

Replacing Distribution Transformers A Hidden Opportunity for Energy Savings

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ABSTRACT

Electrical power distribution transformers are behind-the-scenes equipment in virtually every government and commercial building. They are energized around the clock, providing power to the building's electrical equipment and consuming energy whether or not this equipment is operating. The Department of Energy (DOE) has replaced the aging transformers in its Germantown, Maryland, facility with high-efficiency transformers which minimize these operational losses. This paper discusses why DOE chose energy-efficient replacement transformers and also provided incremental funding for them – even though it is a tenant in this GSA-owned building. We also estimate dollar and energy savings and atmospheric carbon emissions reductions that should be realized, compared with standard efficiency transformers. To estimate these savings we evaluated transformer loading in the building.

The paper describes the load measurements and compares our results with those of other measurements in commercial and governmental buildings. These measurements reveal that distribution transformers are often much more lightly loaded than expected, creating energy savings opportunities for units with low “no-load” losses. The Germantown measurements are extrapolated to estimate savings which could be realized throughout the federal government, other levels of government, and commercial buildings nationwide through replacement with energy-efficient distribution transformers. The paper also provides a perspective on the DOE Federal Energy Management Program initiative to promote purchases of energy-efficient products throughout the federal government and the complementary Energy Star program to promote their use throughout the private sector, as well.

Background

The Department of Energy (DOE) promotes the purchase of energy-efficient equipment in federal facilities as a primary energy management policy. Executive Order 13123 (Clinton 1999) and Chapter 23 of the Federal Acquisition Regulations (FAR) direct federal agencies to purchase Energy Star labeled products or, if no Energy Star label exists for a product category, then products that are in the upper 25 percent of energy efficiency as designated by FEMP. The EPA/DOE Energy Star Purchasing Program encourages similar policies and practices in state and local purchasing.

FEMP issues energy efficiency purchasing recommendations for a wide range of products. For distribution transformers the FEMP recommendations are based on the National Electrical Manufacturers Association Standard TP 1-1996 (NEMA 1996); the Energy Star label for transformers also uses the same efficiency criteria. When the time came to replace the aging distribution transformers in its Germantown, MD building, DOE recognized the opportunity to showcase the cost-effective application of high-efficiency transformers in an office environment.

Distribution transformers are used within commercial and industrial (C&I) buildings to supply electrical power to individual circuits for lighting, plug loads, air conditioning, and other applications. Transformers reduce the higher voltages used by electric utilities for power distribution to lower levels required by building equipment. They are generally out of sight in mechanical spaces and other out-of-the-way locations, and are therefore often out-of-mind as well. Although transformers last a long time (on the order of 35 years), whenever they are replaced or added as a part of new construction or a renovation or addition, efficiency upgrades can provide an excellent opportunity to save energy and money. In general however, these savings are not great enough to justify replacement of transformers that still retain significant operational life. The opportunities for energy-saving upgrades are best captured for newly installed transformers or when replacement is due.

The original five-story Germantown building, completed in 1958, provides office space for approximately 2,000 DOE personnel. The facility also includes a large auditorium, a cafeteria, and a computer center. DOE, the facility tenant, and the General Services Administration (GSA), the owner, have been upgrading the facility to improve operating conditions and energy efficiency. The original distribution transformers in the building were nearing the end of their useful lives, so GSA initiated a project in the late 1990s to replace a total of 53 aging transformers.

Following a suggestion from the DOE Federal Energy Management Program (FEMP) office, DOE's Mike Shincovich, an engineer with the Engineering and Facilities Division, recognized the transformer replacement as a possible energy-savings measure. His preliminary analysis revealed that the project would readily meet the federal life-cycle cost-effectiveness criterion set forth in Executive Order 13123, and he requested that GSA specify energy-efficient transformers in the Request for Proposals. Based on this request from their DOE tenant, GSA specified the requirement for TP-1 compliant transformers in the RFP.

The basic cost for the transformer replacement project would have been about \$360,000 if standard efficiency units were used. Because TP 1-compliant transformers at the present time cost more than standard efficiency transformers, DOE contributed an additional \$57,000 to cover the added cost. The transformers were installed in the spring of 2001.

Quantifying the Loads and Potential Savings

As partners in the Energy Star program DOE and the Environmental Protection Agency (EPA) agreed to cooperate in a study of the loads on a representative set of the transformers being replaced at Germantown. These measurements also provide a basis for calculating expected savings to be realized by installing the more efficient units.

TP-1 transformers deliver most savings when *average* loads on the transformers are below 50 percent. In fact many TP-1 models are designed to reach peak efficiency near an

average load of 35 percent. It is important to note that it is the average load that is important for efficiency considerations. Even though transformers are sized for anticipated peak load and a margin of safety, actual loads rarely approach the rated capacity and in fact a transformer's highest load often occurs only during a few hours each week. Although average transformer loads had been measured in an earlier study in Massachusetts and southern New Hampshire (Korn et al. 1999), this site presented an opportunity to verify the relationship between average and peak loads in a building in a warmer climate, with a higher fraction of air conditioning loads on peak. The metering effort showed that loads in the DOE building were consistent with those measured in the Massachusetts study

Methodology

Transformers were metered for two weeks. Spot measurements were taken prior to installation of data logging equipment to ensure proper operation of the datalogging equipment and to properly size current transducers used for the metering.

Spot measurements. Using portable metering equipment, including a Fluke[®] Model 41 power analyzer¹, instantaneous measurements were collected for each phase (1) just prior to installation of recording current meters and (2) when the meters were removed 2 weeks later. Measurements included:

- Voltage.
- Current in amperes (also measured in the neutral leg).
- Power (watts).
- Power factor (kW/kVA).
- Total harmonic distortion as a percent of the fundamental frequency.
- K Factor, a measure of harmonic current.

Spot measurements of the two harmonics metrics were collected to provide a general indication of their presence. Because the harmonic measurements are point-in-time they do not provide statistically significant values for these parameters.

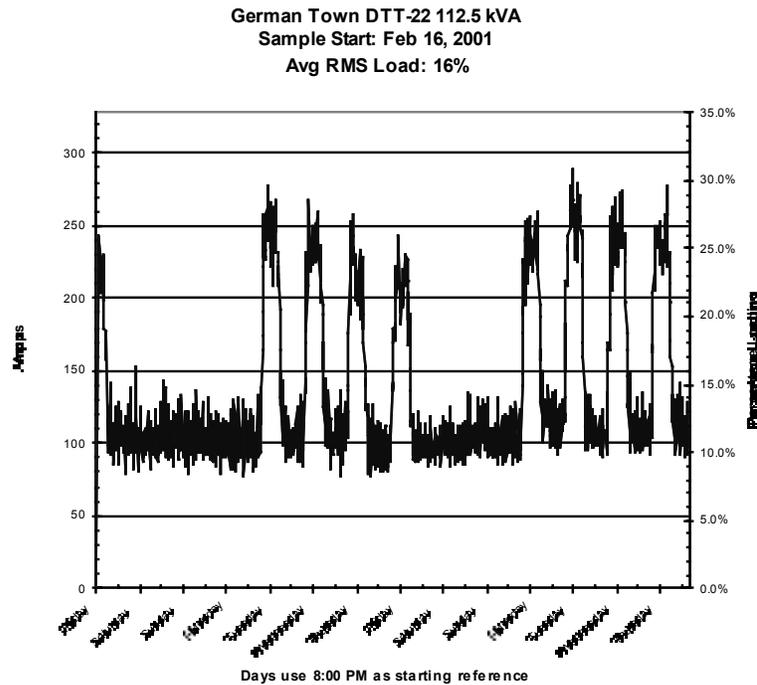
Datalogging. Current transducers (CTs) were sized for the expected current and attached to each of the three secondary legs. Where metering the secondary legs was difficult because of spacing in the transformer or secondary distribution panel, the primary side of the transformer was metered. Each CT was connected to a channel of a *MicroDataLogger*[®] which was programmed to collect current measurements every 10 minutes continuously for two weeks (over 2000 measurements per leg, up to 8,136 measurements per transformer).

Results

To determine just how much energy the TP-1 transformers would save, we measured actual loads on a representative set of 20 randomly selected standard transformers for 2

¹ Crowley Associates of Norwood, Massachusetts generously provided Fluke[®] equipment for use in the study.

weeks. We found that the root mean squared² average load was only 16 percent of nameplate values. This was consistent with the findings of an earlier Cadmus Group, Inc. study of office buildings in Massachusetts (Korn, 1999). Peak loads at the DOE facility never exceeded 45 percent of rated capacity, and in most cases were much less. This is a particularly important finding because TP-1 transformers often are most efficient—and so deliver their greatest savings—at these lower loads. The new transformers use less energy primarily because of lower core losses of modern Energy Star/TP-1 transformers. Harmonic measurements indicated that harmonics are not great enough in the Germantown facility to necessitate special K-rated transformers. The following graph illustrates a typical transformer's measured load over a two week period.



Energy and Cost Savings at Germantown

The facility will save more than 160,000 kWh per year by replacing its old transformers with energy-efficient transformers rather than baseline efficiency units. At the current Germantown electricity cost of \$0.063 per kWh, the facility will save more than

² The average load of the monitored transformers for the time period was calculated using a root-mean-square (rms) method to properly weight periods of high loads and thus properly calculate losses. Because losses are proportional to the square of the current, the arithmetic average of the current does not properly weight periods where current is relatively high or low. The rms method properly weights the average so that it can be readily used to calculate losses. In the rms method, the load for each time period is squared and the average of all the squared values is calculated. The square root of this average yields an rms value. For a transformer with a relatively constant load, the rms and arithmetic averages are nearly identical. For a transformer with wide variation in its load, the rms will differ from the simple average.

\$10,000 per year. The upgrade to TP 1 units over conventional transformers in this contract will pay for itself in just 5.7 years. Even better, using current GSA pricing for Cutler Hammer TP-1 models, the differential in transformer cost versus standard models could pay for itself in roughly 2.5 years. GSA prices are those published and offered to qualified purchasers for the federal government. They are also probably representative of what prices a large purchaser could obtain. This is compelling when one considers that the transformers can last 30 years or more. Over the nominal life of the transformers savings will total \$300,000 in today's dollars. Considering that electricity prices in the northeast and other parts of the country are over \$0.10/kWh the savings and payback opportunities in these areas are even more attractive.

The FEMP Perspective

As the world's largest-volume buyer of energy-related products, the federal government can reduce energy consumption and achieve enormous cost savings by purchasing energy-efficient products. FEMP helps federal purchasers identify highly efficient products, such as an energy-efficient distribution transformer, through a series of nearly 40 energy-efficient purchasing recommendations (on-line at www.eren.doe.gov/femp/procurement). Other product categories range from exit signs and fluorescent ballasts to large chillers and boilers. Where a product category is also covered by the DOE/EPA Energy Star labeling program (see below), the FEMP purchasing criteria match the Energy Star label requirements.

These recommendations:

- identify federal supply sources that offer efficient products;
- suggest ways for buyers to identify efficient products when buying from commercial sources;
- present cost-effectiveness examples in order to help buyers judge whether a higher price is really “worth it”;
- offer tips to help buyers and users save energy in selecting and using the products; and
- provide leads to other useful sources of information on product energy efficiency, such as the American Council for an Energy-Efficient Economy (ACEEE), Home Energy magazine, and many more.

Federal purchases of energy-efficient products are not only required by Executive Order, they also:

- save taxpayer money because energy-saving products have lower lifetime operating costs, which more than offset a higher (in some cases) initial purchase price;
- reduce pollution and greenhouse gas emissions by lowering energy consumption; and
- provide market leadership by increasing the market presence of these products and lowering prices.

The Energy Star Perspective

Energy Star was introduced by the Environmental Protection Agency in 1992 as a voluntary labeling program designed to identify and promote energy-efficient products, in order to reduce energy-related carbon dioxide emissions. Buildings of all types consume about one-third of all the energy used in the United States and are responsible for a comparable fraction of air pollution and CO₂ emissions. By encouraging building owners and product users to buy and install products with the Energy Star label, this pollution can be significantly reduced.

EPA partnered with the Department of Energy in 1996 to promote the Energy Star label, with each agency taking responsibility for particular product categories. Energy Star has expanded to cover labels for new homes, certain non-residential buildings, residential heating and cooling equipment, residential lighting and major appliances, office equipment, consumer electronics, and other products – including distribution transformers that meet the NEMA TP-1 requirements (see www.energystar.gov/products).

By providing a single Energy Star label that highlights efficient products in the marketplace, the EPA/DOE program ensures that consumers can quickly and easily find products that will protect the environment and reduce their energy bills, while simultaneously ensuring that manufacturers can safely invest in developing and commercializing new or underutilized energy-efficient technologies. The overall goal is to accelerate the market penetration of energy-efficient products, working with industry and other stakeholders.

ENERGY STAR Labeled Transformers

With this in mind, the Energy Star label for commercial and industrial transformers was launched in April, 1998. Electricity losses from C&I transformers were estimated to be between 60 and 80 billion kWh per year in the United States. Despite the fact that larger liquid-immersed transformers had made efficiency gains in the past few decades, efficiencies of smaller dry-type distribution transformers had in general declined somewhat over this period. It was determined that that even modest improvements in efficiency levels of 2% to 3% could deliver important savings. Moreover, unlike many products, transformers have a long life span thereby increasing the potential for significant, cumulative energy savings.

EPA is working with manufacturers, utilities, specifiers, and other groups in the sales/trade chain to encourage the use and expand the market share of Energy Star labeled transformers. As of February, 2002, there were 19 manufacturers signed up as Energy Star partners to offer Energy Star labeled transformers, including all of the major manufacturers. EPA has also developed cost calculators, case studies, and other market materials that demonstrate the economic, energy saving, and environmental benefits of these efficient transformers.

Opportunities in Other Federal and Non-Federal Facilities

Essentially all of non-residential buildings and industrial facilities have distribution transformers feeding their internal electrical circuits. As noted above, in office buildings these loads typically include lighting and outlets for computers, office equipment, and other

end uses. Similar requirements are found in other building types, including lodging, public assembly, and warehousing. Other more specialized buildings, such as food service, laboratory, health care and educational facilities have not only these types of loads but also special requirements for their unique equipment types. All of these loads require distribution transformers sized to their respective needs.

Virtually every non-residential building, federal and non-federal, could be a candidate for more efficient transformers, depending on the age and efficiency of its internal electrical distribution equipment. A fundamental factor in judging the cost-effectiveness of a more efficient replacement transformer is the cost of electricity to the facility. Higher than average energy costs yield a shorter payback period, making the selection of energy-efficient distribution transformers even more attractive. In addition, prices for TP 1-compliant transformers are falling as more manufacturers add them to their product lines, so the opportunity for savings continues to improve. Quotes received by Cadmus in New England and New York State show price differentials for many sizes have dropped by 50 percent or more (Cadmus, 2000).

The facility manager can assess the applicability to the facility by evaluating the building energy consumption patterns and the age and efficiency levels and loading of its transformers. Furthermore, because distribution transformers consume energy even when the building is not occupied or equipment is not operating, more efficient distribution transformers result in savings around the clock, every day of the year.

Even admitting that many of these factors vary from site to site, we can make a first-order estimate of savings potential if we assume that savings documented at the DOE Germantown facility are somewhat typical of those in other large federal and non-federal buildings. The projected annual savings of 160,000kWh are approximately 1.25 percent of annual energy consumption at the Germantown facility, typically on the order of 12,700,000 kWh (Shincovich 2001). This corresponds to a cost savings of about \$10,000. If we conservatively reduce this to about one percent and consider this ratio representative of other government and commercial buildings, it can provide a basis for estimating savings on a larger scale.

Within the federal government, the annual electricity consumption in commercial buildings is on the order of 42 billion kWh, at a cost of approximately \$2.5 billion (DOE/EIA 1998). Assuming replacement of all distribution transformers with more energy-efficient ones after 35 years (a typical transformer lifetime), electricity cost savings of one percent would amount to about 420 million kWh, or \$25 million per year. Extending this to state and local governments, which collectively consume about 132 billion kWh annually at a cost of approximately \$9.3 billion for electricity in their non-residential buildings (DOE/EIA 1998), the potential savings after a complete turnover of the stock are on the order of 1.3 billion kWh and \$90 million per year. Nationally, all non-governmental commercial buildings spend approximately \$44.8 billion annually on electricity (DOE/EIA 1998). A changeover to energy-efficient distribution transformers here could eventually result in savings of roughly \$450 million per year.

Pollution Reduction at Germantown and Beyond

Using less energy can not only save money, it can also reduce the emission of greenhouse gasses such as carbon dioxide (CO₂), which are released when electricity is generated. As discussed earlier, the efficient transformers installed at the DOE Germantown facility are projected to save annually more than 160,000 kWh and \$10,000 in energy costs. As DOE estimates that 1999 carbon dioxide emissions for site electricity consumption were 49.74 million metric tons of carbon per quad (10¹⁵ Btu) (DOE 2001) the Germantown transformer replacement will reduce electricity-related greenhouse gas emissions by over 27 tons of carbon per year.

According to a 1999 report by Cadmus Group, Inc., if Energy Star labeled transformers made up 20 percent of annual sales, after 5 years about 350 million kWh of electricity could be saved nationwide due to reduced core and winding losses (Korn et al. 1999). The savings figures are based on an annual market of transformers with a combined capacity of 11,700,000 kVA. Based on manufacturer supplied core and winding losses and a weighted set of transformers to match the size distribution sold, savings are roughly 30 kWh per kVA of capacity, resulting in an annual savings of approximately 350 million kWh/year³ if one year's sales (equivalent to 5 years of 20 percent market share) is replaced. Therefore the 350 million kWh saved annually, at the end of 5 years correspond to savings of approximately 60,000 metric tons of carbon per year.

Conclusions

This project highlights the opportunity presented for installation of more efficient transformers when existing units are due for replacement. The additional cost is low enough that the \$10,000 annual savings provide a simple payback of about 5.7 years, well within the limits of guidelines for federal facilities. Overall the federal potential is for savings can be on the order of \$25 million per year. Similar opportunities exist at State and local levels and in the private sector as well. Furthermore electricity costs for private businesses are typically higher than those governments can negotiate, so their savings will be proportionally greater. Some of these organizations may require shorter payback times for their replacement projects, but the number of opportunities in these areas should increase as competition causes the cost differential between baseline and high-efficiency units to drop. As noted above, Cadmus has seen price differentials for many sizes drop by 50 percent or more. The project also provides an opportunity to gain further insight into typical loading patterns for distribution transformers in an office building. With average transformer loading measured at about 16 percent and peak loads no more than 45 percent, these results support the contention that transformers in office buildings are very lightly loaded relative to their rated capacities and that energy efficient transformers are particularly well suited to these load levels.

Finally, the project provides a cost-effective real-world example that can be used by FEMP and Energy Star to illustrate the potential for energy, operating cost, and emissions savings from high-efficiency distribution transformers. This actual experience can help to

³ These savings include not only commercial buildings, but other non-utility users as well.

assure other project planners - both in government and the private sector - that they too can benefit from this available technology.

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