Emerging Technologies

Potential for Dry-Type Transformer Retrofit Electrical Energy Savings

Gilbert McCoy, Energy Systems Engineer — WSU Energy Program
Tony Koch, Mechanical Engineer — BPA Energy Efficiency
Nathan Kelly, Electrical Engineer — BPA Energy Efficiency
David Bell, Electrical Engineer — BPA Energy Efficiency

BPA's Emerging Technologies Initiative

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Topics

- Definition of Dry-Type Transformer
- Dry-Type Transformer Efficiency
- Dry-Type Transformer Efficiency Standards
- Transformer Losses and Loading
- Are High Efficiency Units Available?
- Energy Savings from Purchase of Low Loss Transformers
- New Purchase versus Retrofit of Pre-TP-1 Transformers
- Downsizing of Replacement Transformers
- Overloading, T-Ratings, K-Factors and Winding Material Selection
- Maximizing Efficiency Gains
- BPA Energy Savings Incentives via Custom Project Measure

Dry-Type Transformers

Dry-Type Transformers

- Used indoors on each floor of a building
- For lighting or plug loads
- Reduces voltage from a primary of 480 V to 208 V or 120 V
- Also called air-cooled transformers

Liquid-Immersed Transformers for Comparison

- Utility product
- Oil-cooled
- Pad or pole-mounted
- Used outdoors due to concerns over liquid leakage and possible fire or toxicity hazards
- Biodegradable or vegetable oil also available

New Construction vs Retrofit

New Construction

- Multiple layers between designer and owner, contractors
- Difficult for utility rebate program to have influence
- It's a good fit for Market Transformation
- This team did a similar presentation to NEEA staff

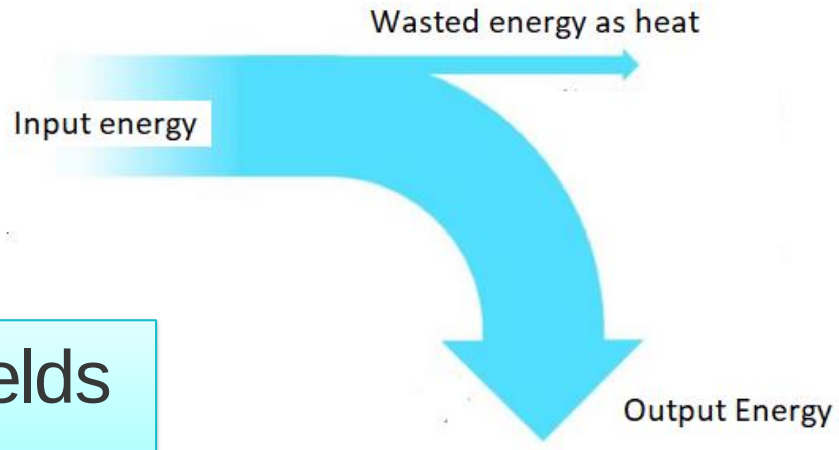
Retrofit

- Replace old and/or oversized transformers
- Focus of this presentation

Transformer Efficiency

Transformer efficiency =
Power output at the secondary side divided by the input power on the supply or primary side

Or, (Input – Losses) / Input



A decrease in losses yields an increase in efficiency

Evolution of Dry-Type Transformer Efficiency Standards

- NEMA, 1996/1998/2002 – TP-1 (Voluntary)
- Energy Star (EPA) – NEMA TP-1 levels (Voluntary)
- EPACT, 2005 – NEMA TP-1 levels (Mandatory)
- NEMA, 2010 – Premium, Losses 30% less than TP-1 (Voluntary)
- CEE, 2011 – Tier 1 and Tier 2 (Voluntary)
- **DOE, 2016 – Approximately equivalent to NEMA Premium or CEE Tier 1 (Mandatory)**

DOE 2016 Dry-Type Transformer Efficiency Standards

Current Dry-Type Transformer Mandatory Minimum Efficiency Standards

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	98.94
250	98.80	300	99.02
333	98.90	500	99.14
		750	99.23
		1000	99.28

Note: All efficiency values are at **35 percent** of nameplate-rated load

Dry-Type versus Liquid-Immersed Transformer Efficiency

Three-Phase Dry-Type versus Liquid-Immersed Mandatory Minimum Transformer Efficiency Requirements (DOE 2016 Standards)

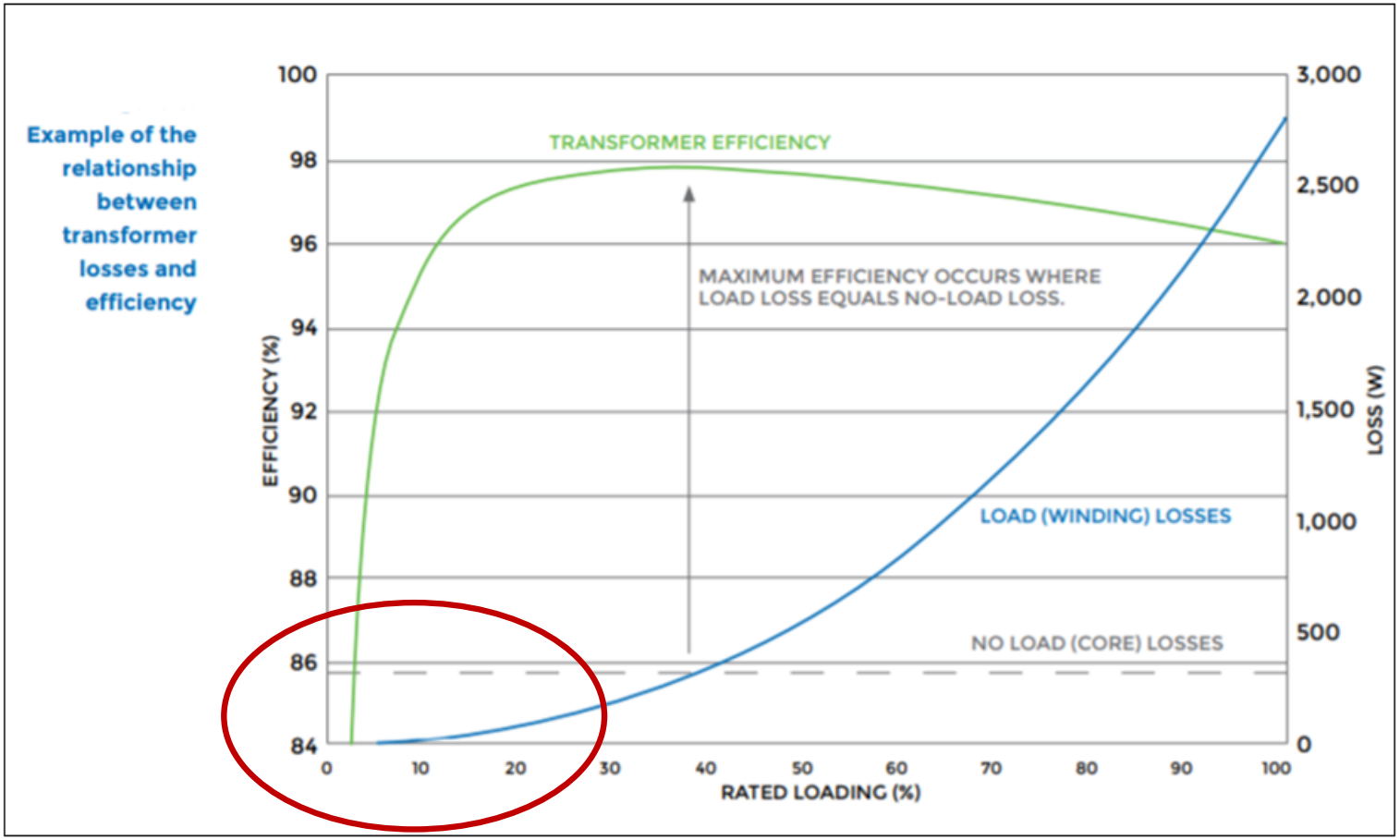
Dry-Type (at 35% Load)		Liquid-Immersed (at 50% Load)	
kVA Rating	**Efficiency (%)**	**kVA Rating**	**Efficiency (%)**
30	98.23	30	98.93
45	98.4	45	98.92
75	98.74	75	99.03
150	98.83	150	99.16

Transformer Losses

- **No-Load Losses**
  - Constant, whenever the transformer is energized
    - Usually 8760 hours/year
  - Loss is the same no matter the load
- **Load or Winding Losses**
  - Changes with transformer load
  - Winding resistance losses vary as the square of the transformer loading
- **Longevity**
  - Lightly-loaded transformer lives are very long---from 30 to 50 years

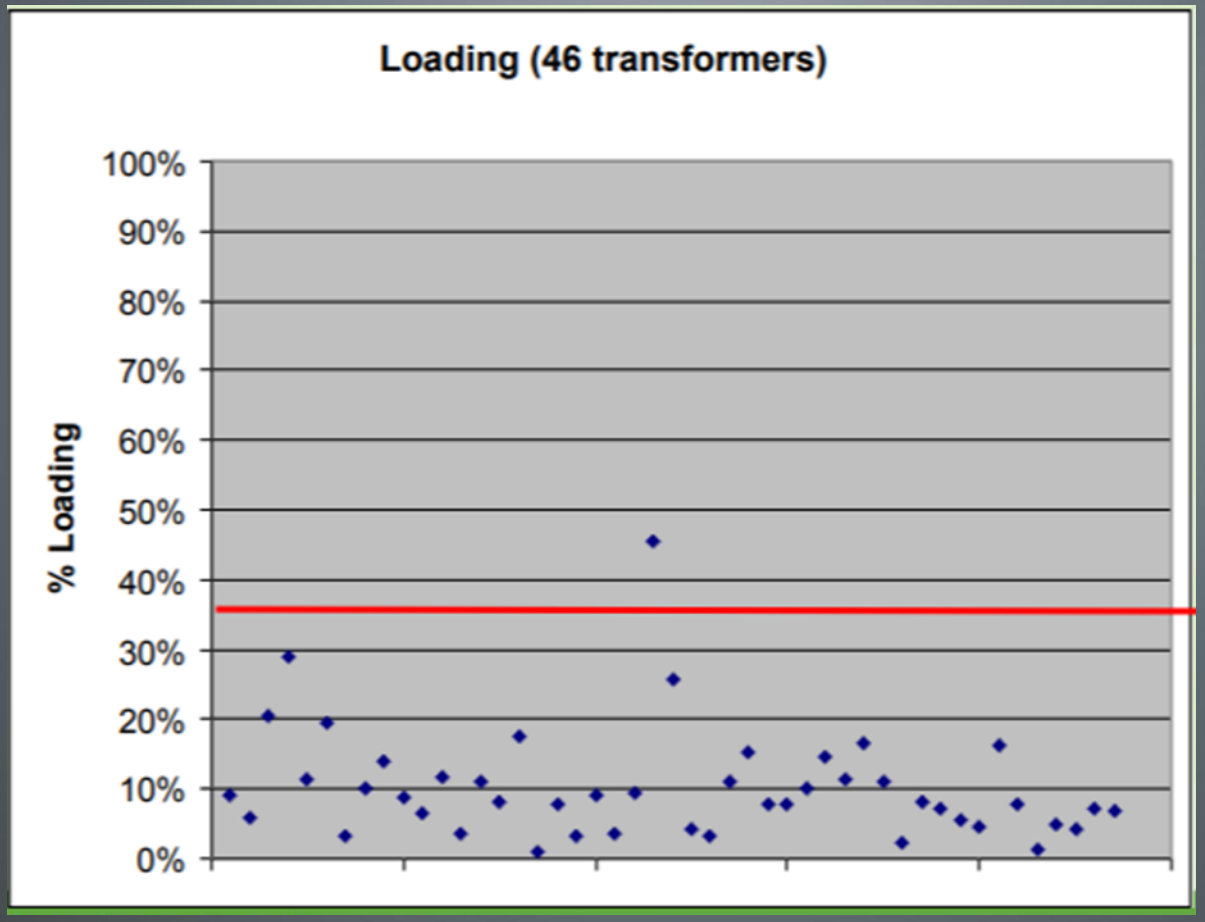
Transformer Losses versus Loading

Transformer No-load and Load Losses versus Loading



Dry Type Transformer Loading

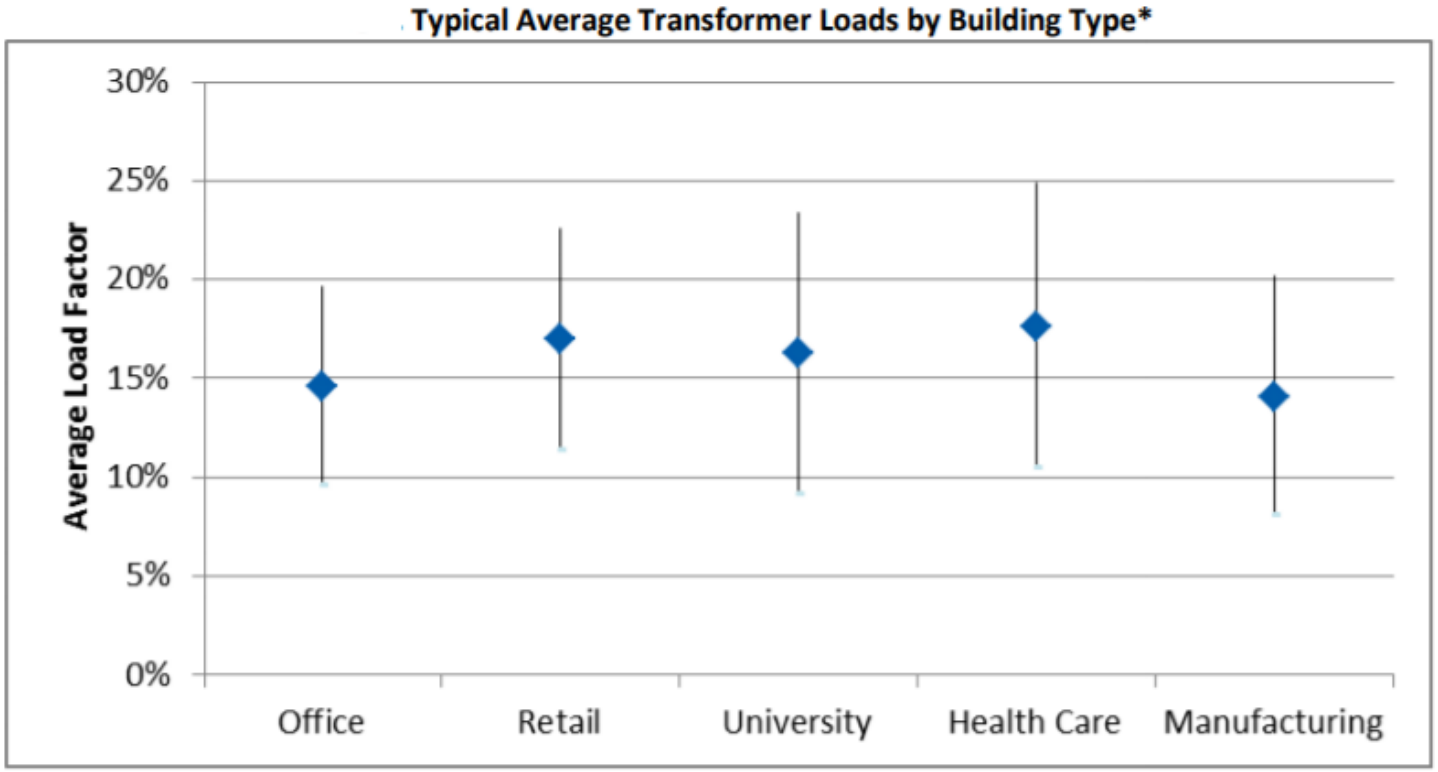
A 1999 study by Cadmus for the Northeast Energy Efficiency Partnership examined the loading on dry-type transformers in various building types. The root mean square (RMS) average load was found to be about 16%.



Source: Powersmiths

Dry Type Transformer Loading

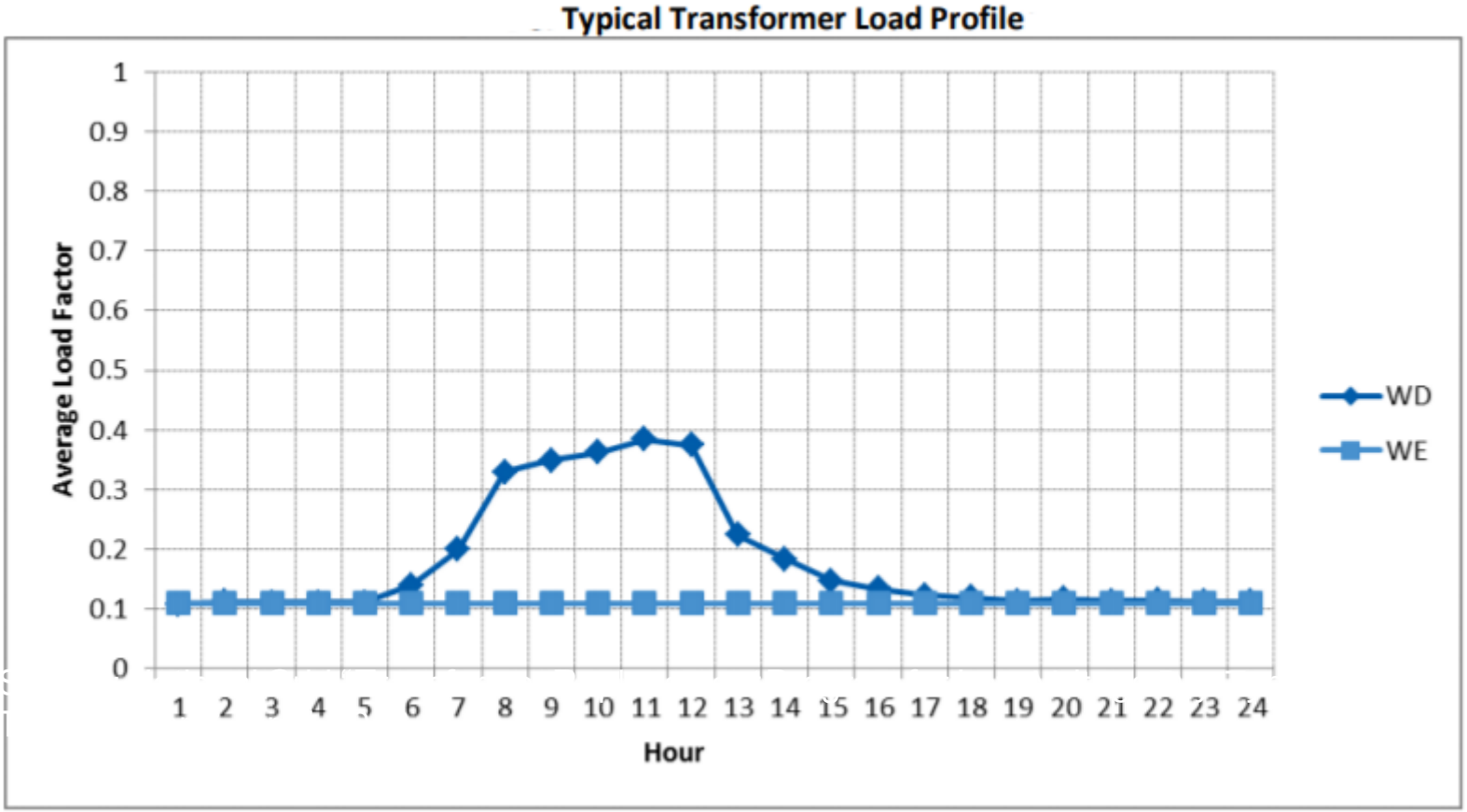
1999 study by Cadmus for the Northeast Energy Efficiency Partnership found the average load of dry-type transformers was about 16%.



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

Source: Powersmiths

Dry-Type Transformer Hourly Load Profile



Decrease No-Load Losses for Energy Savings

For lightly loaded dry-type transformers in commercial and institutional settings, annual energy consumption closely tracks the no-load losses (in Watts) times 8,760 hours per year (the hours that the transformer is energized).

Thus, energy savings from purchase of a transformer with low no-load losses are:

Annual Energy Savings:

kWh ~ $((N_{LLStd} - N_{LLEE}$ in Watts)/1000) x 8,760 hours/year

Better Performing Units are Available (at 16% Load)

3-Phase Dry Transformer at 16% Load Point

	Eaton DT-3, 150°C Rise, Cu Windings			Powersmiths E-Saver 80R Losses, Al, K-7, 130°C rise			
kVA	**NLL, W**	**FLL, W**	**Losses, kWh/year**	**NLL, W**	**FLL, W**	**Losses, kWh/year**	**Savings, kWh/year**
15	73	401	644	35	775	315	**329**
30	114	732	1006	57	1332	513	**493**
45	118	1271	1047	78	1725	701	**346**
75	206	1615	1821	111	2537	998	**823**
112.5	251	2223	2222	164	3313	1471	**751**
150	350	2351	3090	203	3945	1819	**1271**

Existing Utility Transformer Replacement Incentive Programs

Replace older, Pre NEMA TP-1 Dry-Type Transformers.

- National Grid: Focus on 25 to 300 kVA transformers. Failed transformers do not qualify for incentives. Provide Transformer Savings Tool to calculate savings and estimate incentives.
- Hawaiian Electric: Incentive is $125/kW and $0.12/kWh.
- Austin Energy: Part of Commercial Rebate Offerings suite. Rebate is $300/kW as utility is interested in demand reductions. Savings are based upon performance at 35% load point of transformer. Considers new construction and end-of-life replacements.

Information Needed for a Retrofit – An Example

A Hawaii Energy representative visits a site and records:

- primary and secondary voltage, and
- transformer nameplate data, including manufacturer and model number.

A default database is accessed to document baseline transformer performance.

Sometimes, transformer performance – i.e. pre TP-1 or not, is estimated through identifying the date of facility construction.

After no-load losses are determined, annual energy savings are expressed as the difference in the existing transformer and new high efficiency transformer no-load losses – which occur 24/7/365.

Potential Savings from Retrofit of Pre-TP1 Units

Default Pre-NEMA TP-1 expected losses are extracted from the 2013 National Grid "Transformer Replacement Program for Low-Voltage Dry-Type Transformers: Implementation Manual".

Dry Transformer at 16% Load Point

	Baseline			Proposed			
	Pre-NEMA TP-1 Transformers (Nationalgrid)			Hammond Power Solutions, Sentinel G Al, 150°C			
kVA	NLL, W	FLL, W	Losses, kWh/year	NLL, W	FLL, W	Losses, kWh/year	**Savings, kWh/year**
15	162	712	1426	62	420	547	**879**
30	256	1274	2256	86	840	762	**1494**
45	322	1655	2838	120	1110	1063	**1775**
75	462	2542	4073	190	1490	1680	**2394**
112.5	604	3457	5327	226	2260	2003	**3324**
150	661	4690	5838	315	2500	2785	**3053**
225	862	6242	7615	405	3580	3585	**4031**
300	1087	7397	9598	540	4040	4772	**4826**
500	1648	11166	14551	840	5590	7416	**7135**
750	2189	14830	19328	1020	8370	9021	**10307**

Cost Effectiveness of Pre-TP1 Replacements

Hammond Power Solutions provided estimated end-user purchase prices for their Sentinel G dry-type distribution transformers. The prices shown are for transformers with aluminum winding – a 25% price adder would be typical for copper would transformers.

Dry Type Transformer Retrofit Cost-Effectiveness (replacement with a like-size transformer)

kVA	Contractor Cost	Annual Savings, kWh	Value @ $0.06/kWh	Simple Payback, years
15	$ 1,194	879	$ 52.74	28.3
30	$ 1,609	1494	$ 89.64	22.4
45	$ 1,654	1775	$ 106.50	19.4
75	$ 2,663	2394	$ 143.64	23.2
112.5	$ 3,659	3324	$ 199.44	22.9
150	$ 4,071	3053	$ 183.18	27.8
225	$ 6,699	4031	$ 241.86	34.6
300	$ 9,326	4826	$ 289.56	40.3
500	$ 14,508	7135	$ 428.10	42.4

With 25% installation markup

Potential Savings from Retrofit with Downsizing

- Early replacement results in immediate energy savings and avoids an end-of-life replacement event.
- Building energy efficiency measures result in a decreased dry transformer load. Note that a smaller transformer has a reduced first cost.
- National Grid recommends downsizing when the load on the existing transformer never exceeds 35% and they do not allow the load profile on the replacement transformer to exceed 50%.

Dry Type Transformer at 16% Load Point with Downsizing by One kVA Rating

		Hammond Power Solutions, Sentinel G Al, 150°C			
Initial kVA	Replacement kVA	NLL, W	FLL, W	Losses, kWh/year	**Savings, kWh/year**
30	15	62	420	594	**1662**
45	30	86	840	789	**2048**
75	45	120	1110	1121	**2953**
113	75	190	1490	1728	**3598**
150	112.5	226	2260	2043	**3795**
225	150	315	2500	2867	**4749**
300	225	405	3580	3649	**5949**
500	300	540	4040	4983	**9568**
750	500	840	5590	7598	**11730**

Cost Effectiveness for Retrofit with Downsizing

Hammond Power Solutions provided estimated end-user purchase prices for their Sentinel G dry-type distribution transformers. The prices shown are for transformers with aluminum winding – a 25% price adder would be typical for copper would transformers.

Dry Type Transformer Retrofit Cost-Effectiveness (replacement downsized by one kVA rating)

kVA	Contractor Cost	Annual Savings, kWh	Value @ $0.06/kWh	Simple Payback, years
15	$ 1,194	1662	$ 99.72	15.0
30	$ 1,609	2048	$ 122.88	16.4
45	$ 1,654	2953	$ 177.18	11.7
75	$ 2,663	3598	$ 215.88	15.4
112.5	$ 3,659	3795	$ 227.70	20.1
150	$ 4,071	4749	$ 284.94	17.9
225	$ 6,699	5949	$ 356.94	23.5
300	$ 9,326	9568	$ 574.08	20.3
500	$ 14,508	11730	$ 703.80	25.8

With 25% installation markup

Simple paybacks are based upon HPS transformer performance and prices.

Dry-Type Transformer Retrofit Benefits

- Significant loss reduction. Can be >75%
- Removal of end-of-life failure risks
- Installation of a transformer optimized for modern electronic equipment and for non-linear loads.
- Decades of energy savings without the need for upgrades, control systems or building occupant behavior change.
- Reduction in air-conditioning due to less heat released into building spaces.
- Carbon footprint benefits.

Source: Powersmiths

Dry Transformer Tradeoffs and Options

Most of the efficiency gains in the past have come from reducing core or no-load losses. To achieve additional gains, cores must be made bigger, which results in trade-offs with full-load losses as winding lengths become longer.

--Mike Van Gheem, Hammond Power Solutions

Additional considerations include:

- Enclosure type
- Winding material selection (Aluminum versus Copper)
- Specification of an "Allowable Temperature Rise"
  - Options include 150ºC, 130ºC, 115ºC, and 80ºC.
- K-Factor rated dry-type transformers are recommended for applications where high harmonic loads must be tolerated. Harmonic mitigating transformers are available with harmonic cancelation capabilities.

K-Rated Transformers

K-factor is a unit that measures a transformer's ability to withstand the harmonic content of a system.

Transformer K-factor ratings

Transformer K-factor ratings	
K-factor	Load type
K-1	Linear loading
K-4	Solid-state electronics
K-9	Medium-density solid-state electronics
K-13	Heavy-density solid-state electronics
K-20	Switching loads and variable frequency drives
K-40	High-order harmonics switching loads

Source: RTM Engineering Consultants

From: Consulting/Specifying Engineer, "Selecting and Sizing Transformers to Achieve Energy Efficiency, June 19, 2017

Non-linear Load	K-rating
Incidental electronic equipment representing <5 percent	K1
Harmonic-producing equipment representing <35 percent	K4
Harmonic-producing equipment representing <50 percent	K7
Harmonic-producing equipment representing <75 percent	K13
Harmonic-producing equipment representing <100 percent	K20

Eaton, "No Harmony in Harmonics", Jan 2010

Aluminum versus Copper Windings

Low Voltage Dry-Type Transformer Performance versus Coil Material and Allowable Temperature Rise

Square D 3-Phase Dry Type Low Voltage Distribution Transformers 480 to 208Y/120					
kVA Rating	Winding	**150°C Rise**		**80°C Rise**	
		N.L.,Watts	Load, Watts	N.L.,Watts	Load, Watts
15	Al	46	521	69	214
30	Al	54	1050	100	449
45	Al	90	1242	128	650
75	Al	135	2219	171	1062
112.5	Al	180	2938	210	1460
150	Al	210	3192	328	1518

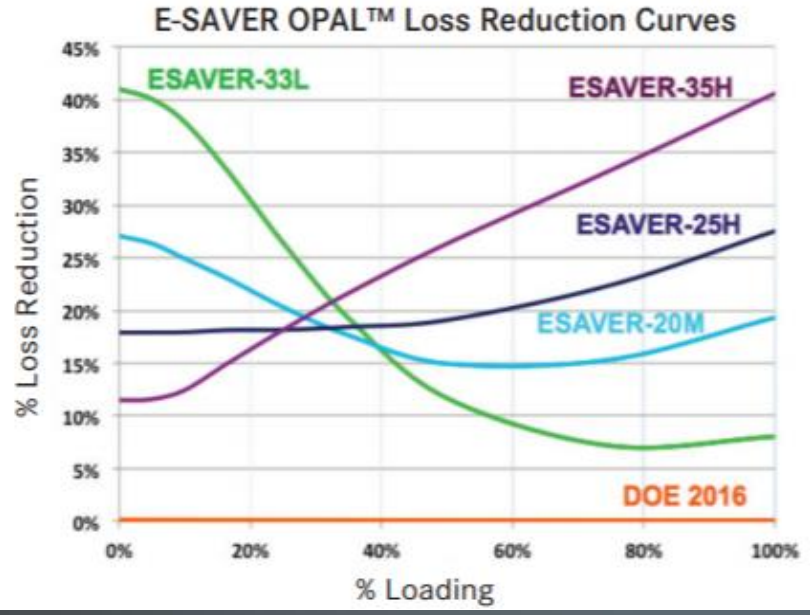
3-Phase Dry Type					
kVA Rating	Winding	**150°C Rise**		**80°C Rise**	
		N.L.,Watts	Load, Watts	N.L.,Watts	Load, Watts
15	Cu	43	580	72	186
30	Cu	72	907	96	476
45	Cu	96	1310	139	602
75	Cu	139	2044	167	921
112.5	Cu	167	2534	259	1098
150	Cu	259	2386	333	1549

Product Differentiation

- Powersmiths has focused on the production of "ultra-efficient" dry-type transformers, with their market niche being those wanting to meet LEED requirements, obtain net-zero building performance, or in meeting carbon footprint reduction goals.
- They claim that their performance optimized transformers deliver 20% to 50% lower losses than those designed to just meet the 2016 DOE efficiency standards.
- Their OPAL (Optimized Performance for the Application Load) model lines are designed for maximum performance over a given load range i.e. light loads versus heavy loads.
- Their transformers are "K-rated" i.e. K=7, and **do carry a significant price premium.**

Powersmiths E-Saver OPAL Performance

Powersmiths has built transformers that are optimized for either light loading or heavy loads. You wouldn't want to use a transformer optimized for light loading conditions in an application with high loading. They also facilitate "right sizing" through offering intermediate transformer kVA ratings.



Energy savings are passive---they are not dependent upon controls or changes in occupant behavior. There is no efficiency degradation over the installed life of the dry-type transformer.

Selected Dry-Type Transformer Costs

Powersmiths' costs reflect those for a K-rated premium product

kVA Rating	HPS Sentinel G, K=0, 150°C	Eaton K-9, Al, 115°C	MGM K-9, Al, 115°C	Powersmiths OPAL 80-R, K-7, 130°C
75	$2,663	$3,570	$3,393	$5,413
112.5	$3,659	$4,817	$4,220	$7,768
150	$4,071	$6,176	$5,355	$9,455
225	$6,699	$8,841	$7,560	$12,399

Source: HPS and Powersmiths

A Transformer Retrofit Case Study—112.5 to 63 kVA

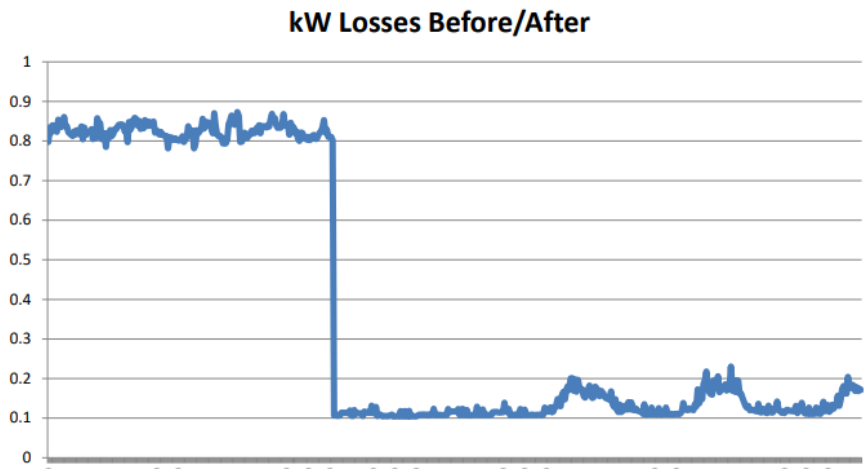
Center Core Temperature 198° (F)
Sound Level 81 dB

Nominal kVA	112.5			63		
Loading Period	Min Load	Max Load	Average Load	Min Load	Max Load	Average Load
% Loading (kVA)	6.8%	17.5%	10.2%	9.6%	28.7%	15.2%
Losses (kW)	0.781	0.873	0.826	0.104	0.231	0.129

Representative Output Current THD under load (%)	30% before 32% post

Annual Direct Transformer Loss kWh & Dollar Savings with Powersmiths*	6106 kWh	$977
Associated A/C cooling Annual kWh & Dollar Savings *	2,602 kWh	$416

Center Core Temperature 99° (F)
Sound Level 45 dB



Source: Powersmiths

Typical:
Pre-TP 1
NLL = 640 W;
Powersmiths
NLL = 111 W
Testing on sinusoidal wave forms

Maximizing Energy Savings

Incentivize the purchase of transformers with no-load losses below a set value for each kVA rating.

3-Phase Dry Type Low Voltage Distribution Transformers 480 to 208Y/120

kVA Rating	Winding	Powersmiths E-Saver 80R 130°C		Square D EX 150°C	
		N.L., Watts	Load, Watts	N.L., Watts	Load, Watts
15	Al	35	775	46	521
30	Al	57	1332	54	1050
45	Al	78	1725	90	1242
75	Al	111	2537	135	2219
112.5	Al	164	3313	180	2938
150	Al	203	3945	210	3192

kVA Rating	Winding	Hammond Power Solutions, 150°C Rise Sentinel G (Cu)		Siemens Series H 150°C	
		N.L., Watts	Load, Watts	N.L., Watts	Load, Watts
15	Cu/Al	64	400	63	537
30	Cu/Al	96	760	109	853
45	Cu/Al	135	990	143	1200
75	Cu/Al	194	1470	188	1950
112.5	Cu/Al	275	1850	240	2760
150	Cu/Al	335	2335	350	2800

Dry-Type Transformer Manufacturers

- ABB
- Eaton
- Emerson
- Federal Pacific
- Hammond Power Solutions
- Hubbell Inc.
- Jinpan International USA
- MGM Transformer Company
- Milbank Manufacturing Company
- PDI
- Schneider Electric (Square D)
- Siemens Industry, Inc.
- Powersmiths

BPA Custom Project Measure

- Newly formed Reconductor-Transformer (RT) Calculator does not support C&I measures
- C&I facilities will be included in the future (in BEETS for sure)
- This measure needs to be documented via C1 custom project
- The measure has a 30 year life therefore incentive rate is 35 cents/kWh
- Some logger measurements are needed to perform energy savings calcs
- BPA engineering staff is here to help with field metering and calculations

1-phase and 3-phase Units Look Alike

- When performing a site inspection take a close up photo of nameplate.
- Does nameplate show manufacturing date?
- If not, estimate approximate year unit was installed from building staff.
- Temperature of the top surface can indicate light or heavy load.

Considerations on Existing Units

- Nameplate usually does not provide no-load and load loss
- BPA can help estimate no-load and load loss based on size and vintage
- Some logger measurements may be needed to estimate no-load and load loss. The following can be explored:
  - Measure input power at 480V on existing transformer
    - Turn off secondary loads (breakers), if possible, to measure no-load loss
    - Leave power logger recording input kW and kVA to asses loading on the transformer
    - Perform a one-time secondary power measurement to assess load loss
- BPA engineering staff can make available power loggers and assist in their use in the field

The New Replacement Transformer

- New transformer bids provide the no-load and load loss in Watts
- No need to post meter New Transformer
- Energy Savings are calculated based on limited logger metering
  - (needed to determine annual load factor and annual peak power)

Load Factor = [annual energy kWh / 8760 hr] / peak kW

Energy Savings Calculator

- RT calculator does not support C&I sector
- Need to use Custom Project C1 file
- Simple stand-alone Excel file performs the energy savings calculation
- **Inputs Needed**, for baseline and proposed transformer:
  - Size in kVA
  - No-Load Loss in W
  - Nameplate Load Loss in W
  - Annual Load Factor in %
  - Annual Peak Load in kVA
  - Annual Energized Hours, typically 8760 hours

Excel Calculator

Name of Facility	Utility Name			date		
Transformer Loss Savings Calculation :	Blue cell is manual data entry					
	Existing			**Proposed**		
NamePlate Power of the TX	30	kVA		30		
Peak Annual (Hourly) Power through the TX	15	kVA		15		
Average (Hourly) Power through the TX	5	kVA		5		
Load Factor (Avg / Peak)	0.333			0.333		
Loss Factor [0.85(LF)^2 + 0.15(LF)]	0.144			0.144		
Annual Energized Hours	8,760	Hours/Year		8,760		
BASELINE (old transformer)						
No Load Loss at Name Plate	0.250	kW				
Load Loss at Name Plate Rated Power	1.300	kW				
Peak Load-Loss	0.325	kW				
Annual No-Load (core) Energy Losses	2,190	kWh/year				
Annual Load (winding) Energy Losses	411	kWh/year				(loss fac) x
Total Annual Energy Losses	2,601	kWh/year				
PROPOSED						
No Load Loss at Name Plate		kW		0.054		
Load Loss at Name Plate Rated Power		kW		1.050		
Peak Load-Loss		kW		0.263		
Annual No-Load (core) Energy Losses		kWh/year		473		
Annual Load (winding) Energy Losses		kWh/year		332		(loss fac) x
Total Annual Energy Losses		kWh/year		805		
Purchase Cost of TX				$ 1,600		
Annual Energy Savings : Transfomer Site Savings		kWh/Year		1,796		$ 0.350
Project Cost:		1.5		$ 2,400		70%
Energy Savings: at Bus Bar		kWh/Year		1,959		1.090560
BPA Incentive: (the lesser of)						
Based of energy savings				$ 686		
Based on project cost				$ 1,680		

Utility (Oil Filled) Transformers

Initial phase work: BPA Webinar on April 7, 2020

If you are interested in the PowerPoint contact:

Tony Koch, jakoch@bpa.gov

Second phase work: BPA Webinar, on January 28, 2021

For Assistance and Support

Contact:

Tony Koch jakoch@bpa.gov 206.220.6777

Emerging
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