Transformer Replacement Program
Low-Voltage Dry-Type 25-300 KVA Transformers

Implementation Manual

Version 2

Date: January 24, 2018

nationalgrid

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Disclaimer:
Please acquire and review the latest version of this document before submitting a project for an incentive pre-approval.
Ongoing consultation with the National Grid program manager during development of the project is essential to maximize the chances for receiving an incentive. Circumstances may require additional requirements for the customer to receive an incentive.

Program Manager

Contact the program manager with questions about the program or the Transformer Savings Tool (TST) which embedded in this manual.

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Section 1 Transformer Program Description

The National Grid transformer program provides incentives for early replacements of existing, inefficient distribution 25-300 KVA Pre TP-1 standard transformers with new transformers meeting or exceeding the minimum efficiency required by Federal Standards**. The replacement of failed transformers does not qualify for incentives.**

Existing Transformer Requirements

This program focuses on the early replacement of low-voltage dry-type transformers in commercial, industrial, and municipal facilities, installed prior to state and Federal adoption of the TP-1 standard. These older transformers have much lower efficiencies, varying from 92% to 95% at rated load conditions, and even lower efficiencies at typical loading conditions.

The *existing transformer* must be a low-voltage dry-type that does not meet the TP-1 efficiency standard. The age of the existing transformer can be compared to the state's TP-1 adoption year (Table 1) to determine whether it is eligible for the Transformer Replacement Program. Transformers installed *before* the state's TP-1 adoption date likely do not meet the TP-1 standard and qualify for replacement**. Transformers installed *after* the state's TP-1 adoption date most likely meet the TP-1 standard and do *not* qualify for replacement.**

Table 1 TP-1 Adoption Year by State

State	TP-1 Adoption Date
Massachusetts	January 1, 2000
New York	July 1, 2002
Rhode Island	January 1, 2007

Replacement Transformer Requirements

The *replacement transformer* must be a low-voltage dry-type between 25- and 300 KVA, meeting or exceeding the 2006 Federal efficiency standard. The rated size (kVA) of the replacement transformer must be equal to or less than the existing transformer replaced.[1]

Transformer Downsizing Requirements

If an existing transformer is lightly loaded, the replacement project may also include downsizing existing equipment (replacing the existing unit with a new, smaller unit). Downsizing the transformer may increase the project's demand and energy savings by optimizing the unit's operating efficiency, and may improve the project's cost-effectiveness by reducing the project's cost.

[1] In rare cases, the customer may choose to consolidate loads on multiple existing (non TP-1) transformers onto a new larger transformer. In such cases, the new transformer size must not be greater than the combined sizes of the existing transformers.

It is important to confirm with the customer that measured loads on the existing transformer represent the loads experienced by the replacement transformer. If the customer plans to increase the transformer load (e.g., by converting the existing space to a function with a higher load density), the estimated load profile must be modified to account for this, if considering unit downsizing. Metering the existing unit also must represent the maximal annual use. For example, metering a school during summer could miss higher loads occurring during higher-occupancy periods.

Downsizing transformers should only be considered upon meeting the following criteria:

1. The measured load profile of the existing transformer never exceeds 35%.
2. The estimated load profile for the replacement transformer never exceeds 50%.
3. The customer has no plans to increase the load on the existing transformer.

Downsizing Example

Figure 1 shows profiles for existing Transformers A and B. The profile for Transformer A never exceeds 35%, and may be a downsizing candidate. The profile for Transformer B exceeds 50%, and should only be replaced with a like-sized transformer.

Figure 1. Sample Existing Unit Load Profiles

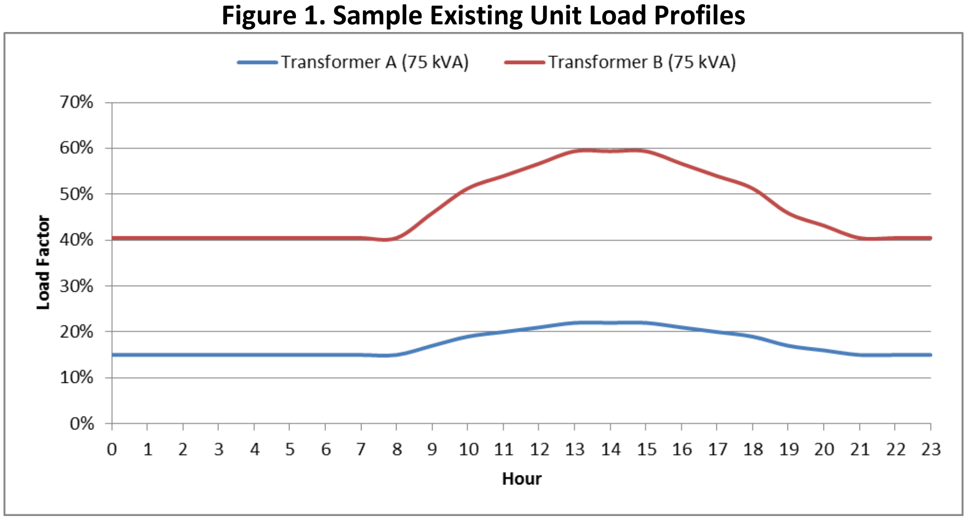


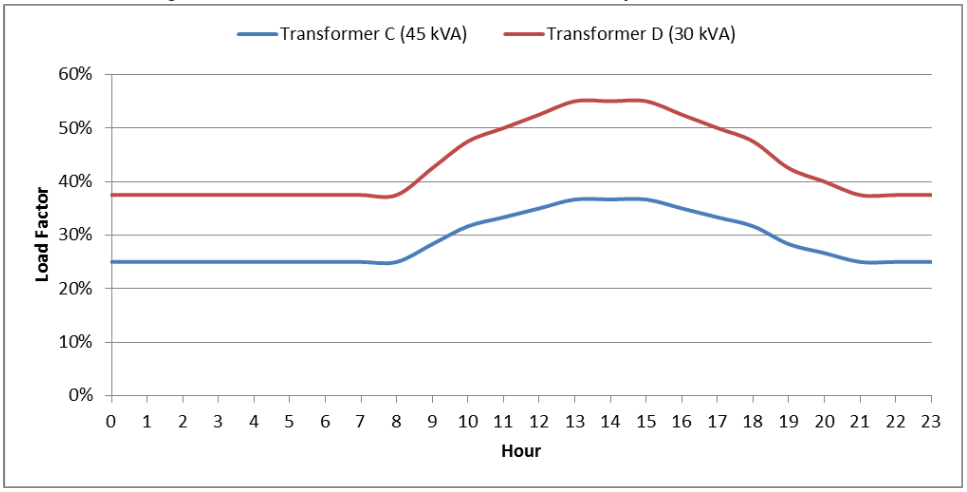
Figure 2 shows the estimated load profiles for two potential replacement transformers for the existing Transformer A. Transformer A, shown in, has a rated capacity of 75 kVA, and could be downsized based on its metered load. Transformer C has a rated capacity of 45 kVA and Transformer D has a rated capacity of 30 kVA.

The estimated load profile for a down-size transformer can be calculated as:

$$LF_{NEW} = LF_{OLD} * \frac{kVA_{OLD}}{kVA_{NEW}}$$

The load profile for Transformer C never exceeds 40%; so this 45 kVA transformer serves as a good candidate to replace the existing unit. Transformer D's load profile likely will exceed 50% for at least a couple hours during a typical day, indicating a 30 kVA transformer may be too small to replace the 75 kVA existing unit.

Figure 2. Estimated Load Profiles for Replacement Units



Using the downsizing criteria it can be determined that Transformer A is a good candidate for downsizing, and Transformer C is the appropriate replacement.

Savings Calculations

Estimates for energy and demand savings achieved through transformer replacement projects must be determined using the Transformer Savings Tool (TST). This tool:

- Indicates whether existing units likely qualify, based on the state and the unit age;
- Provides guidelines for metering requirements only if applicable or asked by the PA;
- Calculates energy and demand savings for custom application preparation

See Section 3 for more information about using the tool.

Determining Program Eligibility - Cost Effectiveness

Program contacts should be consulted to determine project eligibility. All projects should receive an incentive preapproval before moving to purchase and/or installation phases.

To qualify for an incentive, a transformer replacement project generally must be a part of a cost effective (BCR ≥ 1) project. The 2017 Custom Screening Tool contains specific screening policies and guidance that must be followed to determine cost effectiveness. The Custom Screening Tool should be used to determine cost effectiveness for each proposed project using project specific savings, calculated from the TST, and project specific costs. For a transformer retrofit scenario, the full cost of the new transformer, including both labor and materials, should be used. The incentive cannot be used to reduce project costs

Incentive Levels

Incentives will be provided to reduce customer costs for qualifying projects after the application is reviewed and project passes the BCR test.

Section 2 Transformer Program Application Process

This section describes the process for completing an application for a transformer replacement project.

Transformer Savings Tool

A completed TST will collect and document project information required for both project screening and the application process. The TST should be completed prior to completing the application form. All project documentation, including the TST, screening tool, and application form should have matching project information, such as energy and demand savings.

Additional Metering

In rare cases, spot measurements and short-term metering of existing transformers must be performed to determine the transformer losses. Meters used for establishing loads and efficiencies of existing transformers must meet the requirements outlined in Appendix A – Metering Transformers.

Determine Cost Effectiveness

Once savings and costs are established with the TST, the project should be screened by the National Grid Technical Support Consultant (TSC) using the Custom Screening Tool, using the relevant policies and directions given in the tool. If the project has a BCR greater than or equal to 1, it should qualify for an incentive (pending program manager approval).

Contact the TSC and ask them to run the screen, given the savings and costs values on the TST Summary tab.

Application Form

Once the TST is completed and the project is found to be cost effective, the application process can begin. Applications for transformer replacement projects should be created and submitted using the Custom form for retrofit projects. Table 2 provides the Web links to the custom application form for each state.

Table 2 Web links for Custom Retrofit Application Forms for 2017

State	Web Link
Massachusetts	https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/custom_ri_retrofit_form_final.pdf or www.MassSaveApplicationPortal.com
Upstate New York	https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/customform_fillable.pdf
Rhode Island	https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/custom_ri_retrofit_form_final.pdf

The TST captures and summarizes all information necessary to complete the Custom Measure Application Form. The TST inputs and summary should be used to complete the application form. Savings, costs, and non-electric benefits should match between the application form and the TST.

The TST generates the Minimum Requirements Document (MRD). To complete the MRD for the Custom form, print the MRD page from the TST, and obtain the required signatures.

The following documents must be submitted with the project application:

1. A completed TST.
2. Excel files with spot-measurement and short-term power meter data if required.
3. Documentation of project costs estimated.
4. A completed MRD.
5. Results of the Custom Screening Tool.

Post-Installation Inspection

Installation of new transformers must comply with all local, state, and federal requirements, and should be performed as outlined in the project MRD. Once installation has been completed, the customer must provide access to National Grid representatives to perform a post-installation verification inspection of the installed equipment.

National Grid is not obligated to pay any incentives until it has performed a satisfactory post-installation verification of the installation. If National Grid determines the project has not been installed in accordance with this program manual or with the terms and conditions described on the Custom Project Application Form, National Grid will have the right to require modifications before making any incentive payments.

At its discretion, National Grid may withhold payment of incentives until all project documentation has been submitted.

Post-Installation Evaluation

National Grid must evaluate its energy-efficiency programs to determine the percentage of predicted energy savings actually realized, and to utilize those results to make program improvements. Typically, National Grid performs evaluations of such energy-efficiency projects on a subset of projects each year.

National Grid reserves the right to perform monitoring and inspection of any transformer projects for a three-year period following installation completion to evaluate the project's energy and demand impacts. As a condition of receiving an incentive, the customer agrees to provide access and information to National Grid and to cooperate with National Grid and its selected third-party evaluators regarding such activity.

Section 3 Transformer Savings Tool

This section describes the TST and the step-by-step instructions for using the tool. The tool should be used to collect project information, determine metering and replacement transformer specifications, and calculate savings parameters. The information generated in the tool can then be used to complete the project application form, perform the project screening in the Custom Screening Tool, determine project incentives, and complete the MRD.

TST Required Inputs

The TST requires the following project inputs:

- General project information:
  - Customer information
  - Technical Assistance (TA) Vendor information
- Existing transformers:
  - Description of locations a
  - Nameplate data (make, model, size [kVA], age)
- Replacement transformer information:
  - Nameplate data (make, model, size [kVA]), No Load Losses
- Project costs:
  - Material and labor cost

All inputs required to perform calculations in the TST are mandatory for the project application process.

Appendix A - Metering Transformers if required or requested

Metering Challenges

One does not measure the losses of a transformer metered *in situ* directly, but, rather, one determines losses by subtracting output from input. The percent of losses equal losses divided by the metered input energy. At low loads, losses are the same magnitude of the output power, and small errors in measurement do not appreciably impact the loss calculation.

For example, consider a 75 kVA transformer with an output of 6 kW and an input of 5.5 kW. Losses by subtraction would be 500 W, or 8%. As power meters have an accuracy approaching 1%, some uncertainty exists to the loss calculation, but the loss would be known fairly precisely. At a load of 35%, a transformer operates at roughly 98% efficiency, and has losses of about 2%. Assuming power measurements are accurate to 1%, metering errors would be nearly as large as the losses, and the loss calculated by subtraction would be relatively uncertain. Thus, the challenge facing a technician metering the transformer would be to match the equipment to the load, making the measurements as accurate as possible. This could best be done by ensuring: the CTs have been sized to meter the load; and even a spot measurement lasts for 10 minutes to damp out some errors.

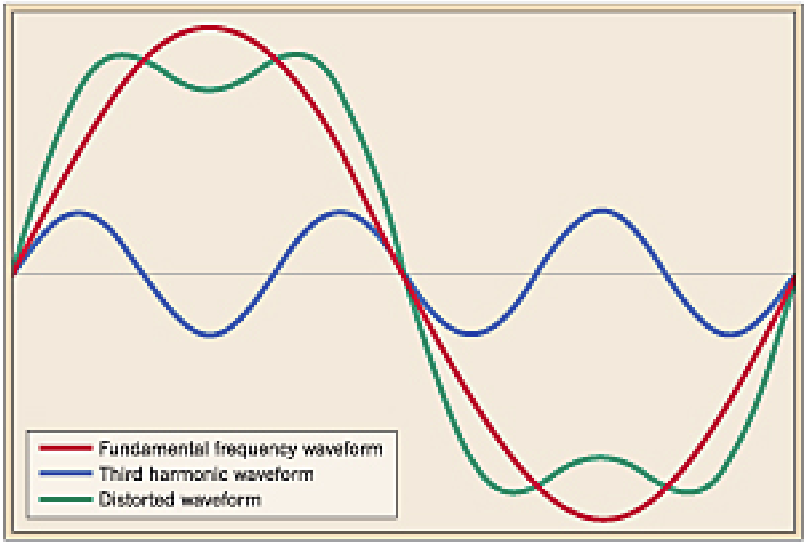
Basic Metering Requirements

1. The meter must be rated to give true RMS values of current and voltage.
2. The CTs for the up and downstream metering of the transformer must be sized so loads fall within the recommended range, typically 5% to 125% of the CT rating. Data outside of these ranges should be discarded.
3. Power must be recorded up and downstream of the transformer, and meters must be launched at the same start time to ensure the two meters collect readings during similar time periods.
4. Power measurements must be averaged through pulse accumulation or by other methods, and averages must be logged at a frequency no less than one logged reading per five minutes.
5. To account for varying schedules and loads, power readings must be logged for at least seven consecutive 24-hour periods for the base condition, and for 14 days for any transformer to be replaced with a smaller size.
6. Power measurements must be converted into watts, and the loss must be calculated by subtracting the transformer output from the transformer input. All zero and negative readings must be discarded.

Harmonic Considerations

How different load types use electricity can affect the shape of the voltage and current waveforms. Some loads cause the voltage and current waveforms to lose their pure sine wave appearance and become distorted. This distortion can be represented by additional harmonics or higher frequency waves superimposed on the original sine wave (as shown in Figure 3). [2]

Figure 3. First and Third Harmonics and Resulting Distorted Wave



A metering challenge arises regarding significantly altered current waves in that the meter may miss important parts of the wave form, and may not report the power used with full accuracy. Figure 5 shows how a digital meter samples and simulates an analog power wave. The more frequent the sampling rate, the more accurate the analog wave represented. This also holds true for a wave distorted by harmonics.

The Nyquist Criterion states that, to reproduce a time-varying signal without distortion caused by aliasing, the signal must be bandwidth-limited, and the sample rate must be at least twice the frequency of the bandwidth limitation. This essentially means that to sample to the xth harmonic, the sample rate must be:

$$60 \text{ Hz} * x * 2.$$

Characteristics of Commonly Used Meters

Cadmus reviewed specifications for meters most commonly deployed for field *in situ* metering, and developed Table 3, which shows the sampling frequency, reported harmonic capability, and analog bandwidth.

Based on this review, most meters deployed meet the ISO requirement of 2.6 kHz, and any meters shown in Table 3 prove acceptable for transformer metering. While meters intended for

[2] Richard P. Bingham. *HARMONICS—Understanding the Facts.*

power quality studies have much higher sampling frequencies, Cadmus finds 1.32 kHz a good compromise between frequency and cost for in situ metering, and proves sufficient for determining transformer losses.

Table 3. Common Field Power Loggers and Their Ability to Capture Harmonic Waves

Manufacturer	Model	Sampling Frequency	Harmonics	Input Frequency	Corresponding Analog Bandwidth
Continental Controls	WattNode	5.00 kHz	Up to 11th	50-60Hz	660 Hz
DENT	ELITEpro	7.68 kHz	Up to 63rd	50-60Hz	3.96 kHz
AEMC	Power Pad	256 samples/cycle – 15 kHz	Up to 50th	40-70Hz	3.5kHz
Veris	E50	2.52 kHz	Up to 21st	45-65Hz	1.26 kHz
ISO New England	NA	2.6 kHz	Up to 21st		
Minimum required	NA	1.32 kHz	Up to the 11th		
Required for harmonic mitigating measures	NA	3.96kHz	Up to the 33rd		

*Cycle is determined by user.

<u>**Requirement**</u>: Power meters used for demonstrating transformer losses must operate with a sampling frequency of 1.32 kHz of higher. Where replacing a transformer specifically with a harmonic mitigating transformer, and where savings are based on reducing high harmonics, the meter must be capable of capturing at least the 33rd harmonic or a sampling rate of 3.96 kHz.

Meters and Power Harmonics

CCS WattNode (http://www.ccontrolsys.com/ww/images/3/3e/Data_Sheet_WNB_Pulse.pdf)
(http://www.eetasia.com/ARTICLES/2001OCT/2001OCT04_HBM_AN2.PDF?SOURCES=DOWNLOAD)
(http://www.ccontrolsys.com/w/Internal_Computations)

- **Sampling Frequency:** 5.00 kHz
- The WattNode measures harmonic energy, but its solid-state measurement circuitry cannot make measurements if the noise level is too high.
- **"Too high" is assumed to be anything above the 11th harmonic.**

DENT ELITEpro (http://www.goodmart.com/products/dent-instruments-elitepro-indoor-recording-poly-phase-power-meter-512kb-line-power-ep-u-h-ps-d-c.htm)
(http://www.goodmart.com/pdfs/dent/elitepro.pdf)

- **Harmonic Level:** to the 63rd harmonic.
- **Sampling Frequency:** 7.68 kHz (128 points per current waveform).

AEMC Power Pad (http://www.aemc.com/products/index.asp)
(http://www.instrumart.com/products/34388/aemc-powerpad-model-3945-b-power-quality-analyzer)
(http://www.instrumart.com/assets/AEMC-3945-B-Data-Sheet.pdf)

- Measurement of harmonic angles and rates (referenced to the fundamental or RMS value) for voltage, current, or power, up to 50th harmonic.
- Display of harmonic sequencing and direction, and of calculation of overall harmonics.
- Recording, time stamping, and characterization of disturbance (swells, sags and interruptions; exceedence of power; and harmonic thresholds).
- Sampling Frequency: 256 samples/cycle.

Veris E50
(http://www.powermeterstore.com/crm_uploads/veris_e50b1_installation_guide.pdf)

- Sample Rate: 2,520 samples per second.
- Type of measurement: True RMS, up to the 21st harmonic @ 60 Hz.

Appendix B - Technology Background and Savings Assumptions

This section provides information about low-voltage dry-type distribution transformers, including:

- Descriptions of transformer energy consumption and losses;
- Transformer efficiency and energy codes;
- Typical loading profiles; and
- Expected equipment lifetimes.

What is a transformer?

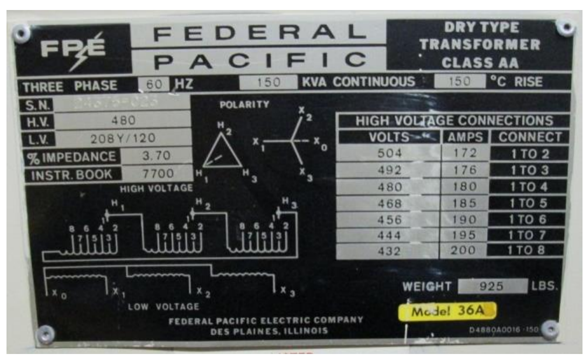
Transformers pass alternating current electricity, and normally are used to step voltage up or down. This specification focuses on is low-voltage dry-type transformers used in commercial, industrial, and municipal facilities to transform 408/277 volt power to 208/120 power used for equipment or plug-loads within buildings. These transformer sizes range from 15 kVA to 750 kVA, with most transformers in the 45 kVA and 75 kVA size categories.

Commercial and industrial facilities served by three-phase power from a utility typically use low-voltage dry-type transformers to distribute power internally at 208/120 Volts. Loads commonly served by such transformers include: wall plugs, lights, fans, and equipment such as computers, printers, and small industrial machinery.

Figure 4 shows a typical low-voltage dry-type transformer and Figure 5 shows a sample transformer nameplate. The transformer nameplate provides information about the transformer type (dry type), size (150 kVA), and rated temperature rise (150 deg. C).

Figure 4. Low-voltage Dry-type Transformer

Figure 5. Nameplate for Existing Transformer



Transformer Energy Consumption and Losses

Transformer designs seek to *transform* power and energy rather than *consume* it. A perfect transformer provides useful output power equal to the input power. In reality, the transformation process is not 100% efficient and some power and energy is lost through waste heat and vibration. The total transformer loss is the difference between the input power and the useful output power.

Transformers lose energy through two pathways:

- **Core Losses or No-Load Losses (NLL)**. Core losses, often referred to as NLL, remain relatively constant, and do not vary with the load.
- **Winding Losses or Full Load Losses (FLL)**. Winding losses, normally expressed as FLL, arise from current traveling through a transformer's coils, and vary with the square of the load.

Table 4 shows typical calculated no load energy losses for low voltage dry-type transformers, manufactured prior to the TP-1 standard. This data was obtained from a transformer manufacturer and it based on measured losses for transformers loaded below 5% of the rated capacity. The number of data points in each transformer size was adequate for statically validity of the data regarding no load losses.

Table 4 Expected Losses (Watts) for Pre-TP-1 Transformers

Calculated No Load Losses:	
kVA	**Calculated No Load Losses (W)**
30	403
45	598
75	835
112.5	1,198
150	1,463
225	1,744
300	2,219

A regression analysis was performed and the following equation was developed and was used in the (Transformer Savings Tool) **TST** to calculate savings.

History of Transformer Energy Codes

In 1996, the National Electrical Manufacturer's Association (NEMA) established the TP-1 standard for transformer efficiency, which recommends efficiency requirements for various sizes of transformers. For dry-type transformers, these efficiency standards set minimum efficiency requirements for a 35% load fraction, at least 0.5% higher than standard transformers available at the time of the specification. Although a 0.5% rise in efficiency seems small, these transformers had operating efficiencies of roughly 97% to 98%, meaning losses of 2% to 3%. Improving the efficiency by 0.5% out of 2% results in cutting energy and power losses by 25%.

NEMA Premium® Efficiency Transformer Program

After the Federal government adopted the TP-1 standards in their rulemaking, NEMA developed the Premium® Efficiency Transformer program, which specifies the criteria to qualify low-voltage dry-type transformers as NEMA Premium® Compliant Transformers. The program applies to low-voltage dry-type transformers between 15 kVA and 333 kVA for single-phase units and between 15 kVA and 1000 kVA for three-phase units. To qualify as a NEMA Premium® Compliant Transformer, units must meet or exceed the nominal energy-efficiency levels presented in Table 5. NEMA Premium® Compliant Transformer specifications became effective in May 2010.

Table 5 Minimum Efficiency Requirements* for NEMA Premium® Efficiency Transformers

Single-phase		Three-phase	
kVA	Efficiency (%)	kVA	Efficiency (%)
15	98.39%	15	97.90%
25	98.60%	30	98.25%
37.5	98.74%	45	98.39%
50	98.81%	75	98.60%
75	98.95%	112.5	98.74%
100	99.02%	150	98.81%
167	99.09%	225	98.95%
250	99.16%	300	99.02%
333	99.23%	500	99.09%
		750	99.16%
		1000	99.23%

*Efficiencies are determined at the following reference conditions: (1) for NLLs, at the temperature of 20°C; and (2) for load-losses, at the temperature of 75°C and 35% of nameplate load. (Source: Table 4–2 of NEMA Standard TP–1–2002, “Guide for Determining Energy Efficiency for Distribution Transformers.”)

Distribution transformers meeting the NEMA Premium® specification typically include the NEMA Premium® Mark on the equipment nameplate (shown in Figure 6).

Figure 6. NEMA Premium® Mark

Current Federal Standard

In its rulemaking for a national standard, the U.S. DOE adopted a new standard starting January 1, 2016. The standard states:

> The efficiency of a low-voltage dry-type distribution transformer manufactured on or after January 1, 2016, shall be no less than that required for their kVA rating in the table below. Low-voltage dry-type distribution transformers with kVA ratings not appearing in the table shall have their minimum efficiency level determined by linear interpolation of the kVA and efficiency values immediately above and below that kVA rating.

Table 6. Minimum Efficiency * Requirements for Low-Voltage Dry-Type Transformers

Single-phase		Three-phase	
kVA	Efficiency (%)	kVA	Efficiency (%)
15	97.70%	15	97.89%
25	98.00%	30	98.23%
37.5	98.20%	45	98.40%
50	98.30%	75	98.60%
75	98.50%	112.5	98.74%
100	98.60%	150	98.83%
167	98.70%	225	98.93%
250	98.80%	300	99.02%
333	98.90%	500	99.14%
		750	99.23%
		1000	99.28%

*Efficiencies are determined at the following reference conditions: (1) for NLLs, at the temperature of 20°C; and (2) for load-losses, at the temperature of 75°C, and 35% of nameplate load

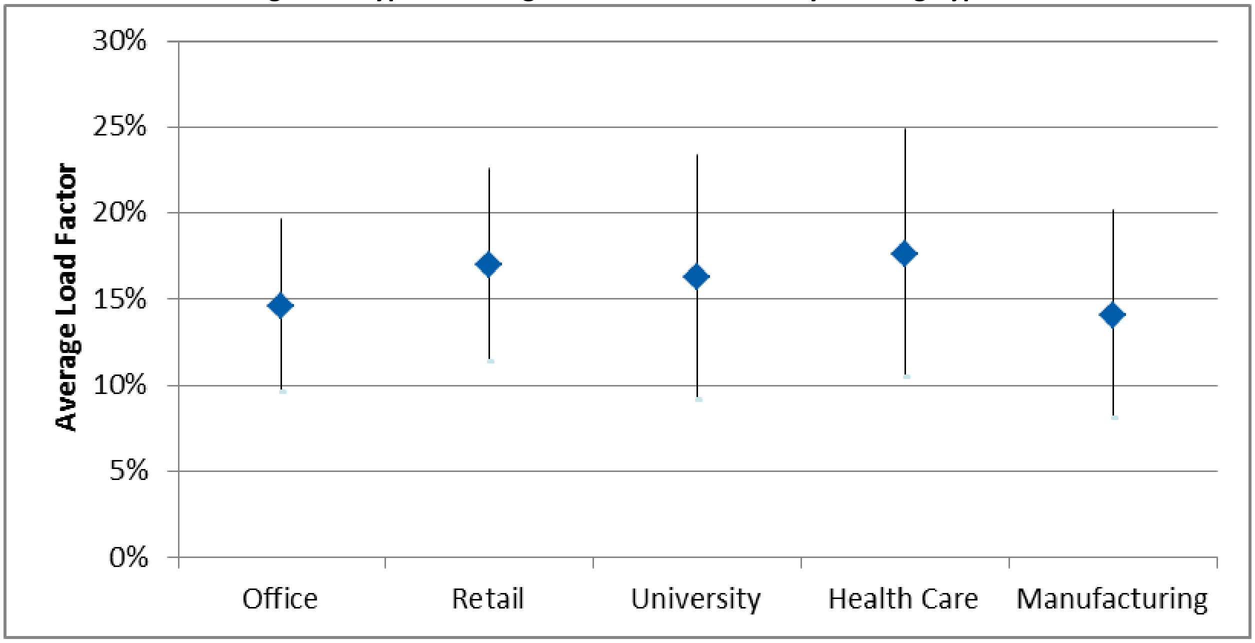
Transformer Loading

Many National Grid vendors and contractors have observed that most commercial distribution transformers are oversized. A 1999 study found low-voltage transformers in commercial and municipal facilities had average loading of 16% of the nameplate.[3]

Figure 7 shows the average load factor for transformers, per various building types, as measured during the same study. The data show that the typical transformer load is about half of the 35% load factor on which the TP-1 efficiency standards are based.

[3] The Cadmus Group, Inc. 1999. *Low-Voltage Transformer Loads in Commercial, Industrial, and Public Buildings. Prepared for Northeast Energy Efficiency Partnerships.*

Figure 7. Typical Average Transformer Loads by Building Type*



*The Cadmus Group, Inc. 1999. *Low-Voltage Transformer Loads in Commercial, Industrial, and Public Buildings. Prepared for Northeast Energy Efficiency Partnerships*.

Many transformers are oversized for the following reasons:

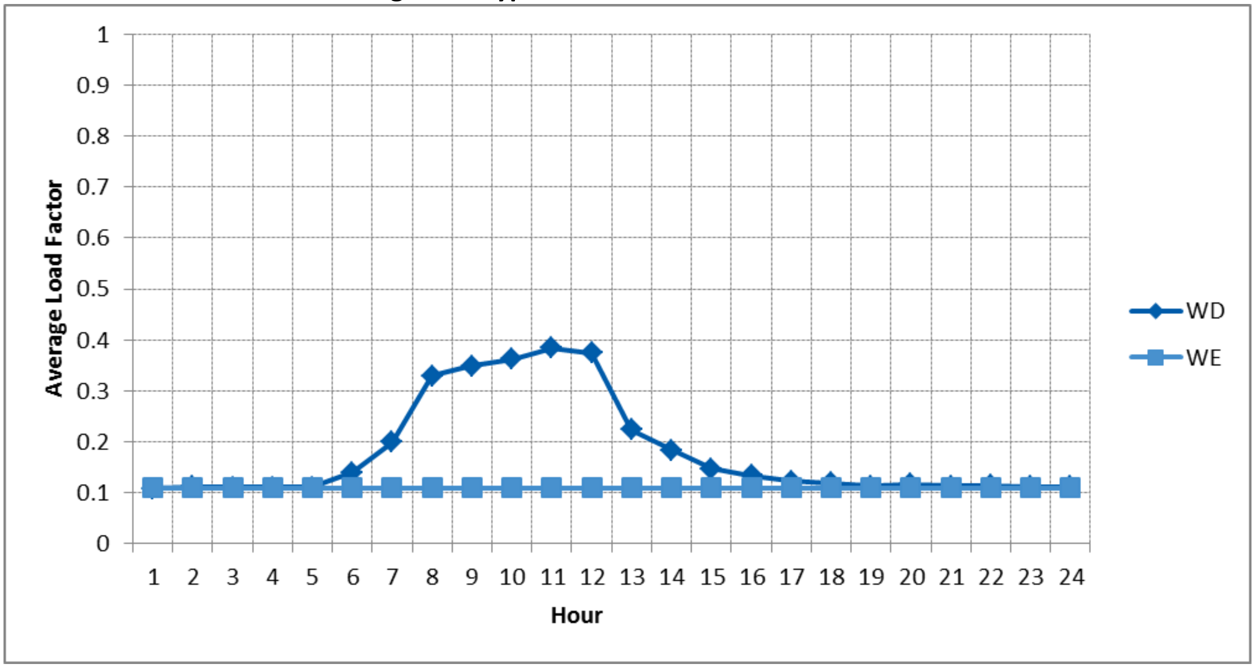
1. In commercial buildings, transformers sizes are specified based on power density tables in the electrical code and the number of receptacles, or on outdated lighting power density assumptions. In industrial applications, they are based on the nameplate of the connected loads, which engineers calculate using conservative values, allowing for future load growth (which often does not occur). When this happens for many pieces of equipment and loads throughout the building, the compounded oversizing effect makes the transformer sizing much larger than required by loads.

2. Transformer sizing often neglects or underestimates load diversity factors.

3. National Grid has conducted energy-efficiency programs for more than 20 years, thus reducing loads on transformers. For example, lighting power densities have fallen from 1.5 watts/sq. ft. to less than 1.0 watts/sq. ft., resulting in a large reduction in the loading of transformers serving lighting loads. Lighting controls—such as occupancy controls, scheduling controls, daylight dimming, and others—have further reduced loads on existing transformers. Office equipment, including computers, printers, and monitors, has become more efficient. These devices also now go into sleep mode when not in use. Few years ago, computers drew 80 watts, and CRT monitors drew 60 watts. Today's desktop computers use roughly 45 watts, and LCD monitors use roughly 20 watts, while laptops use even less. Consequently, peak office plug loads have dropped by more than half, and, due to sleep functions, average loads have dropped even further.

Figure 8 shows the average weekday (WD) and weekend (WE) load profile for a transformer in a commercial application.

Figure 8. Typical Transformer Load Profile[4]



Energy Savings

Energy and demand savings can be achieved by replacing existing transformers with new transformers that are more efficient and by downsizing transformers to reduce the core losses.

Efficiency Improvements

Energy-savings opportunities arise from the higher efficiency of new transformers, compared to those installed in facilities prior to that state's or the Federal adoption of the TP-1 efficiency standard. Commonly sized transformers can produce efficiency gains of 1% and NLL savings of nearly 400 Watts.

For example, a pre TP-1 225 kVA unit typically produced core losses of 860W, and the same size NEMA Premium® models produces core losses of about 480W. Based on 24/7 operations, replacing this pre-TP-1 transformer with the premium unit would save 3.3 MWh each year.[5]

Table 7 shows the expected annual kWh losses for a pre-TP-1 transformer, a TP-1 compliant transformer, and a NEMA Premium® transformer; and the expected annual kWh savings from replacing a typical pre-TP-1 transformer with a TP-1 compliant or NEMA Premium® transformer of the same size.

[4] The typical load profile is based metered data for commercial transformers.
[5] (860 Watts – 480 Watts) * 8760 hours/year / 1,000,000 Watts/MW

Table 7. Typical Annual kWh Losses and Savings for Same Size pre-TP-1 Replacement[6]

Size (kVA)	Expected Annual Losses, kWh (pre-TP-1)	Expected Annual Losses, kWh (TP-1)	Expected Annual Losses, kWh (NEMA Premium®)	Expected Annual Savings, kWh (TP-1)	Expected Annual Savings, kWh (NEMA Premium®)
15	1,600	1,300	900	300	700
30	2,500	2,000	1,400	500	1,100
45	3,200	2,500	1,800	700	1,400
75	4,600	3,200	2,300	1,400	2,300
112.5	6,000	4,800	3,400	1,200	2,600
150	6,800	5,400	3,800	1,400	3,000
225	8,900	7,100	5,000	1,800	3,900
300	11,100	8,900	6,200	2,200	4,900
500	16,800	13,400	9,400	3,400	7,400
750	22,300	17,800	12,500	4,500	9,800
1000	27,300	21,800	15,300	5,500	12,000

Downsizing Units

As shown in Table 8, most transformers are lightly loaded. Higher energy and demand savings can be achieved by downsizing lightly loaded transformers, due to the reduced core (NLL) losses on smaller units. Downsizing involves replacing the existing unit with a new TP-1 or NEMA Premium® unit with a lower kVA capacity. For example, replacing a lightly loaded 80C 75 kVA transformer with a core loss (NLL) of 700W with a 45 kVA NEMA Premium® model, with a typical core loss (NLL) of 180 Watts, would save over 500 Watts.

It is important to note that the additional energy and demand savings resulting from reduced core losses on a smaller transformer could be offset by increased winding losses due to higher load factors on the smaller unit in cases where the unit is highly loaded. Therefore, the loading on the existing transformer should be considered when downsizing.

Table 8 shows the expected annual kWh savings for replacing a pre-TP-1 transformer with a TP-1 compliant transformer or NEMA Premium® transformer that is one size smaller than the existing transformer.

[6] The expected annual kWh losses and savings are based on typical NLL and FLL values for each transformer size and the typical transformer loadshape shown in **Error! Reference source not found.**.

Table 8. Typical Annual kWh Savings for pre-TP-1 Replacement and Downsize[7]

Original Size (kVA)	New Size (kVA)	Expected Annual Savings, kWh (TP-1)	Expected Annual Savings, kWh (NEMA Premium®)
15	N/A	N/A	N/A
30	15	800	1,300
45	30	900	1,600
75	45	1,500	2,400
112.5	75	1,800	3,100
150	112.5	1,500	3,100
225	150	2,300	4,300
300	225	3,100	5,500
500	300	5,500	8,900
750	500	6,000	10,900
1000	750	7,300	13,300

The expected annual energy savings for a downsized replacement are typically higher than the expected annual energy savings for a same size replacement. However, for highly loaded units, the lower core losses (NLL) could be offset by the higher load levels (and therefore, higher winding losses) on the smaller transformer. Generally, the benefit from downsizing is the lower cost of the smaller transformer, rather than the increased savings, which improves the project cost-effectiveness and reduces the payback period.

Transformer Life Expectancy

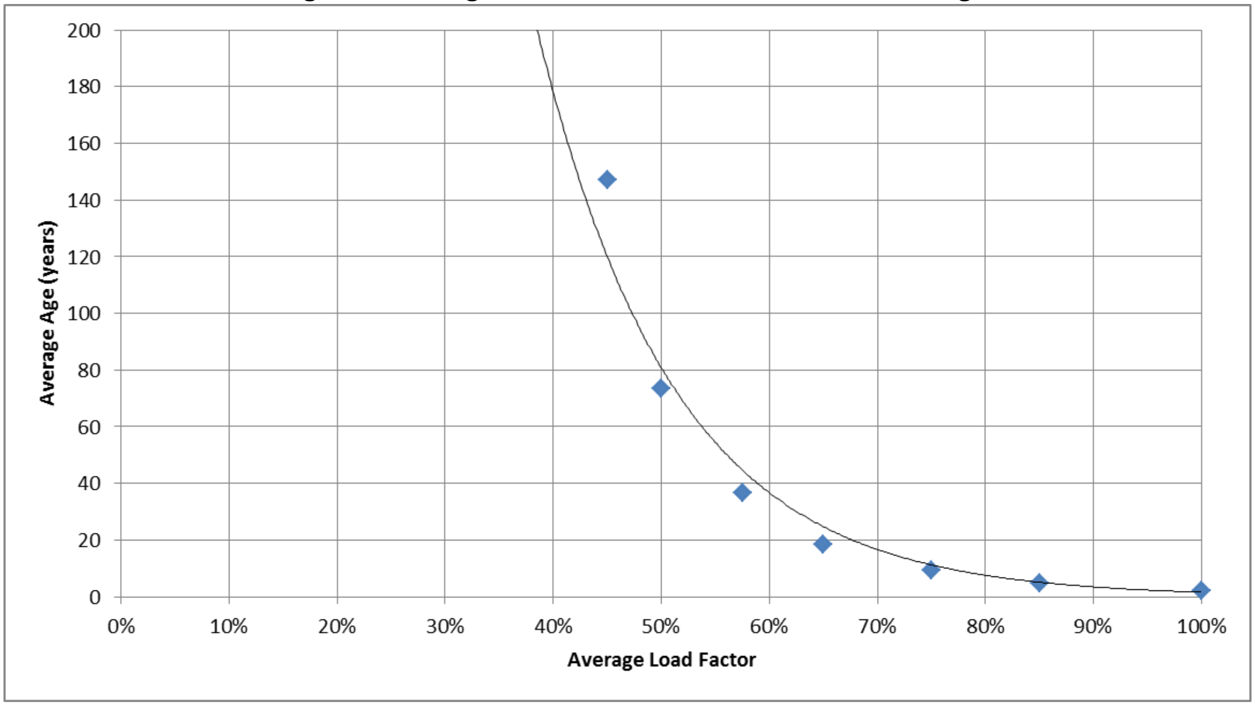
In typical use, transformers last more than 20 to 30 years, with a transformer's life expectancy generally related to its average operating temperature (which is proportional to its average loading conditions). Most transformer designs operate at a 150 ºC temperature rise upon fully-loaded conditions, but do not operate at those fully loaded conditions continuously. Given light loads, most transformers never operate at maximum design conditions, and, in reality, run much cooler than conditions for which they were designed. Consequently, life expectancies can increase many times, and most transformers last much longer than 50 years. Electricians and building inspectors, which Cadmus contacted in writing this manual, stated they rarely see transformers fail, and almost never have to replace these devices.

Figure 9 shows a curve of average transformer life versus loading, which Cadmus adapted from a Square D publication[8] that predicted transformer life with temperature rises. The curve shows a transformer operated continuously at full capacity experiences a very short life, but continuous operation an average load of 50% lengthens its life to 75 years.

[7] The expected annual kWh savings are based on typical NLL and FLL values for each transformer size and the typical transformer loadshape shown in. The loadshape on the downsized

[8] Power Logic Solutions. Volume 3, Issue 3. Square D Corporation. October 2003.

Figure 9. Average Transformer Life vs. Fractional Loading



Source: Square D Life versus temperature data, converted to age versus load by Cadmus using full load and 35% load temperatures.

In a study of 89 randomly selected transformers, Cadmus only found one transformer with a 60% load, and only four with a 40% to 50% load. The remaining 84 transformers operated at average loads less than 37%, and, averaged over all transformers, operated at load factors just 16% of the transformers' nameplate capacity.

Based on Cadmus' findings, National Grid's program estimates a conservative effective useful life (EUL) of 50 plus years for low-voltage dry-type transformers in nonresidential facilities.

Since these studies were conducted energy efficiency measures such as LED lights have reduced the transformer loads significantly and average load factors have dropped significantly below 15% and the remaining life is now more than 30 Years even for the pre-TP1 Transformers that is still operating.

DoE – use 33 years for Life of Low Voltage Distribution Transformers
IEEE Standard C57.96 – 1999 Guide for Loading Dry-Type Distribution and Power Transformers
– Fully Loaded Low Voltage Transformers Standard
- *150°C Rise – ~8 years*
- *115°C Rise – ~60 years*
- *80°C Rise - ~ >200 years*

– @ 35% Loading Point – 75°C Temperature instead of 170°C
- *150°C Rise - ~>100 years*

• *115°C Rise - ~>100 years*
• *80°C Rise - ~ >100 years*

Actual Real World Loading for Commercial Applications – 15-20%

(https://www.l-3.com/private/pacific_crest/articles/IEEE%20Dry%20Liquid%20Cast%20Transformer.pdf)

Measure Lifetimes for Transformer Replacement Projects

Energy-efficiency measures have a maximum allowable lifetime of 30 years; so measure savings can only be claimed for the first 30 years of a new transformer's lifetime. Regardless of the age of the existing transformers the measure life for early replacement is now considered 30 years.

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