POWER QUALITY INTERNATIONAL

APPLICATION GUIDE

Type DV e-Rated® Distribution TransFilter™
Ultra-Efficient, Low Voltage, Dry-Type Isolation Transformer for High K-Factor, Phase-to-Neutral Connected Nonlinear Loads with an integrated Type TPM Transformer Performance Meter™

Product Description

Type DV ***e-Rated***® low voltage dry-type isolation transformers provide ultra-efficient alternatives to conventional or K-Rated distribution transformers. Type DV transformers are ideally suited for new construction or the replacement of older transformers with historically low efficiencies as part of a power system optimization and energy reduction plan.

Efficiency

With reference to *Table 1,* Type DV ***e-Rated***® transformers, with *standard* 'Z3' efficiencies, exceed the energy efficiency requirements of NEMA TP 1-2002, CSA C802.2-12, NEMA Premium™, US DOE Candidate Standard Levels (CSL) 3 and 4 and pending US DOE 2016 levels. With reference to the table, optional 'Z3+' and 'Z4', with progressively higher levels of energy efficiency, are also available.

Efficiency Confirmation

The efficiencies of Type DV ***e-Rated***® transformers are confirmed using NEMA TP 2-2005 *(Standard Test Method for Measuring the Energy Consumption of Distribution Transformers)*. If necessary these results can be subjected to CSA C802.5 *(Guide for Selection of Efficient Dry-Type Transformers for Nonlinear Loading)* calculations to determine their *nonlinear* efficiencies, at any load level, with any defined or measured harmonic current profile.

kVA Sizing and Efficiency Considerations for New Construction

A *Load Factor* survey, undertaken by The Cadmus Group Inc.in 1999, found that the average loading of low voltage dry-type distribution transformers in commercial, industrial and public buildings was in a range between 9% and 17% of their full load ratings. They also found that loading, for at least 12 hours a day, was only 10% of the average. More recent surveys have shown much lower *Load Factors*, the result of upgrading to more energy efficient loads.

Transformer oversizing is a typical outcome when meeting the requirements of national and local electrical codes in the USA and Canada. Selecting the optimum transformer kVA can be determined by referring to CSA Standard C802.4-13 *(Guide for kVA Sizing of Dry-Type Transformers).*

In addition to the high capital cost of oversizing, the cost of operating a lightly loaded transformer is high. Using the Cadmus survey findings, *Figure 1* displays the efficiencies of a typical 75kVA NEMA TP 1 transformer and a Type DV ***e-Rated***® transformer with the same kVA rating. Their efficiencies at 9% and 17% FL are shown.

The required efficiency of a 75kVA transformer meeting NEMA TP 1 is 98% at 35% FL, but at 9% FL the efficiency is only 95.94%. Based on more recent surveys, average loading is often lower than 9%. For example, at 5% FL the efficiency of the NEMA TP 1 transformer is only 93.21%. Rightsizing a transformer, as recommended by CSA C802.4, can result in a substantial reduction in losses and operating costs.

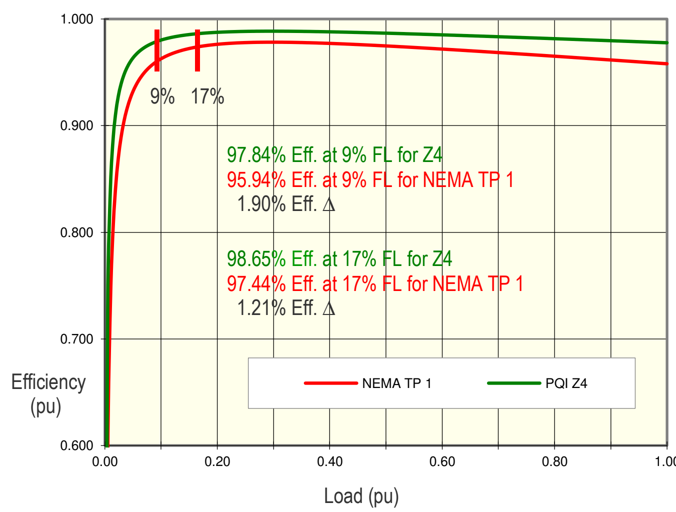
Since the recommendations given in CSA C802.4 are for transformer efficiencies under *linear* loading, before proceeding with a final selection, CSA C802.5 must be used to determine a transformer's *nonlinear* losses and efficiencies under the anticipated loading and harmonic current profiles.

Table 1
Required vs. PQI Energy Efficiencies [1]

kVA Rating	*NEMA TP 1 2002* [2] *CSA C802.2*	*NEMA Premium* [2]	*DOE 2016* [3]	***PQI Z3*** *exceeds CSL 3* [4]	***PQI Z3+***	***PQI Z4*** *exceeds CSL 4* [4]
15	97.00	97.90	97.89	**98.23**	**98.25**	**98.43**
30	97.50	98.25	98.23	**98.29**	**98.52**	**98.68**
45	97.70	98.39	98.40	**98.45**	**98.66**	**98.81**
75	98.00	98.60	98.60	**98.64**	**98.82**	**98.95**
112.5	98.20	98.74	98.74	**98.77**	**98.93**	**99.05**
150	98.30	98.81	98.83	**98.86**	**99.01**	**99.12**
225	98.50	98.95	98.94	**98.97**	**99.10**	**99.20**
300	98.60	99.02	99.02	**99.04**	**99.16**	**99.26**
500	98.70	99.09	99.14	**99.16**	**99.26**	**99.35**
750	98.80	99.16	99.23	**99.24**	**99.33**	**99.41**
1000	98.90	99.23	99.28	**99.29**	**99.38**	**99.45**

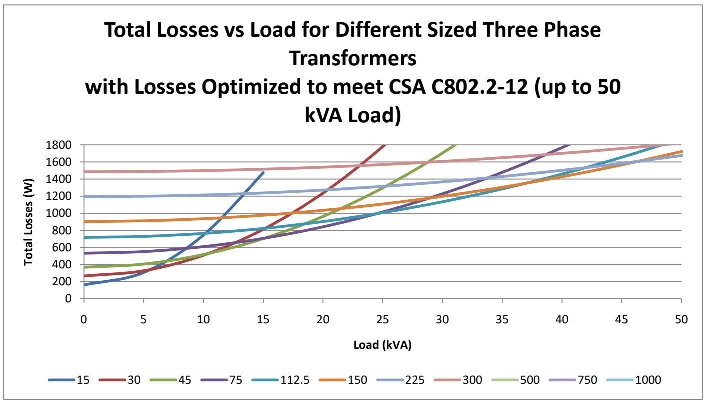
Table 1 Notes:

[1] Efficiency values are measured at 35% of nameplate rating.
[2] The efficiency of transformers manufactured after January 1, 2007, but before January 1, 2016 must meet the efficiency requirements of NEMA TP1 2002.
[3] The efficiency of transformers manufactured after January 1, 2016 must meet the efficiency requirements of US DOE 2016
[4] PQI Z3 & Z4 efficiencies exceed the requirements of DOE Candidate Standard Level 3 & 4 (CSL 3 & CSL 4) respectively



75kVA Distribution Transformers under Linear Loading
NEMA TP 1 vs. PQI Z4 Efficiencies at 9% & 17% FL
Figure 1

Based on these efficiency outcomes, one can then compare the energy savings, payback, return-on-investment (ROI) and EPA environmental outcomes for all alternatives, which may also include downsizing per C802.4. A comparison of total losses in a downsizing scenario may be found in *Figure 2,* which is found in CSA Standard C802.4.



Graph taken from CSA C802.4
Standard for kVA Sizing of Dry-Type Transformers
Figure 2

With reference to the *Figure 2*, using the 9% and 17% load levels described in *Figure 1,* one can examine the ‘rightsizing’ possibilities. For example, if a 75kVA transformer was initially considered, but the anticipated load was only 9% FL or 6.75kVA, the best alternative may be a 30kVA transformer with an average equivalent load of 22.5% FL. Based on the graph a 15kVA unit at 45% FL may also qualify since its calculated average *Load Factor* would not exceed 50% FL, a national**grid**® transformer replacement program recommendation. Before proceeding with this alternative, however, one must consider the possible addition of future loads.

Applying the same logic, if a 75kVA transformer was initially considered, but the anticipated load was only 17% FL or 12.75kVA, a 45kVA unit at 28.33% FL or a 30kVA unit at 42.50% FL could be considered.

Based on the 75kVA, 9% FL average load example, *Figures 3* & *4* detail the differences in losses and efficiencies when comparing the 75kVA vs. 30kVA transformers. With 1863W lower losses and 2.6% higher efficiency, the 30kVA ultra-efficient transformer will provide significant energy savings.

kVA Sizing and Efficiency Considerations when Replacing Existing Transformers

The motivation to replace an existing transformer is usually based on its questionable reliability and/or a need to reduce energy consumption and cost. Based again on the *Load Factor* survey undertaken by The Cadmus Group, the higher excitation losses and lower efficiencies of pre-NEMA TP 1 transformers, particularly at low *Load Factors,* provides an even greater opportunity to save energy and reduce operating costs.

As demonstrated in *Figure 5,* at 9% FL the efficiency of the pre-NEMA TP 1 transformer is only 92.84%. Based on more recent surveys, average loading is often much lower. At 5% FL the efficiency of the pre-NEMA TP 1 unit is only 88.11%. Rightsizing a transformer, as recommended in CSA C802.4 and the national**grid**® *Transformer Replacement Program for Low-Voltage Dry-Type Transformers* program*,* can result in a substantial reduction in operating costs.

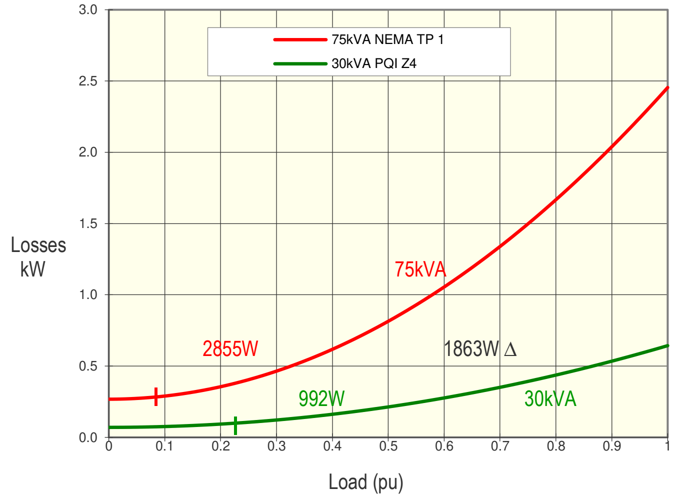
The national**grid**® program recommends that downsizing should only be considered if:

1. The measured *Load Factor* of the existing transformer never exceeds 35% FL or
2. The calculated *Load Factor* of the replacement transformer never exceeds 50% FL.

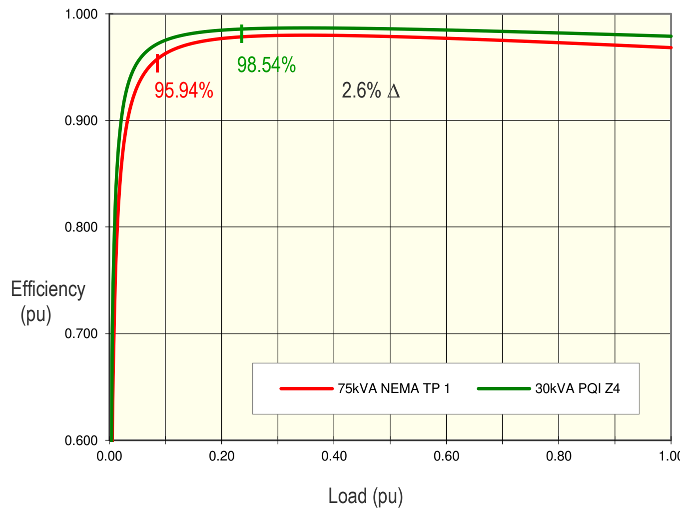
Based on these criteria, the *Load Factor* for the replacement transformer can be calculated as follow:

$$LF_{NEW} = LF_{OLD} \times (kVA_{OLD} / kVA_{NEW})$$

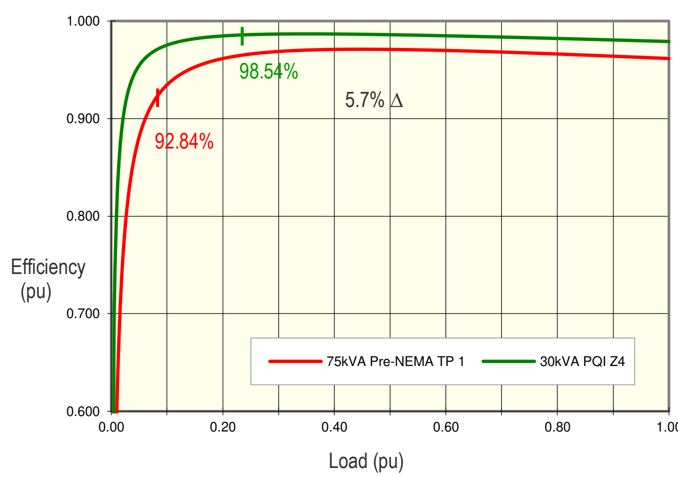
To determine the replacement transformer’s potential energy savings, payback, ROI and EPA environmental outcomes, CSA C802.5 must first be



75kVA & 30kVA Distribution TransFilters™ Losses
75kVA NEMA TP 1 vs. 30kVA PQI Z4 under 6.75kVA Linear Loading
Figure 3



75kVA & 30kVA Distribution TransFilters Efficiency
75kVA NEMA TP 1 vs. 30kVA PQI Z4 under 6.75kVA Linear Loading
Figure 4



75kVA & 30kVA Distribution TransFilters Efficiency
75kVA Pri-NEMA TP 1 vs. 30kVA PQI Z4 under 6.75kVA Linear Loading
Figure 5

used to calculate the efficiency of the existing and proposed replacement transformers, under their measured or calculated *Load Factors.* At low *Load Factors* the national electrical codes are somewhat more flexible regarding downsizing, if the load profiles can be confirmed. Since even an ultra-efficient transformer's efficiency begins to fall off below 15% FL, downsizing with a smaller, more efficient transformer will also provide an attractive capital cost reduction.

High K-Factor Nonlinear Loading

Type DV Distribution TransFilters' ultra-low zero-sequence impedances effectively reduce voltage distortion (THD_V) at their subsystem's loads, the principal cause of reduced load efficiency. Type DV transformers can often be applied as 'standalone' harmonic mitigating solutions or in combination with Type Z I_0Filters™ and/or 'Mini-Z™ (zero-sequence harmonic shunt filters). Type DV transformers are available with optional primary-to-secondary phase-shifts, allowing the system designer to create 12-, 18- or 24-pulse harmonic current profiles at a common primary bus. Progressively high pulse-numbers will reduce harmonic current related 'penalty losses' in the primary system and improve system Power Factor.

Type DV transformers are ideally suited for new construction or the replacement of older transformers with historically low efficiencies as part of a power system optimization and energy reduction plan.

Product Application

The benefits of a Distribution TransFilter™ application are optimized when these devices are installed as close as possible to the sources of positive-, negative- and zero-sequence harmonic currents. This is typically accomplished by installing the transformer in close proximity to the three-phase, four-wire panel that supplies single-phase, nonlinear loads.

The determination of preferred Distribution TransFilter™ types, locations and ratings will be demonstrated in the following examples:

Case 1

With reference to *Figure 6,* the 120/208V Subsystem 1 includes a Type DV0 - Distribution TransFilter™, with a primary-secondary phase-shift of 0° @ 60Hz, while the 120/208V Subsystem 2 includes a Type DV30 - Distribution TransFilter™, with a primary-secondary phase-shift of -30° @ 60Hz. The secondary outputs from these transformers are therefore 30° out-of-phase. Each of these transformers is connected to its panel via a 3Ø, 4W circuit.

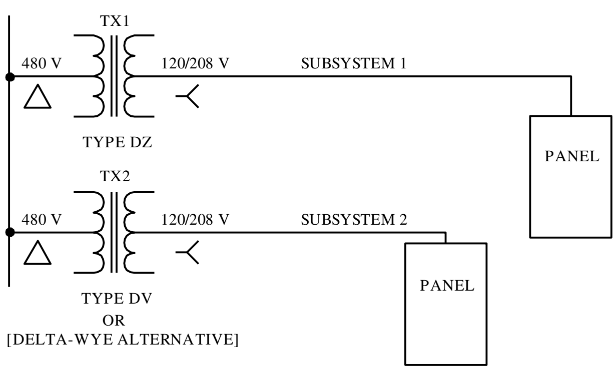


Figure 6

If we assume that the two panels will be used to supply single-phase, nonlinear loads, then the 5th, 7th, 17th, 19th --- positive- and negative-sequence harmonic currents, generated by the loads connected to each panel, will be out-of-phase by 30° @ 60Hz or approximately 180° at each targeted harmonic frequency. As a result, most of these particular harmonic currents will cancel on the transformers' common primary bus.

Under these conditions, the exact phase-shift, which is required to cancel any particular harmonic frequency, would be as follows:

$$\angle° \text{ @ } 60Hz = 180° \text{ @ } 60Hz / H \qquad [1]$$

where:

$\angle°$ @ 60Hz - The exact phase-shift @ 60Hz which is required, between two separate sources of a particular harmonic current, in order to create a 180° phase-shift at that frequency which will result in its cancellation.

H - The harmonic number of the particular harmonic frequency.

In order to achieve the maximum benefit, it is normal practice to select the second order, zero-sequence harmonic frequency that separates the positive and negative frequencies to be cancelled. This method results in a significant reduction of both targeted harmonic currents.

As an alternative to the above, and again with reference to *Figure 6,* the 120/208V Subsystem 1 includes a Type DV0 - Distribution TransFilter™, with a primary-secondary phase-shift of 0° @ 60Hz, while a preexisting 120/208V Subsystem 2 includes a conventional Delta-Wye Distribution Transformer, with a primary-secondary phase-shift of -30° @ 60Hz. The secondary outputs from these transformers are, therefore, 30° out-of-phase as before. Each of these transformers is connected to its panel via a 3Ø, 4W circuit.

Again, all of the system improvements listed under PRODUCT DESCRIPTION will accrue to Subsystem 1 while many improvements will also accrue to Subsystem 2.

As an alternative, the Distribution TransFilter™ may be installed at some distance from the sources of positive-, negative- and zero-sequence harmonic currents when the installation includes the application of an I_0Filter™ - Zero Sequence Harmonic Filter(s). This may be the only alternative when the Distribution TransFilter™ has high kVA ratings and the 120/208V subsystem includes multiple panels and/or sub-panels. In this case, a filter(s) may be required at each remote three-phase, four-wire sub-panel that supplies single-phase, non-linear loads. Detail on the application of I_0Filters™may be found in the Type Z - APPLICATION GUIDE.

The determination of preferred Distribution TransFilter™ and I_0Filter™ locations and ratings will be demonstrated in the following examples:

Case 2

With reference to *Figure 7,* the 120/208V Subsystem 1 includes a Type DV0 - Distribution TransFilter™, with a primary-secondary phase-shift of 0°@ 60Hz, while 120/208V Subsystem 2 includes a Type DV30 - Distribution TransFilter™, with a primary-secondary phase-shift of -30° @ 60Hz. The secondary outputs from these transformers are, therefore, 30° out-of-phase. Each of these transformers is connected to its panel(s) via a 3Ø, 4W circuit.

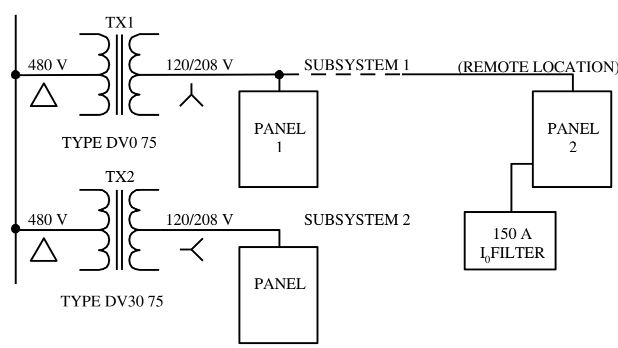


Figure 7

If we now assume that the three panels will be used to supply single-phase, nonlinear loads, then the 5th, 7th, 17th, 19th --- positive- and negative-sequence harmonic currents, generated by the loads connected to each Distribution TransFilter™, will be out-of-phase by 30° @ 60Hz or approximately 180° at each targeted harmonic frequency. As a result, most of these particular harmonic currents will cancel on the transformers' common primary bus.

If we also assume that each panel in Subsystem 1 will be used to supply 30kVA ([75kVA x 0.8]/2) of single-phase nonlinear loads exclusively, then a 150A I_0Filter™ should be installed at Panel 2. The zero-sequence harmonic currents, generated by the loads connected to Panel 1, will be shunted by the Type DV0 - Distribution TransFilter™(TX1). The installations must be in accordance with the appropriate I_0Filter™ - Connection Diagram.

Product Application Alternatives

In the event that a 480V bus supplies three or more Distribution TransFilters™, other phase-shifting angles may be chosen in order to cancel additional positive- and negative-sequence harmonic currents. For example, if three (groups of) transformers (≈equal kVA) are installed, Types DV10, DV30 and DV50 can be applied in order to cancel the 5th, 7th, 11th, 13th, 17th, 19th, --- positive- and negative-sequence harmonic currents.

Alternatively, if four (groups of) transformers (≈ equal kVA) are installed, Types DV0, DV15, DV30 and DV45 can be applied in order to cancel the 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, --- positive- and negative-sequence harmonic currents.

The PQI Solution™

Power Quality International uses IEEE Std. C57.110 and CSA C802.5 compliant engineering software to quickly and accurately compare the losses and efficiencies of any two transformers, under any anticipated or measured harmonic and loading profile. Given the cost of each transformer, or a single transformer in a replacement scenario, and utility rates, the software also calculates the annual energy savings, including A/C costs, payback on incremental or replacement costs, return-on-investment and EPA environmental benefits.

PQI's Application Engineers can also develop a harmonic mitigation plan that will reduce the system's 'penalty losses' and ensure that voltage distortion at the loads will not exceed 5% THD_V, an IEEE Std. 519-1992 recommendation.

PQI offers these analytical services, with recommendations, on a 'no charge' basis. To access this service, please contact PQI at (888) 539-7712 or engineering@PowerQualityInternational.com.

All Specifications are subject to change without notice.

e-Rated®

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