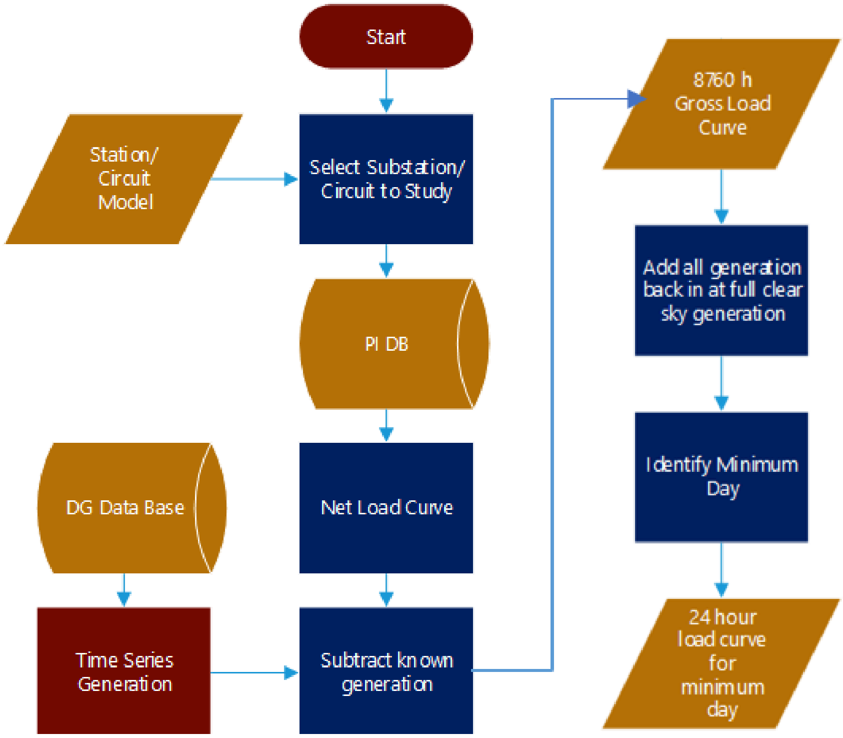


Figure 4. Process Flow for Determination of Critical Load and Generation Condition

I. **For each station or group of stations**, the Minimum Load is calculated by using historic PI readings (Net Station Load) and removing the contribution of existing DER to create a true, or gross load data set. Thereafter, the minimum load condition is identified as the coincidence of the maximum possible DER output scenario with light load conditions, representing the worst-case condition the system can experience (e.g., a low load condition during midnight hours is not relevant for the group study).

   a. DER generation values are determined using historic PI readings where available, time of use metering data, or historic solar irradiance profiles for behind the meter applications (when applying solar irradiance data to determine historic output, Eversource assumes a DC/AC rating ratio of 1.2, unless the panel rating is known). With all generation subtracted from the recorded Minimum Load, this gives the true demand value (load that is not offset by DER) during light load conditions at the substation.

   b. For other DERs such as hydro installations, wind turbines, combined heat and power generation, or other non-solar DG, PI readings or time of use (TOU) metering is used where applicable.

II. **Once the Gross Load is determined**, existing DER are added back into the model at their maximum output level (AC nameplate capacity) in accordance with their clear sky capabilities (time series irradiance profile under ideal weather conditions for solar assets). As a result, the worst-case Minimum Net Load condition at the substations can be determined, the minimum load model (Note: the minimum net station load must not correlate with the minimum gross system load, as it can be offset by time dependent DER)

   a. In the next step, all DER in the group study are added at their respective locations to the model. In the same manner as already existing DER, they are studied at maximum clear sky output limits.

   b. Storage applications in the vicinity of the group study are treated as sources (discharging) at maximum allowable output based on technical and/or operational limitations.

   c. System planners can now identify if system violations occur, where they occur, and the magnitude and frequency of occurrence.

III. **At this stage forecasts for load and DER adoption** are added to the minimum load model and analyses can be conducted to determine the reinforcements needed to safely and reliably accommodate the current DER group as well as future projected DER in the area. This step provides a crucial opportunity to develop a comprehensive long-term solution that creates significant headroom for additional DER growth beyond the existing DER Group Study.

Figure 5 below shows the results of this process on sample data files. The station modeled has 70 MW of installed solar photovoltaic (PV) generation. Figure 5(a) shows the calculation of the Gross Load Curve. Figure 5(b) shows the reapplication of the existing solar at maximum clear sky output to determine the minimum load condition that the group study needs to account for.

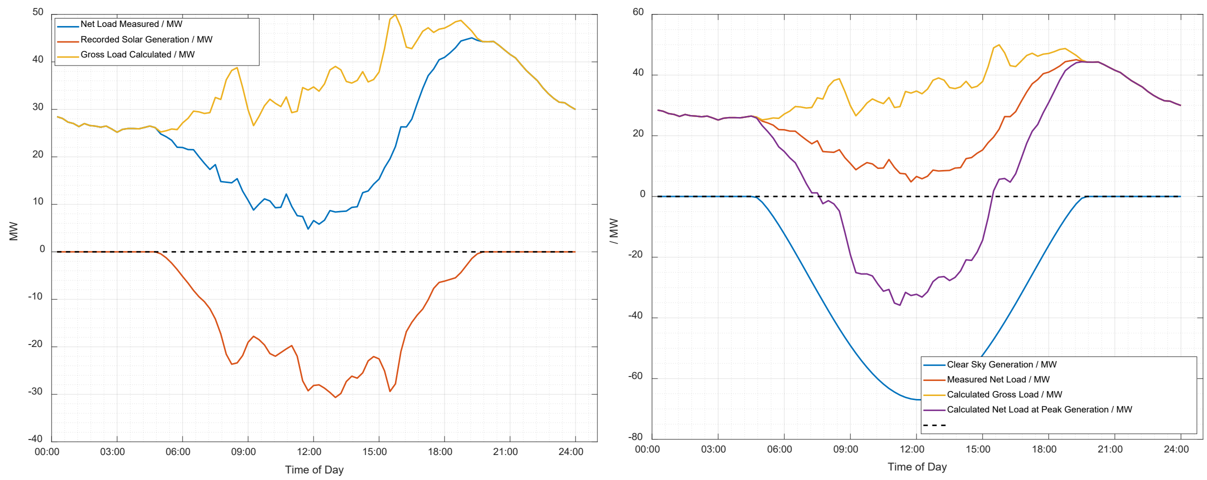


Figure 5. (a) Sample Data Sets for Measured and, (b) Calculated Net and Gross Load Data

It should be noted that this analysis is ideally done on an 8760-hour basis as high DER penetration makes it nearly impossible to determine the true minimum conditions by observing a single day.

Planning Studies

As part of the integrated planning process, the following analyses are conducted in accordance with the applicable standards and criteria identified in the Distribution System Planning Guide:

I. **Steady-state analysis** to assess thermal overloads and voltage limit violations resulting from load demand and DER output. The steady state analyses are conducted through time series power flow simulations in the Synergi distribution analysis package under both N-0 and N-1 scenarios.

II. **Dynamic/transient analysis** to verify acceptable model performance and to identify any violations of stability criteria or transient overvoltage criteria following system disturbances and switching actions. For this analysis, the Synergi models are converted to PSCAD models to allow for power systems (electromagnetic transients) EMT simulations.

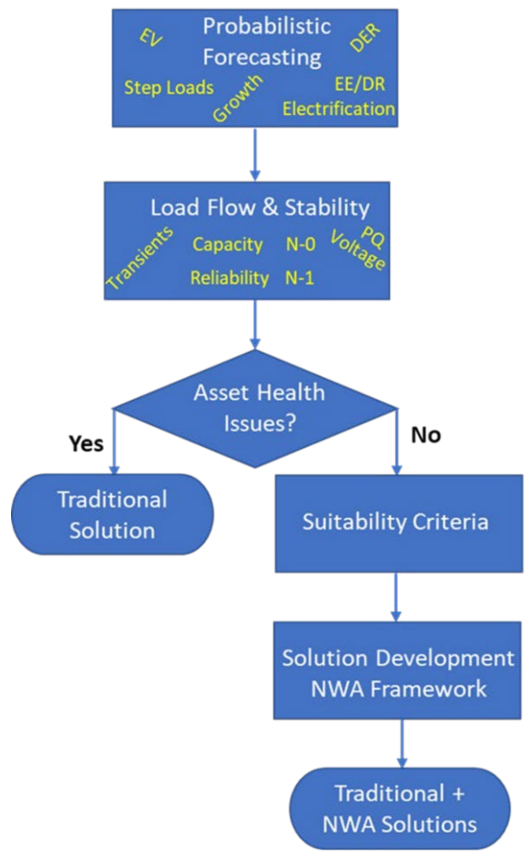
III. **Short-circuit analysis** to assess if circuit breaker fault circuit interrupting capability or bus work short-circuit structural limitations are exceeded, and to inform system protection schemes.

IV. **Protection review** to assess if direct transfer trip (DTT), ground fault (zero sequence) overvoltage (3V0) protection or other special protection schemes are required based on the risk of islanding, back-feed at stations, and other operational requirements.

V. **Reliability and operational flexibility assessment** to determine loss of load/DER reliability risk and degradation in transfer capability following a single-contingency event. This does not constitute a stand-alone analysis, but rather signifies that all previous analyses must account for the various permutations of system configuration, ensuring that the EPS is safe and reliable under all practical operating scenarios.

Solution Design

Eversource engineers design and implement a variety of projects to resolve thermal/capacity, power quality/voltage, reliability and stability violations where station and line equipment may be operating under conditions beyond their design limits. As described above, the annual planning process begins with load/DER forecasts, model development and analyses to identify violations affecting distribution substations and backbone feeder sections that impact substation load-carrying capability (LCC) under Normal (N-0) and Contingency (N-1) system conditions. As part of this process, Eversource generally applies several design concepts to resolve and mitigate issues identified in system analysis. Four of the more common design concepts are briefly described below:



I. **Upgrade existing equipment:** By replacing existing equipment with similar equipment with greater capacity, such as increasing the transformer size at a station or reconductoring a distribution feeder, the system capacity is increased.

II. **Add new equipment/capacity:** Through additional hardware, such as new circuits, substations, or the addition of an extra transformer to a substation the system capacity is increased. An example is the upgrade of substations to standard multibank substation configuration[1] using standard transformer sizes[2] and increasing capacity of the substations that will maximize group

[1] Substations with two or more transformers connected to a Common bus provide better reliability than single transformers substations which are limited by distribution line capacity.

[2] Using standard transformer sizes is more cost-effective than step size upgrades (e.g., upgrading from 20MVA to 50MVA to 75MVA in a short time period).

firm capacity at the lowest capital cost,[3] up to the point where transmission cost becomes the limiting factor.[4]

III. **Reconfigure the system:** Through load transfers, customers can be moved to different circuits or stations permanently to better utilize resources. This however is limited by the need for sufficient capacity on nearby equipment to support potential N-1 scenarios.

IV. **Apply non-wires alternative solutions**: Where technically feasible and economically viable, NWA solutions can be used to modify the load shape or resolve technical constraints, in order to defer distribution level upgrades.

The high-level solution and benchmark cost estimates may be determined during the system analysis phase. However, final system modifications and costs estimates would require some level of engineering to resolve site-specific issues related to environmental permitting, physical constraints and rights of way, procurement and construction scheduling, all of which might significantly impact the cost.

Transmission Study Considerations

Distribution planning, and in particular planning for large amounts of DG, must often be coordinated with the ISO New England Inc. (ISO-NE) transmission study processes. More specifically, as part of a comprehensive T&D study process a transmission system impact study must also completed for the DER Study Group. The objective of this study is to demonstrate that the proposed DER Study Group projects will not in aggregate have adverse impacts on the reliability and operating characteristics of the transmission system, the transmission facilities of another Transmission Owner, or the system of a Market Participant, and if they do, to recommend system improvements that would eliminate the adverse impacts.

The ISO-NE categorizes levels of analysis needed to be performed to support modifications to the transmission system, in accordance with the ISO-NE Planning Procedure 5-3, “Guidelines for Conducting and Evaluating Proposed Plan Application Analyses”. For the purposes of this study a Level 3 analysis is required; which includes steady-state, stability, and short circuit analyses. The analysis will evaluate the

[3] A DER Group Study approach looks at all the substations in the group instead of finding solutions for individual substation or feeder. Accounting for the capacity of nearby substation provides an opportunity for developing cost effective solutions while maintaining the reliability and operational flexibility of the group.

[4] For example, if upgrading a substation from 1 to 3 transformers is cost effective due to minimum transmission cost, then this solution is proposed. If upgrading the same substation from 1 to 4 transformers is cost prohibitive due to significant transmission costs, the proposed substation upgrades will be limited to 3 transformers.

impact of the proposed DER projects on the affected system operator (ASO), i.e., Eversource. Eversource uses this same analysis framework to study impacts of these future projected DERs to identify reliability transmission constraints and plan appropriate associated transmission upgrades.

4. SOLUTION IMPLEMENTATION

Once the comprehensive solution and/or solution alternatives are determined via the system analysis process the Eversource project approval/construction process is used to initiate and implement a capital project. The process is designed to ensure that the technical approach is sound, and resources are budgeted and allocated to facilitate successful and timely execution of the projects. The overall process flow for capital projects is depicted in Figure 6.

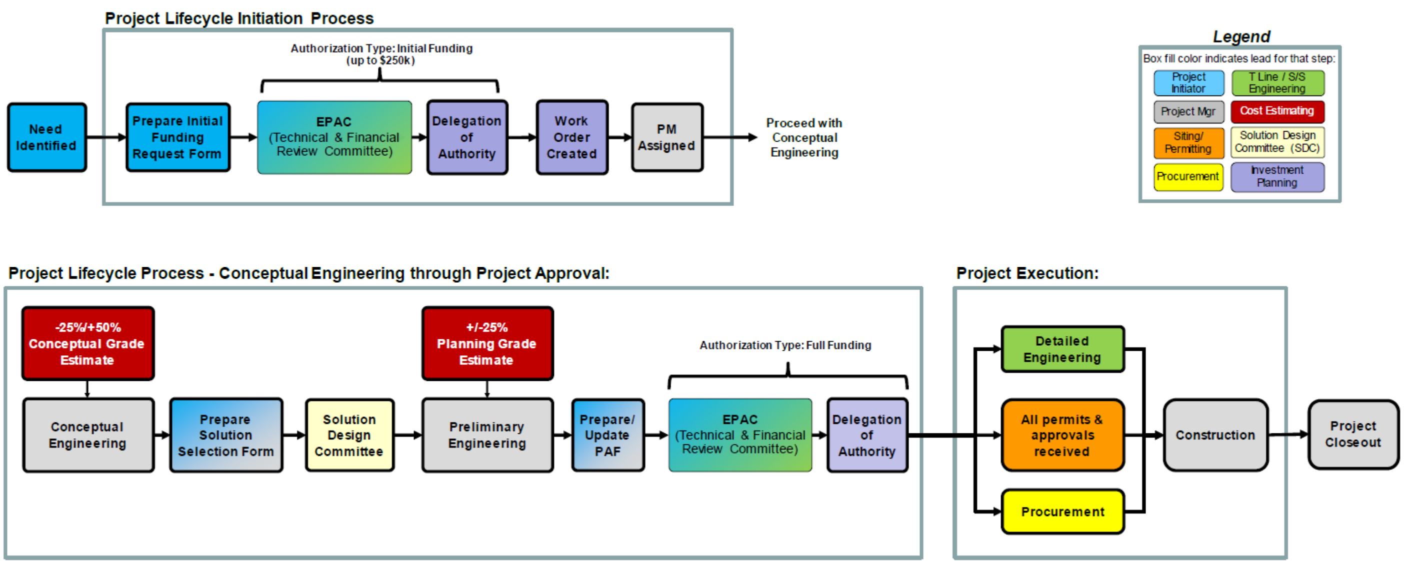


Figure 6: Schematic overview of the approval/construction process

As shown in the figure above, following the final approval of a project, the initiator will secure initial funding for preliminary engineering. The initiator will be required to document the project need, objectives and include an explanation of the funding request amount, including a budget for conceptual and preliminary engineering activities and a schedule for acquiring full project funding. Key process steps include:

- Project initiation
- Conceptual Engineering
- Solution vetting
- Preliminary Engineering

- Full Project authorization
- Detailed Engineering, Siting, and Permitting
- Construction and Construction Variance Monitoring.

The assigned project manager will track execution and construction by monitoring spend vs. authorized cost. The project manager will submit a revised supplemental request form if any of the following occur:

- The project cost exceeds approved tolerances
- Significant scope change such as added unit of property or change in technology
- Significant technical design change

All project documents will be closed, and associated databases updated upon project closeout in accordance with Project Management Process or applicable local project closeout process.