Submitted To:

Recommendations for

Dry-Type Transformer Energy Conservation Opportunities

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Submitted By:

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1 INTRODUCTION

One of the stated purposes of the State of Colorado Governor's Energy Office (GEO) is to encourage the use of energy efficient technologies in Colorado buildings. This paper investigates the available energy conservation opportunities and explores enhanced code requirements to minimize energy losses in dry type transformers installed in buildings.

2 EXECUTIVE SUMMARY

A significant energy conservation opportunity exists within Colorado's new and existing building electrical systems. Dry-type transformers are commonly utilized within a large building's electrical distribution system, because they provide the final link between electrical devices, such as lighting, electronics and appliances and high voltage transmission systems. While transformers are relatively efficient, delivering over 95% of their input power, they are constantly energized; consequently, electrical losses are constant. In 1997, losses attributed to dry-type transformers was estimated nationally at 64.5 billion kWh annually[1], or adjusted 985 million kWh for the State of Colorado[2], which equates to 49% of the Xcel Energy Valmont Station power generating facility in Boulder, Colorado[3].

In 2007, The National Electric Manufacturer's Association (NEMA) established TP-1 as a minimum dry type transformer efficiency standard to address this inefficiency. TP-1 explicitly addresses transformers with a primary voltage 34.5 kV and below, and a secondary voltage of 600V and below. While the standard was significant improvement for some transformer manufacturers, it only established an efficiency floor. Furthermore, this manufacturing standard does not address other frequent operating conditions that can also significantly reduce transformer energy efficiency, low loading and prevalence of electronics. While there is not a one-size-fits-all solution, there are three (3) dry-type transformer energy conservation factors that current stakeholders should consider:

- **Transformer Sizing:**
  Oversized transformers can have up to 50% higher energy losses than correctly sized transformers. Efficiencies can be further reduced by 15% during actual operating conditions, which are commonly lower than reference standards.

- **Electronics:**
  Efficiencies can be reduced by 25% or more based on the prevalence of electronics or non-linear loads.

- **Higher Efficiency Equipment:**
  Transformers with a 30% greater efficiency are marketplace available and can have a simple payback less than 4 years, depending on operating conditions.

This report recommends that the Colorado Governor's Energy Office (GEO) provide the following actions to encourage energy conservation in step-down transformers:

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[1]Barnes 1997. Barnes, P.R., S. Das, B.W. McConnell, and J.W. Van Dyke. *Supplement to the "Determination Analysis" (ORNL-6847) and Analysis of the NEMA Efficiency Standard for Distribution Transformers.* Oak Ridge National Laboratory ORNL-6926, September 1007.

[2]2000 Census data of 281.4 million for United States and 4.3 million for State of Colorado.

[3] 112MW of transformer losses over 8,760 hours as compared to a generation capacity of 229MW per Xcel Energy website on June, 2009.

- Promote code enhancements to documents authored by the International Code Council (ICC) or American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) to minimize unnecessary oversizing of transformers. Some of the applicable energy codes are ASHRAE 90.1 and IECC.

- Provide access to educational information on factors impacting transformer efficiency to building designers and the general public.

- Adopt construction standards for new and existing buildings operated by State of Colorado agencies to require the use of higher efficiency transformers.

3 BACKGROUND

Dry-type transformers form a critical element in the lifeblood of large building's electrical distribution system. Elevated electrical voltages provide an efficiency and material benefit, because they allow electricity to travel long distances or large amounts of electricity through smaller conductors without significant loss. However, these higher voltages are not practical for common consumer equipment such as computers, appliances or even incandescent lighting fixtures. Transformers provide the critical interconnection between the elevated voltages and the consumer equipment by "stepping-down" the higher distribution voltages to lower, safer voltages, utilized by most end-use equipment and lighting equipment.

While dry-type transformers provide a system efficiency, they have internal inefficiencies that need to be balanced with the overall system design. Since transformers are continuously operational, even small inefficiencies can be consequential. On a national scale, annual losses from dry type transformers have been estimated at 60 to 80 billion kWh, equating to 3 to 4 billion dollars of loss. It is worth noting that this only considers losses measured at the transformer, and that there are likely additional energy expenditures in order to remove the waste heat created by transformer losses.

Dry-type transformers represent a non-utility market segment used within the building interior. Dry-type transformers are differentiated from their utility counterparts, because they have no internal liquids which aid in heat dissipation.

3.1 TRANSFORMER EFFICIENCY REQUIREMENTS

These transformer losses have been recognized for some time and in 1996, NEMA published a final voluntary standard (TP-1) to substantially raise efficiencies from current transformer product offerings. The Energy Policy Act (EPACT) of 2005 adopted the 2002 version of NEMA TP-1 as the minimum manufacturing standard and as of January 1, 2007, dry-type transformers with primary voltages less than 600 volts with efficiencies less than NEMA TP-1 are no longer commercially available, with limited exception. Refer to Table 1, for common transformer efficiency standards.

Table 1: TP-1 Minimum Dry-Type Transformer Ratings

Dry-Type Distribution Transformer – Low Voltage Primary (600V and below)			
Single Phase		Three Phase	
kVA	Efficiency	kVA	Efficiency
15	97.7	15	97
25	98	30	97.5
37.5	98.2	45	97.7
50	98.3	75	98
100	98.5	112.5	98.3
167	98.7	150	98.3
250	98.8	225	98.5
333	98.9	300	98.6
		500	98.7
		750	98.8
		1000	98.9

Minimum transformer efficiencies for liquid filled and dry-type secondary voltages exceeding 600 volts are also established in NEMA TP-1; however, these were not adopted under EPACT 2005. Minimum liquid filled and dry-type medium voltage transformer efficiencies are scheduled to be updated in 2010.

3.2 ISSUES IMPACTING TRANSFORMER EFFICIENCY

Transformer losses are comprised of a steady core loss in addition to a coil loss that is a function of transformer loading. The core losses exist with no loading, and are due to magnetic fields on the steel core construction, which are referred to as eddy current losses. Coil losses are resistive losses in the internal wiring that are due to current flow that changes with transformer loading. Transformer efficiencies are inversely proportional to losses. Refer to Figure 1 for NEMA TP-1 efficiency curve for different transformer ratings.

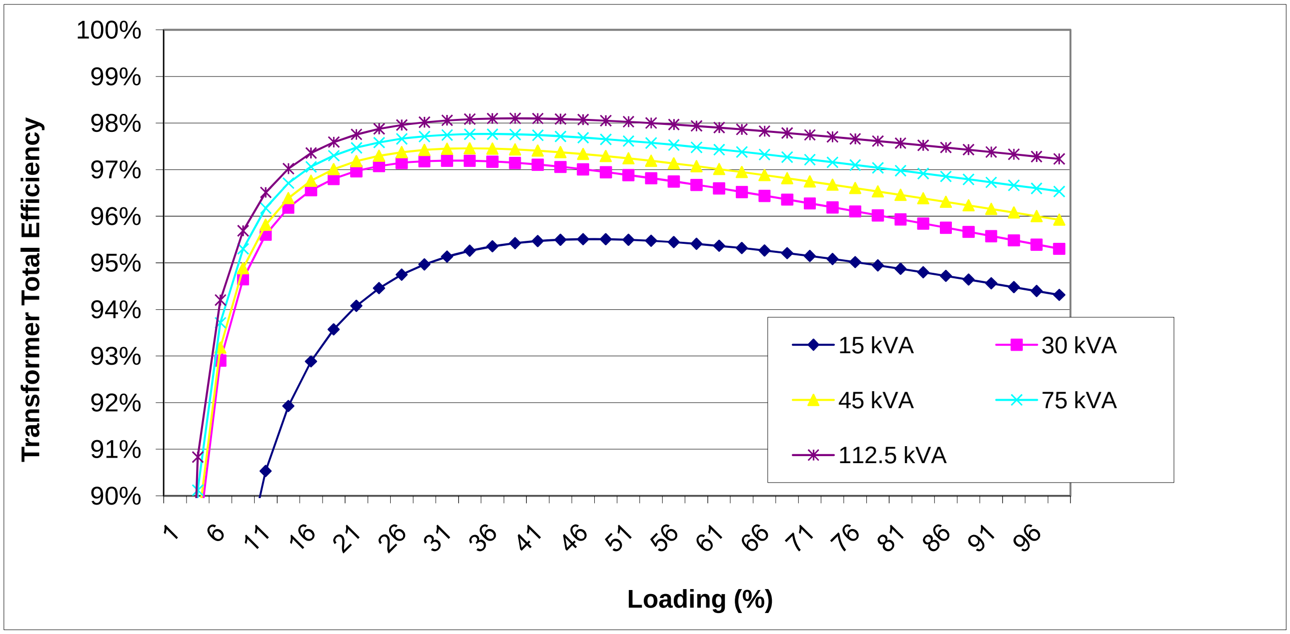

Figure 1: NEMA TP-1 Transformer Efficiency compared to Loading %

3.2.1 Transformer Loading

In December, 1999, The Cadmus Group completed a field survey study on dry-type transformer loading in commercial buildings for the Northeast Energy Efficiency Partnerships (NEEP). The study concluded that the average transformer loading was 15.9% and only 9% of transformers were loaded above the 35% loading test threshold established in the NEMA TP-1 efficiency standard[1].

Consequently, the typical dry-type transformer efficiency should be evaluated at 16% loading or nearest published efficiency data. There are applications where this methodology should not be used, especially when a transformer is provided for a specific function that allows limited diversity of loading, such as medical, manufacturing or laboratory loads.

[1] The Cadmus Group, "Metered Load Factors for Low-Voltage, Dry-Type Transformers in Commercial, Industrial, and Public Buildings", Dec. 7, 1999 for Northeast Energy Efficiency Partnership (NEEP)

3.2.2 Prevalence of Electronic Loads

Modern electronic devices, such as computers and medical equipment, often contain Switch Mode Power Supply (SMPS) devices that can introduce harmonic currents into the loads served by the transformers. These harmonic conditions, classified by the Institute of Electrical and Electronic Engineering (IEEE) as non-linear loads, can cause significant transformer coil losses under heavy loading and even unsafe overheating conditions. Testing has shown that non-linear loads can increase NEMA TP-1 transformers losses by over 30% in severe loading conditions.

Standard NEMA TP-1 compliant transformer loss data due to non-linear loading is not published by the manufacturer, as it not UL listed for use with loads with a Total Harmonic Distortion (THD) greater than 5%.

4 ENERGY CONSERVATION OPPORTUNITIES

4.1 EQUIPMENT SIZING

Since dry-type transformers are traditionally installed in a non-utility environment (downstream of the utility connection and/or inside a building), the capacity rating is governed by the National Electrical Code (NEC). The NEC's objective is to ensure public safety by establishing minimum sizing requirements for electrical equipment and conductors. However, when evaluated against actual field survey such as the Cadmus study, average transformer loading is only 16% of rated capacity.

4.1.1 Distribution Transformers

No-load transformer core losses can increase 50% for each incremental available capacity rating increase. As seen in the following table, oversized transformers can have a significant energy loss; consequently, it is critical stakeholders select the correct transformer rating.

Table 2: *No Load Summary for NEMA TP-1 Low Voltage Transformer Ratings*

Transformer Description	No-load core loss	Percent Increase	Total Annual Impact
30kVA, TP-1 CU winding	138 watts	n/a	**1,208kWh** or (2 ½) 60W light bulbs left on 24/7 for entire year
45kVA, TP-1 CU winding	199 watts	44.2%	**1,743kWh** or (3 ½) 60W light bulbs left on 24/7 for entire year
75kVA, TP-1 CU winding	305 watts	53.3%	**2672kWh** or (5) 60W light bulbs left on 24/7 for entire year
112.5 kVA, TP-1 CU winding	422 watts	38.4%	**3,670kWh** or (7) 60W light bulbs left on 24/7 for entire year

4.1.2 Service Entrance Transformers

Refer to Table 3 below for examples of no-load core losses for large capacity service transformers. These are of particular concern, because of the relatively large no-load core losses. Normally, these transformers are selected by the electric utility company, which utilize significant historical field data to select transformers that are considerably less than the NEC calculated "connected" loads. The transformer "derating" is customarily close to 50%, but will depend on actual electrical and project sector type. Additionally, some loading data is available through IEEE standard C57.

Table 3: *No Load Summary for Non-NEMA TP-1 Medium Voltage Transformer Ratings*

Transformer Description	No-load core loss	Percent Increase	Total Annual Impact
1000kVA, TP-1 CU winding	3400 watts	n/a	**29,800kWh** or (2) single family home kwh per year
1500kVA, TP-1 CU winding	4500 watts	32.3%	**39,420Wh** or (3) single family home kwh per year
2000kVA, TP-1 CU winding	5700 watts	26.7%	**50,000Wh** or (4) single family home kwh per year
2500kVA, TP-1 CU winding	7300 watts	28%	**64,000Wh** or (5) single family home kwh per year

However, when a building (non-utility) design engineer is specifying this same transformer under a primary service, derating is not allowed by the NEC. This type of situation might arise on a large campus or industrial setting.

4.2 IMPROVED EQUIPMENT EFFICIENCY

4.2.1 CSL-3 Transformers

Prior to EPACT 2005 adoption of the NEMA TP-1 classification as it minimum standard, the Department of Energy (DOE) evaluated five (5) different transformer energy conservation classifications to ensure the appropriate standard was established. These classifications are known as Candidate Standard Levels (CSL) one through five and serve as benchmarking classifications for energy efficiency beyond NEMA TP-1, which is CSL-1.

The prevalent available dry-type transformer that exceeds CSL-1 (NEMA TP-1) transformer efficiency standards is constructed to satisfy the CSL-3 level. The CSL-3 benchmark improves transformer losses by 30% from the established CSL-1 (NEMA TP-1) at 35% loading (98.6% as compared 98.0% efficiency). The DOE transformer proposed rulemaking analysis concluded that CSL-3 had the lowest life cycle cost (LCC), saving $3,156 (CSL-1) versus $3,927 (CSL-3)[1]. This conclusion has led ASHRAE to include CSL-3 transformers as a recommended energy efficiency measure K-12 schools.

4.2.1.1 Cost Benefit Analysis (new construction, linear analysis)

The following cost benefit analysis utilizes actual product data current as of May, 2009 utilizing 35% average daily loading profile for new construction. **General Electric 75KVA**, TP-1, copper winding transformer versus **Powersmiths 75KVA** e-saver-C3L with 100% resistive load. This assumes an average cost of electricity at $0.10/kWh.

[1] Federal Register, "10 CFR Part 430, Energy Conservation Program for Commercial and Industrial Equipment: Energy Conservation Standards for Distribution Transformers; Proposed Rule", United States Department of Energy, Office of Energy Efficiency and Renewable Energy

Table 4: *Cost Benefit Analysis for 75KVA transformer with linear load (new construction)*

Type	First Cost	Transformer losses (kWh/yr)	Cooling Interactive (kWh/yr)	Total Losses (kWh/yr)	Total Loss ($/yr)
TP-1	$3,850	3650.0	547.5	4197.5	$420
CSL-3	$4,800	2263.0	339.5	2602.5	$260
Incremental Benefit	$950	2073.2		1595.1	$160
Simple Payback = 6 years					

4.2.1.2 Cost Benefit Analysis (new construction, non-linear analysis)

The following cost benefit analysis utilizes actual product data current as of May, 2009 utilizing 35% average daily loading profile for new construction with a Total Harmonic Distortion (THD) greater than 5%. **General Electric 75KVA**, TP-1, copper winding transformer versus **Powersmiths 75KVA** e-saver-C3Lwith electronic loading.

Table 5: Cost Benefit Analysis for 75KVA transformer with electronic load (new construction)

Type	First Cost	Transformer losses (kWh/yr)	Cooling Interactive (kWh/yr)	Total Losses (kWh/yr)	Total Loss ($/yr)
TP-1	$3,850	4562.5	684.4	5256.9	$525
CSL-3	$4,800	2489.3	373.4	2862.7	$286
Incremental Benefit	$950	2073.2		2384.2	$238
Simple Payback = 4 years					

4.2.1.3 Cost Benefit Analysis (retrofit analysis)

General Electric 75KVA, non-TP-1, copper winding transformer versus **Powersmiths 75KVA** e-saver-C3L with school loads. Existing transformer loss and savings characteristics as cited from metered data in Charlotte-Mecklenburg school district study performed in 2008[1].

[1] Unknown, "PRE / POST Study on a Low Voltage Distribution Transformer", June, 2008, for Charlotte – Mecklenburg Schools

Table 6: Cost Benefit Analysis for 75KVA transformer (retrofit condition)

Type	First Cost	Transformer losses (kWh/yr)	Cooling Interactive (kWh/yr)	Total Losses (kWh/yr)	Total Loss ($/yr)
Existing	n/a (1)	10037.5	0.0	10037.5	$1,004
CSL-3	$7,500 (2)	2263.0	0.0	2263.0	$226
Incremental Benefit	n/a	7774.5		7774.5	$777
Simple Payback = 10 years					

(1) Does not include avoided future costs of equipment costs due to failure

(2) Includes estimated costs for retrofit design, installation and management costs

4.3 HARMONIC MITIGATING TRANSFORMERS

Energy losses created by harmonics can either be dissipated by the transformer in the form of heat or can be dealt with by utilizing Harmonic Mitigating Transformers (HMTs). These transformers provide energy savings by utilizing electro-magnetic flux cancellation and return the efficiency and energy loss values to TP-1 levels, resulting in energy savings up to 30%. These transformers also provide non-energy benefits, such as increase transformer life expectancy and interference issues caused by harmonics. Cost benefit analysis should be performed on a case by case basis.

5 RECOMMENDATIONS

5.1 CODE IMPLEMENTATION

Currently no adopted energy conservation building standards or codes, such as ASHRAE 90.1-2007 and/or 2006/2009 International Energy Conservation Code (IECC) regulate transformer sizing, efficiency, or specification type in commercial buildings. Introduction of energy conservation requirements for dry-type transformers to the building code would be a ground-breaking moment, but a necessary regulation in light of the significant potential energy savings.

Any code enhancement would need to complement other established codes and not impact public safety concerns, real or perceived, such as sizing criteria established in the NEC.

The IECC is the proper code for energy conservation code enhancement. The following code enhancement would apply to section 505.7, which is the electrical system energy conservation section for commercial buildings:

5.1.1 Equipment Sizing

5.1.1.1 Distribution Transformers

Add requirement to eliminate any intentional transformer oversizing, since transformers average 16% loading and oversized transformers can have a 50% greater loss.

"Section 505.7.1 For each transformer, the selected transformer rating shall be not larger than the first available transformer rating larger than the calculated load. Anticipated future shall be identified."

This nomenclature is very similar to ASHRAE 90.1 requirements to limit fan motor oversizing.

5.1.1.2 Service Entrance Transformers

Add opportunity for design engineer to utilize transformer derating data and/or commercially available software.

"Section 505.7.2 Where the transformer serves the purpose as the service entrance equipment, the selected transformer rating is allowed to be reduced by factors established by the design engineer utilizing load data from IEEE C57 standards ."

5.1.2 Non-Linear Loads

Add requirement to ensure transformers are rated for proper use to mitigate losses from harmonics, since NEMA TP-1 transformers are not UL Listed for such use.

"Section 505.7.3 Transformers serving loads with a Total Harmonic Distortion (THD) greater than 5%, shall be rated for such use to maintain energy efficiency."

5.1.3 Improved Efficiency (Colorado State Buildings)

Since Governor Ritter signed Executive Orders to reduce energy consumption in state buildings by 20% in 2012, the recommendation is to standardize transformer selection for CSL-3 transformers and where THD levels are anticipated to exceed 30%, recommend specification of Harmonic Mitigating Transformers. Many higher education facilities and K-12 school districts with strong energy efficiency goals have already standardized on this equipment, such as the University of Colorado at Boulder.

Most commercial construction projects utilize specifications from the Constuction Specifications Institute (CSI). In the pre-2004 MasterFormat, Division 16 typically refers to electrical equipment. A typical specification for transformers would be section 16270.

Specification Section 16270

> **"Interior dry-type transformers shall be constructed to meet DOE CSL-3 energy efficiency standards."**

5.2 PUBLIC EDUCATION

5.2.1 Improved Efficiency (Private Sector)

Since the burden of responsibility to determine non-linear loads and loading factors falls on the design engineer, payback conditions will vary and could exceed 5 years; consequently, the recommendation is not implement any mandatory code enhancements for private sector development. However, there remains a substantial opportunity for energy conservation in new and existing buildings; therefore, the recommendation for Colorado GEO to participate in public awareness of transformer efficiency conservation. This awareness might be practical by making this study available on the GEO website or through design professional and owner education. Technical items to highlight through education:

- High probability of low loading conditions.
- High probability of non-linear loading which reduce transformer efficiency.
- Availability of energy conserving transformers.

6 BARRIERS TO CODE IMPLEMENTATION

6.1 DESEGREGATED ENERGY CODE ADOPTION

Since Colorado is a home rule state, which each jurisdiction having control of specific code enforcement, adoption of this recommended code changes will be difficult. State legislature intervention is anticipated.

6.2 ANTICIPATED STAKEHOLDER OPINIONS

6.2.1 Design Community

It is anticipated that the design community at large will be neutral to implement these recommendations. Some designers will welcome government intervention to promote and enforce energy efficiency, while others will not appreciate heavy-handed mandates from government or code authorities that do not permit design flexibility.

6.2.2 Contracting Community

It is anticipated that the contracting community at large will be slightly negative to implement these recommendations, as these potential increased costs will be communicated by the contractor.

6.2.3 Ownership Community

It is anticipated that the ownership community at large will be slightly negative to implement these recommendations as these potential increased costs will be borne by the owner. However, those owners who operate large facilities or campus will welcome the code enhancements.

6.2.4 Manufacturing Community

It is anticipated that the manufacturing community at large will be negative to implement these recommendations as the major transformer manufacturers do not currently manufacture CSL-3 rated transformers.