DSTAR's Transformer Cost Analysis Software Enhances Utility Decision Process

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Distribution transformers represent a significant cost to electric utilities, both as a capital investment and as an ongoing operating expense. A survey of seven 2003 FERC Form 1 filings shows that distribution transformers can account for approximately 9 to 20% of total distribution capital spending in a year. Productivity tools that help to minimize transformer total owning costs and increase overall asset utilization can make a significant impact on a distribution utility's bottom line. The Distribution Systems Testing, Application, and Research (DSTAR) utility consortium commissioned the development of the Transformer Owning Cost Software (TOCS) tool for analyzing and comparing the total owning cost of distribution transformers.

Transformer Thermal Loading and Insulation Life Expectancy:

Unless a transformer first fails due to tank corrosion, the usual mode of failure is deterioration of its insulation capability. Even when a nearby lightning strike coincides with failure of an aged transformer, most often the decreased voltage withstand of the unit's insulation is the true cause with the lightning stress acting as the *coup de grace*.

Insulation aging is a thermo-chemical process in which aging progresses at a highly nonlinear function of the absolute temperature. Transformer temperature, in turn, is related to loading. However, the long thermal time constants of a transformer make the relationship between load and transformer temperature highly dynamic. This means that the temperature is dependent not only on the present load, but also on the loading in previous hours. In addition, the ambient temperature plays an additive role to the effects of loading. The industry has developed transformer loading analysis algorithms to model transformer thermal behavior and insulation aging, allowing the inherent overloadability of distribution transformers to be exploited. According to IEEE C57.91-1995, when the hottest spot on the transformer winding is at 110°C, the aging acceleration factor (FAA) is 1.0, meaning that the transformer is aging at a rate such that its useful life is 180,000 hours, or 20.55 years of continuous exposure to this temperature.

The IEEE C57.91-1995 standard provides a simplified thermal dynamic response model having two effective time constants: the hot-spot time constant and the top-oil time constant. The DSTAR TOCS software calculates the hourly temperature rise and estimates the transformer insulation life expectancy by using a method similar to that described in IEEE C57.91-1995. The total temperature rise of the winding hot spot, above ambient, is due to the load placed on the transformer. The absolute temperature, upon which insulation aging is dependent, is the sum of the load-caused temperature rise and the ambient temperature. Higher loading and ambient temperatures will result in accelerated insulation aging and a shortened transformer life.

Economic Calculations:

The total owning cost to a utility for any transformer is made up of two major elements:

1. *The cost of owning the transformer*

This includes the purchase price, installation cost, residual value or cost at the end of the life, as well as the effects of interest, depreciation, taxes, and other factors. TOCS converts all of these factors into a levelized annual carrying charge for each year of the transformer's estimated service life. In addition, the FCR is adjusted to take into account the variation in the transformer's useful life caused by loading.

2. *The cost of losses incurred by operating the transformer*

   This includes the cost of energy consumed by transformer losses and the cost of the system capacity required to accommodate these losses (note that this is not the same as the system capacity required to supply the load itself).

   Transformer losses are divided into two types:

   No-Load Losses - Core losses incurred while the transformer is energized, regardless of loading. **Load Losses** - I^2R coil losses proportional to the square of load current. TOCS calculates load losses according to the yearly, seasonal, and daily loading pattern defined by the user, and it also adjusts load losses for harmonic current heating.

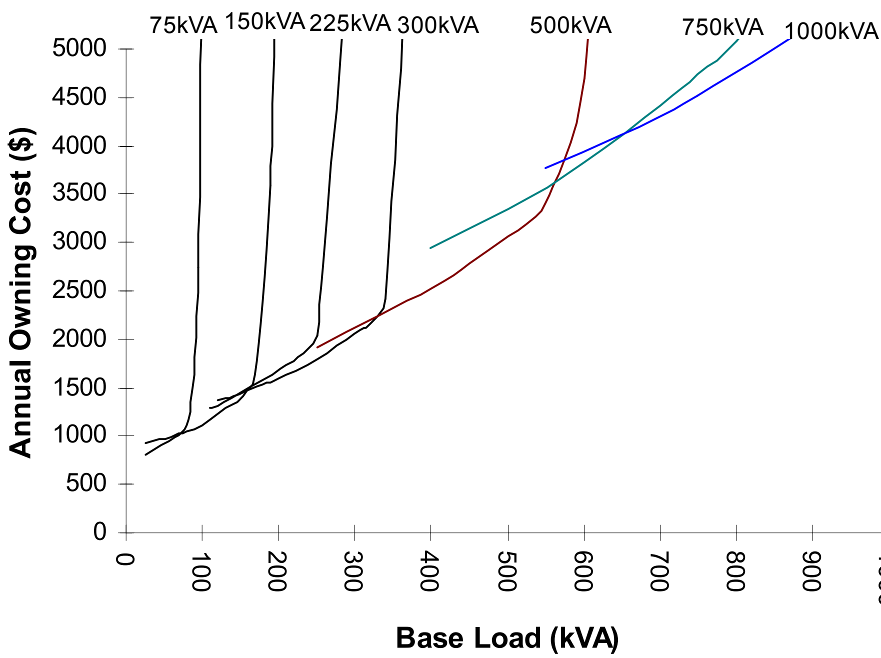
With the annualized carrying charge, cost of losses, and transformer life expectancy the present value of the total owning cost can be calculated and levelized over the calculated transformer life. Transformers that experience premature failure have a higher annual owning cost because the transformer must be amortized over fewer years and there are costs associated with replacing the failed transformer. Although transformer life has not been traditionally included in owning cost calculations, it can have a significant effect on overall owning cost. TOCS brings all of these factors together and performs an hour-by-hour analysis.

Working With TOCS and Example Applications

The TOCS tool is based on a relational database that allows users to build and maintain a library of data that can be used to set up analysis cases in any combination. This library contains transformer design data, yearly and daily loading cycles, harmonic spectra for load current, and yearly load growth factors. Often times, data that can be used within TOCS is located in a spreadsheet or some other electronic format that is difficult to manually input through the standard user interface. TOCS has an import capability that allows users to easily bring data into TOCS for analysis. Additionally, a full year's worth (8760 hour) of hourly loading, temperature, and energy charge data can be imported for analysis. Some of this data can be obtained from interval meters at customer locations.

The user defines an analysis case by choosing the desired data from the library, entering economic parameters, and selecting the transformers to which the load is applied. When the user runs the analysis, the program determines the lifetime and total owning cost for the transformer(s) under that loading scenario. Users are able to compare many transformer designs simultaneously against various loading scenarios.

The TOCS calculation engine is a very powerful tool for performing detailed analysis on different distribution transformer designs and loading characteristics. The batch analysis functionality within TOCS enables users to run multiple loading scenarios against a set of transformers and produce annualized owning cost versus KVA loading curves. These curves define the economic range of operation for a collection of transformer designs.



Example of Annualized Owning Cost versus Base Load Curves

In addition to TOCS, DSTAR has created a spreadsheet-based tool that allows users to import AOC versus Base Load data, load frequency information, and inventory cost data to perform stock and procurement budget analysis. It is recognized that there are costs associated with maintaining transformers in a utility's inventory. Inventory costs are reduced by eliminating transformer kVA ratings that can be covered by other ratings. There is a penalty, however, in total owning cost for eliminating a rating. The stock analysis algorithm cycles through all transformers of interest to determine which transformer rating should be removed from stock to give the largest reduction in total annual owning cost when taking inventory costs into account. Similarly, the procurement budget analysis algorithm has been implemented for the purpose of selecting the mix of transformers that will serve the expected loads with the lowest possible total owning cost while meeting the budget constraints.

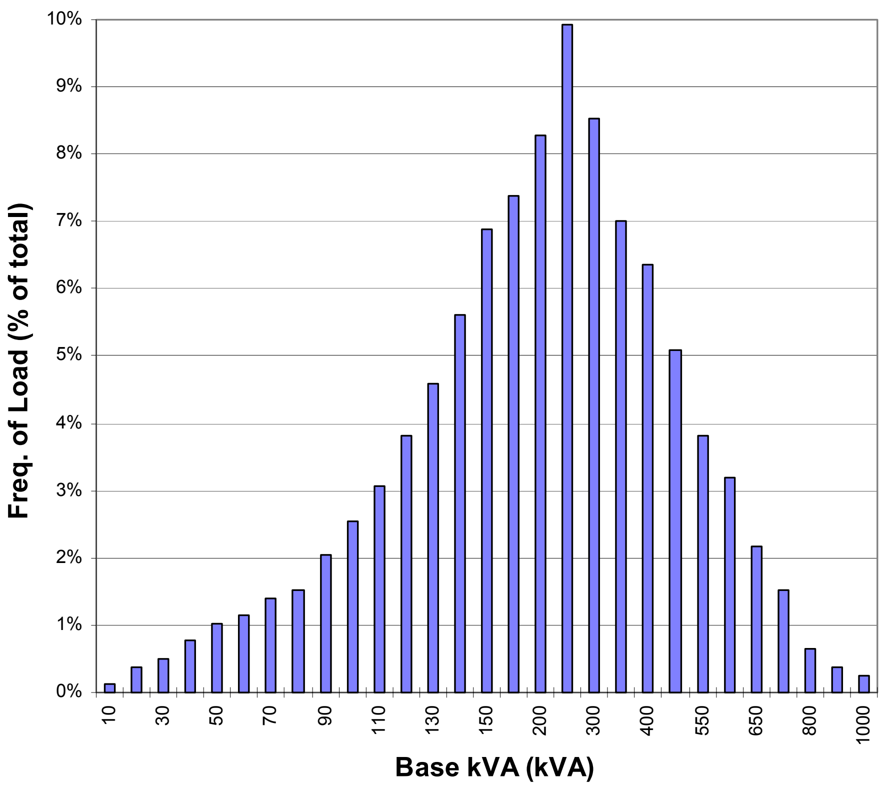
Stock Analysis Example

This example is based on a selection of typical three-phase transformers. With the exception of 112.5kVA, one design was included for each of the ANSI standard ratings from 75kVA to 1000kVA. It has been assumed, for this example, that a TOCS analysis of lowest total owning cost designs has yielded this set of transformers for further analysis. The transformer and loading data for this example has been fabricated and has been chosen to demonstrate the capability of TOCS.

Transformer and Loading Data

KVA Size	Impedance	Price	Load Losses (W)	No-Load Losses (W)	Load Loss Eval.	No-Load Loss Eval.	Total Owning Cost
75	3.25	$ 4,098.00	644	70	644	210	$ 4,952.00
150	3.44	$ 5,152.00	1077	110	1077	330	$ 6,559.00
225	2.83	$ 6,260.00	1558	149	1558	447	$ 8,265.00
300	2.93	$ 6,720.00	1863	194	1863	582	$ 9,165.00
500	4.31	$ 8,571.00	3357	261	3357	783	$ 12,711.00
750	5.69	$ 12,395.00	5663	303	5663	909	$ 18,967.00
1000	5.75	$ 12,298.00	6552	1329	6552	3987	$ 22,837.00

The load base line item cost chosen for this example is high in order to create a scenario where eliminating transformer ratings from inventory significantly impacted total loaded annual owning costs. The inventory carrying-charge factor chosen is 10%, while the inventory utilization factor is set at 10% or approximately one month of inventory. Also, the range and frequency of base loads to be served by this inventory of transformers, arbitrarily chosen, are 785 loads ranging from 10kVA to 1000kVA.



Load Frequency versus Base Load

Initially, the TOCS stock analysis algorithm determines the total owning costs using all transformers to serve the load. It eliminates one transformer design at a time, and re-calculates the total owning cost, including inventory costs, for the full set of transformers. Those eliminations that result in the largest decrease of total owning cost are recorded. This process continues with multiple transformers being removed from inventory until the lowest owning cost combination is selected. In this example, the TOCS analysis showed that an annualized owning cost savings of $1,073 could be achieved by eliminating 75kVA, 225kVA, and 750kVA transformers from inventory. This example demonstrates the powerful analysis capability of TOCS and the potential savings that can be achieved through its usage.

The TOCS software and associated analysis tools demonstrate the benefit of DSTAR's collaborative development of software that meets the specific needs of each participating utility. Products that have been developed by DSTAR cover a wide range of distribution-related areas from pole loading to secondary electrical design. The collaborative nature of DSTAR allows its members to leverage pooled funding while also giving them greater control over the functionality of final delivered products and enabling standardized user interface designs. DSTAR members receive all of the products developed for each program they join.

Authors' Bios

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