“Transformer Reserve”

In response to: The Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability (OE) Request for Information

Submitted by:

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Background

Of the Bulk Power Systems (BPS) physical infrastructure, large power transformers (LPTs) are critical components, because the reliable operation of the BPS depends heavily on the safe and efficient operation of a network of interconnected LPTs.

LPTs have long been a concern for the US electricity sector because:

- The failure of a single LPT can interrupt electricity service to a large number of customers and lead to collateral damage
- It is often difficult to quickly replace an LPT
- LPTs are large, custom-designed pieces of equipment that entail a significant capital expenditure and a long lead-time to manufacture and ship.
- LPTs are not usually interchangeable.
    - System owners often own and maintain spare LPTs at a number sufficient to mitigate risks from premature failure.
- The limited availability of spare LPTs, and the long lead times to procure replacements, could pose a potential threat to the availability and reliability of the Nation's BPS in the event of an emergency where a relatively large number of existing LPTs are damaged or destroyed.

Evolving threats to the BPS include (but are not limited to): Cyber and physical security intrusions, weather-related incidents; geomagnetic disturbances (GMD); and electromagnetic pulse (EMP) effects.

The recently released "Quadrennial Energy Review, Energy Transmission, Storage and Distribution Infrastructure Report, April 2015," recommends that "DOE should coordinate with the Department of Homeland Security and other Federal agencies, States, and industry – an initiative to mitigate the risks associated with the loss of transformers (P. 2-42)."

Request for Information

For the reasons stated above, DOE is exploring possible National strategies to mitigate risk to the reliability of the BPS arising from the loss of LPTs.

1. *Program Need* - Is there a need for a National Power Transformer Reserve (PTR)? How would such a reserve affect the reliability and resiliency of the NA BPS? Are there alternatives to a power transformer reserve program that can help ensure the reliability, resiliency, and recovery of the BPS? Is there a need for a nationally-maintained inventory of LPTs?

2. *Power Transformer Criteria* – What types and sizes of power transformers should be considered for inclusion in a transformer reserve program versus operational spare capacity? What are the design considerations for replacement transformers to support the BPS?
3. *Ownership and Economics* – What would be an appropriate structure for procuring and inventorying power transformers? How, and by whom, should a program of this type be administered? How would a transformer reserve by funded?
4. *Technical Considerations* – Is it technically feasible to develop a reserve of large power transformers when most are custom engineered? Is additional research and development (R&D) necessary to develop suitable replacement transformers that can be rapidly deployed from inventory in the event of an emergency?
5. *Procurement and Management* – How should procurement, maintenance and management of the reserve power transformers be conducted? For example, should manufacturers be pre-qualified, and if so, according to what criteria?
6. *Supply Chain* – What are the critical supply chain components for the manufacture and delivery of LPTs (e.g. electrical steel, copper, silicone, high voltage bushings, etc.)? Are there shortages or other considerations that could necessitate using the Defense Production Act Priority Ratings to ensure sufficient parts are available in a time of need? Are there related skilled workforce issues?
7. *Manufacturing* – Is there adequate manufacturing capacity to support a transformer reserve program? What is the lead time for engineering, manufacture, and delivery of LPTs? Are there approaches that could help to speed manufacture and delivery of LPTs?
8. *Transport and Deployment* – What specialized transport infrastructure would be necessary to ship LPTs from manufacturing site to storage locations, and from storage locations to field site in the event of an emergency? What should be the number and location of transformer storage sites? What are feasible delivery times for LPTs that reside in a reserve to an affected site?
9. *Field Engineering and Installation* – Are there adequate domestic engineering and installation resources available throughout the US to install multiple bulk power transformers simultaneously? What additional resources would be necessary?
10. *Criterial for Deploying Transformers* – What criteria should be used for activating and deploying transformers from the reserve? How would deployment be funded?

Introduction to Aztral Modeling Approach

Aztral Consulting became interested in Supply Chain Management issues related to LPTs after discussions with several Transmission Company executives. The executives sought a better understanding of the critical economic issues related to building a competitive business around providing “spare transformers” and related services to the Transmission industry. Toward assisting this constituency in learning more about these issues Aztral began developing model(s) to understand a variety of important Supply Chain, Inventory and Cost-Benefit questions. We believe that addressing these questions, with the assistance of a well-thought out analytical tool, will be critical to the optimal and effective management of LPTs in the US.

The following sections provide an overview of the model elements identified as essential to an analytic tool of this kind. In addition, we believe these sections directly and indirectly indicate how our model addresses questions 1 through 9 from the "Request from Information," with an emphasis on question 6 (supply chain management) and aspects of question 7 (manufacturing), particularly the cost/benefit trade-offs among inventory, manufacturing capacity, and related options for enabling reduced production and delivery lead time.

Development of Stochastic Model of Transformer Failure, Inventory, Ordering and Replacement

The model will be a fairly custom, ground-up development, for two primary reasons. Typical inventory modeling approaches are:

1. Built on models of short-term demand volatility that don't align with the infrequent failures of transformer over longer time horizons.

2. Don't connect operational performance metrics, such as equipment failure rates, inventory units, and recovery time, to their associated financial impact.

The structure of the proposed model for the DOE NS (DOE National Strategy) situation is:

- i) Simulate the failure of transformers.
  - (1) It should not be a problem to allow the simulation modeling approach to be flexible and accurate, since the model solution approach will be computational (vs. analytic)
- ii) Determine a policy for setting inventory and ordering additional transformers to achieve a facility up-time objective, given failures modeled with (i)
- iii) Calculate operational and financial performance metrics and risk from (i) and (ii)
- iv) Enable the ability to pool any number of facilities modeled by scaling failure rate (i) and applying (ii) and (iii) to quantify the impact of operational and financial performance

Model Data Requirements

Here we identify some important data questions related to the model development for the DOE NS, acknowledging that current data availability may be limited.

- Focus: Basics required for the initial version of the model
  - We can add more details and capabilities to the model as we learn more about the problem and where DOE NS wants to focus.

  - Required (foundational) parameters -- User able to set any of the following parameters:
    - *Failure rate* per unit time (see notes below*)
    - *Cost of capital* (for $ tied up in inventory)
    - *Supply lead time* (to order and receive a new transformer)
    - *Target performance level* (average downtime before replacement complete)
    - *Installation time* (includes transportation time from inventory location + installation time at site)
    - *Physical storage cost* for transformer while held in inventory, and any *maintenance costs* during that time
- Question: Is <u>facility redundancy</u> an important design element?
  - If so, what is the typical level of redundancy at an installation?
  - Example: If 6 functioning transformers are required and 7 are typically installed with 1 serving as a backup, then a second will need to fail before the first is replaced before network performance is impacted
- Future additional detail for the model (to be prioritized based on identified significance):
  - <u>Failure rate as a function of:</u> facility age, design/type, utilization, maintenance, geography (weather), other?
  - Substitutability of transformer with same performance capabilities but different design (this would allow the stocking of fewer varieties of transformers, focusing more on transformer capabilities than on the specific design)
- * Questions:
  - How often is a full transformer replacement done vs. repair or replacement of a transformer's components?
  - Cost of downtime?
    - Eventually, it will be important to put a dollar value on downtime to quantify the benefits of reducing average downtime and risk of extended downtime.
    - Initially, we can use a target "acceptable" downtime and determine the amount of inventory required to support that target

Primary Model Inputs and Outputs:

Key Inputs:

- Primary requirements:
  - *Transformer failure rate* per unit time (see notes below*)
  - *Cost of capital* (for $ tied up in inventory)
  - *Supply lead time* (to order and receive a new transformer)
  - *Installation time* (includes transportation time from inventory location + installation at site)
  - *Physical storage cost* for transformer while held in inventory, including any *maintenance costs* during that time
  - *Target time to recovery* (downtime before replacement complete)

  - *Cost of downtime*: Dollar value of transformer downtime, to quantify benefit of reduced time to recovery and optimize trade-off vs. inventory cost
  - *Installed base of equipment program will support:* Number and type of transformers

- Ideal additional detail about installed base:
  - *Transformer failure rate* as a function of facility age, design, utilization, maintenance, and geography (weather)

- Transformer specifications:
  - *Transformer substitutability:* Can a transformer with the same performance capabilities but different design be used as replacement?
    - Critical to enable stocking of finite range of transformers with capabilities matched to installed base supported (vs. need to match specific design of each transformer supported)
  - *Replacement only, or also repair:* Will only full replacement of failed transformers be considered, or also component replacement and/or equipment repair?
    - If goal is to offer repair as well as replacement, important to determine types of components and repairs to support
    - Inventory requirement may explode, since parts for the wide range of transformers in installed base would be required

Key Outputs:

- Operational metrics: Average number and probability distribution of:
  - Number of failures by time interval
  - Transformer downtime before replacement is complete
- Financial metrics: Average number and probability distribution of:
  - Inventory-related costs (capital, holding, storage and maintenance costs)
  - Cost of downtime
- Ability to calculate these metrics for any number of LPT facilities supported, enabling impact of scale on both mean value and risk (probability distribution) of inventory related costs and downtime performance to be quantified