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Ms. Brenda Edwards-Jones
U.S. Department of Energy
Building Technologies Program
Mailstop EE-2J
ANOPR for Distribution Transformers
EE-RM/STD-00-550
1000 Independence Ave. SW
Washington, DC 20585-0121

Re: HVOLT Inc Statement on DOE Transformer NOPR Comments EE-RM/STD-00-550 for Regulatory Information Number (RIN) 1904-AB08

Dear Ms. Edwards-Jones

HVOLT Inc is a Power and Distribution Transformer Consulting firm, located in Charlotte, NC. HVOLT President, Phil Hopkinson is a long service transformer engineer with lengthy experience at three of the major manufacturers of Distribution Transformers in our country and with consulting experience at most of the US manufacturers. I am a strong believer in Energy Efficiency Standards and support efforts to produce comprehensive standards that will strengthen the US economy and move toward energy independence. At NEMA, I chaired the task force to write NEMA TP-1 in both the first edition of 1996 and in the revision of 2002. At IEEE I have chaired the Power Engineering Societies Policy Development Coordinating Committee and have been a co-author of the IEEE PES Policy Statement on Energy and the Environment that was recently approved by the PES Board of Governors. I am an IEEE Fellow, a Registered Professional Engineer in the State of North Carolina and Technical Advisor (TA) to the US National Committee for IEC TC 14 Power Transformers.

My comments are addressed at concerns of the relationship between single phase and three phase Liquid filled Distribution Transformers as expressed at IEEE's Transformers Committee Meetings in Dallas, Texas on March 14, 2007. At this meeting, the membership appointed me as Chair to a task force to bring comments to your attention.

A The NEMA membership has submitted a strong endorsement for the DOE to select NEMA TP-1 as the National standard for all Medium Voltage Transformers, including Vault Transformers. I fully support this position and find that it meets some important DOE principles:

1. **Doable with known materials and methods by small and large manufacturers**
2. **Pays for itself, originally with a 3-5 year payback period and currently with a 4-7 year payback attributable to higher present material costs translating to higher transformer selling prices with steady energy costs.**
3. **Results in Real Energy Savings.**

These were the initial principles used to choose the efficiency tables for all classes of Distribution Transformers. In arriving at the NEMA tables, large and small manufacturers ran designs for each of the key power ratings with loss evaluation formulas that were based on a 3-year payback for the conditions of:

1. $0.065/kwh energy cost, translating to $0.50/wat/yr. value of losses or $1.50/watt. Of present worth over 3 years.
2. 50% rms equivalent loading for all Medium Voltage Transformers and 35% rms equivalent loading for Low Voltage Dry Type Transformers.
3. 15 kV voltage class at 95 kV BIL.
4. 55C reference temperature for Liquid and 75C for Dry Transformers.

The DOE has recognized the work in NEMA TP-1's treatment of Liquid Filled Distribution Transformers and assigned a TSL-1 designation for the efficiency levels. An engineering study was conducted by the DOE's subcontractors to examine other approaches for energy efficiency. These approaches generally applied life cycle cost methodology with various payback criteria. The over-riding presumption being that

1. TSL-1 is NEMA TP-1
2. TSL-2 is 1/3rd of the difference between TP-1 and the DOE's calculation of minimum Life Cycle Cost (LCC)
3. TSL-3 is 2/3 of the difference between TP-1 and the DOE's calculation of minimum LCC
4. TSL-4 is the DOE's calculation of minimum LCC

NEMA TP-1 tables were derived from careful studies of fundamental relationships between single phase and three phase transformers and resulted in identical efficiency for a three phase transformer that is three times the single phase kVA. For example: the tables from NEMA TP-1 show the following efficiencies:

Single phase kVA	TP-1 efficiency	Three phase kVA	TP-1 efficiency
10	98.3	15	98.0
15	98.5	30	98.3
25	98.7	45	98.5
37.5	98.8	75	98.7
50	98.9	112.5	98.8
75	99.0	150	98.9
100	99.0	225	99.0
167	99.1	300	99.0
250	99.2	500	99.1
333	99.2	750	99.2
500	99.3	1000	99.2
667	99.4	1500	99.3
833	99.4	2000	99.4
		2500	99.4

The smooth progression of the NEMA TP-1 efficiencies as a function of kVA is shown in figure 1 below:

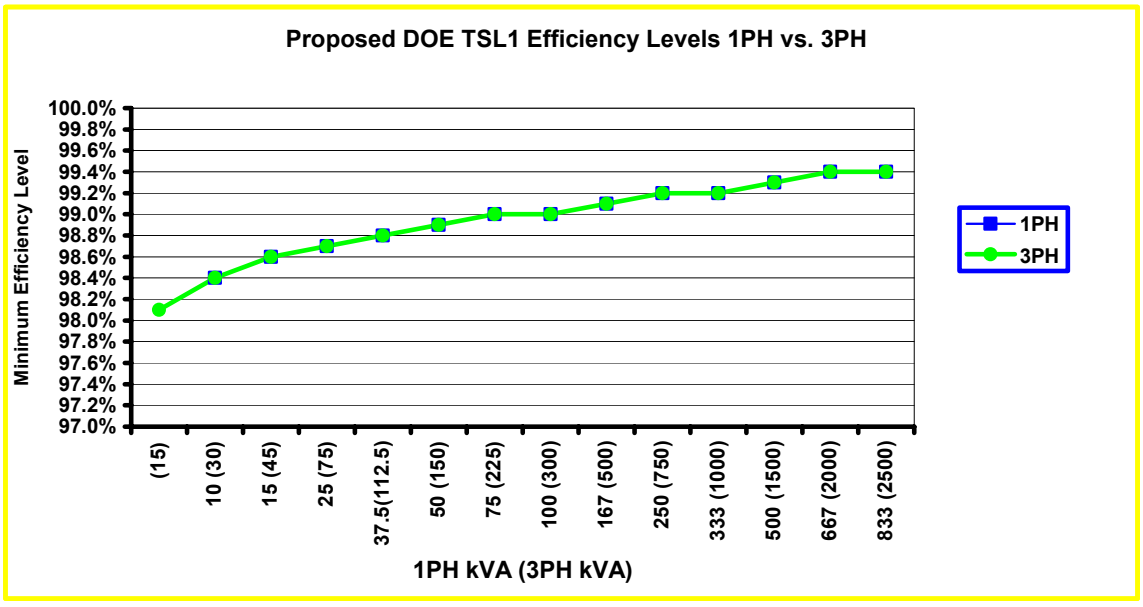

Figure 1 NEMA TP-1 efficiencies versus kVA showing a generally smooth and continuous curve

There is a long standing relationship between single phase and three phase that is fundamental and results in the curve as shown in figure 1 above. The relationship is as follows when comparing a single phase transformer to a three phase transformer with three times the kVA (for example a 25 kVA single phase and a 75 kVA three phase:

a. At the 50% load measurement point for energy efficiency, single phase core loss is generally equal to single phase winding loss (this is fundamental for loss minimization). Note that at full load, the winding loss is approximately 4 times the core loss before temperature correction adjustment.

b. Three phase transformers are assumed to be constructed with wound cores in a 5-leg arrangement. This results in 4 core loops, the outer 2 of which surround only 1 coil each and the inner loops surround 2 coils each. The outer loops are equivalent to those in a Shell Form single phase transformer, the sum of which could be thought of as 1 per unit weight. Since the inner core loops surround 2 coils each, they sum to a net of ~1.3 per unit weight each. This implies that the total three phase core weighs 2.3 times that of the single phase equivalent. Figure 2 below shows a typical 3-phase core-coil assembly:

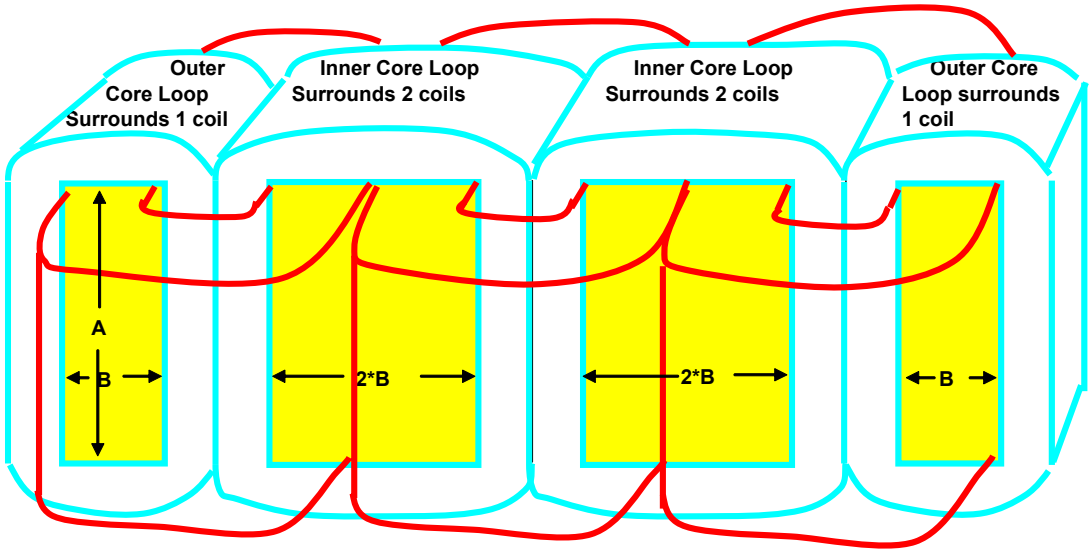

Figure 2: 5-leg 3-phase core and coil assembly. Note the following elements:

- 3 coil windings vs. 1 coil for 1-Phase resulting in 3.0 per unit winding loss vs. the 1-Phase equivalent.
- 2 outer core loops similar to a 1-Phase transformer
- 2 inner core loops weighing 1.3 times the outer core loops
- Net 3-phase core weight = 2.3* 1-Phase core weight
- Circulating 3rd harmonic flux in each core loop resulting in 1.3* 1-Phase core loss watts per pound of core weight
- Net 3-phase core loss = 2.3 * 1.3 or 2.99 per unit of 1-phase core loss
- Total 3-Phase loss = (3.00 winding + 2.99 core)/2 = 3.0 * 1-Phase watts

c. Core loss for the single phase transformer is generally equal to the Epstein performance of the steel. Hence single phase core loss is equal to the weight of the core times the watts/lb. for the given core material at the design flux density.

d. Three phase core loss in wound cores differs from single phase in that there is a circulating component of 3rd harmonic flux that creates additional loss. Hence the three phase core loss is the three phase core weight times the same watts /lb. times 1.3

3-Phase core watts = 2.3 *1.3 * 1-Phase core watts = 2.99 per unit

E The three phase transformer also has 3 electrical windings, one for each phase. Each phase has 1.0 per unit winding loss. Hence for a 3-phase transformer

3-phase winding loss = 3.0 per unit times single phase winding loss

g. Hence the total loss for a 3-phase transformer = 3.0 per unit times the single phase unit
h. Since the three phase transformer has three times the kVA of the single phase, the two have identical efficiency

This long standing relationship has been recognized by the Distribution Transformer manufacturers across the industry and is found to exist in their respective product offerings when designed with similar materials and equivalent loss evaluations.

Our concern is that the DOE has deviated from this relationship in the proposal for TSL-2, TSL-3, and TSL-4. Figure 3 below show plots of the proposed efficiencies for TSL-2.

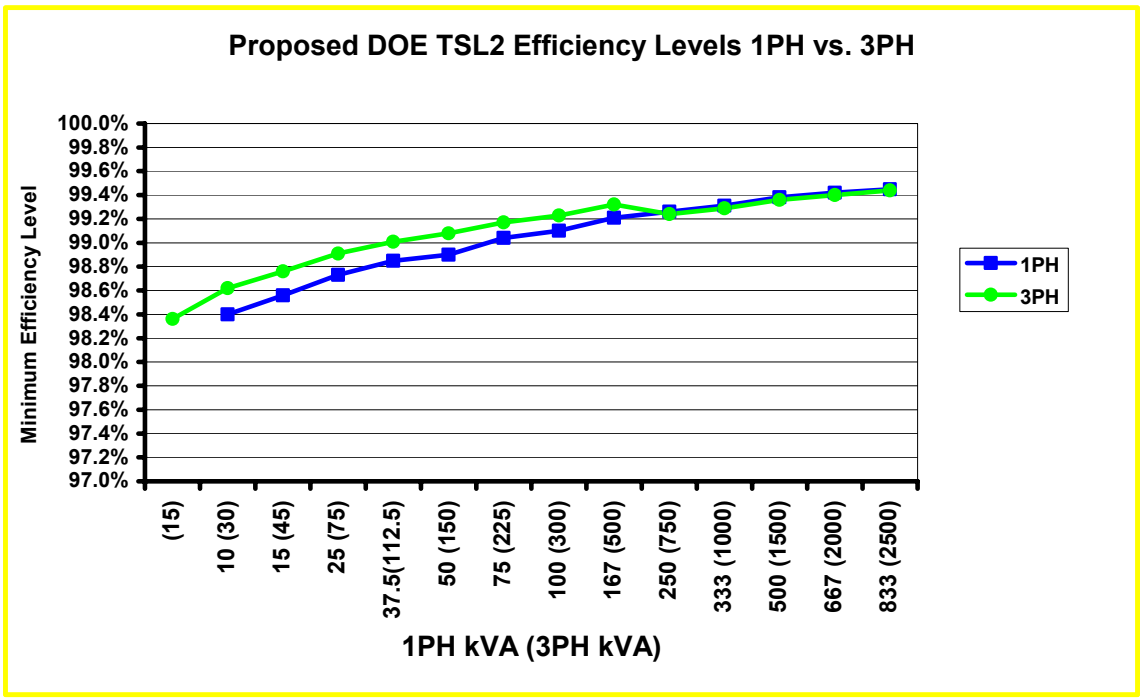

Figure 3 shows proposed DOE TSL-2 efficiencies for single phase and 3-phase transformers. Note that kVA's less than 250 single phase (less than 750 3-phase) propose a more onerous 3-phase efficiency requirement than the fundamental 1-phase to 3-phase relationship as described above.

I have worked through each of the TSL-2designs and find that TSL-2 has an error in the 3-phase calculations that appears to be in the core loss calculation. It is missing the 1.3 factor to account for circulating 3rd harmonic flux for 3-phase kVA ratings below 750. When I corrected that error, all of the TSL-2 3-phase efficiencies fell right on top of the single phase equivalents. Note the plots in figure 4 below:

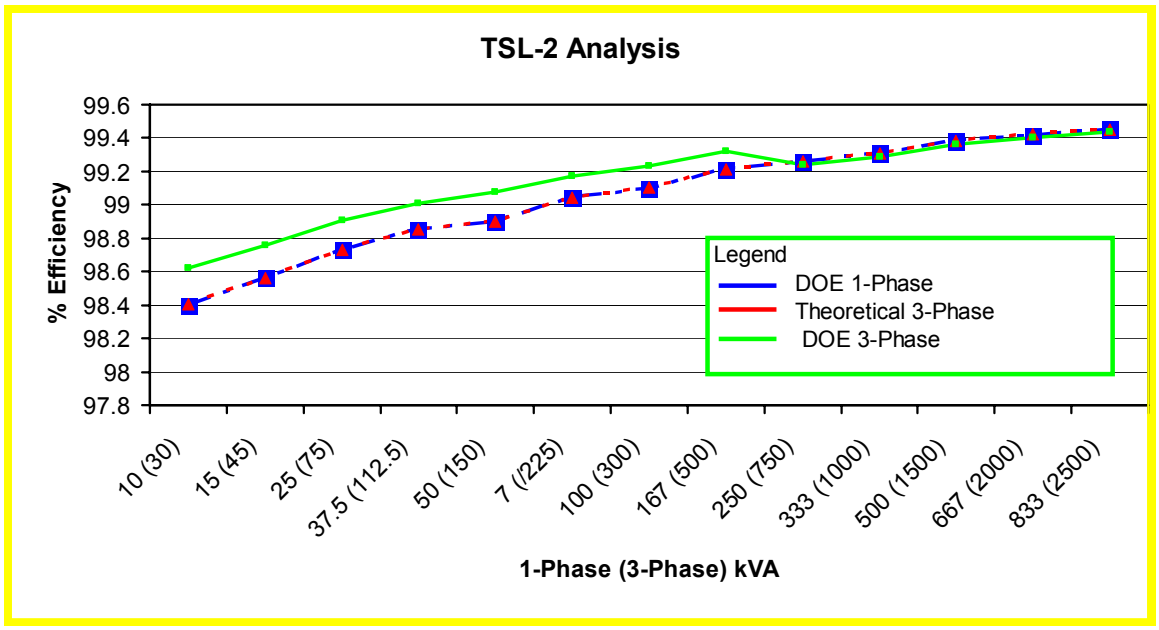

Figure 4 shows an analysis of the TSL-2 efficiencies. The curve in blue is the DOE single phase efficiency. The curve in red is the theoretical 3-phase efficiency that is calculated from the single phase curve. The curve in green is the DOE calculation for 3-Phase TSL-2.

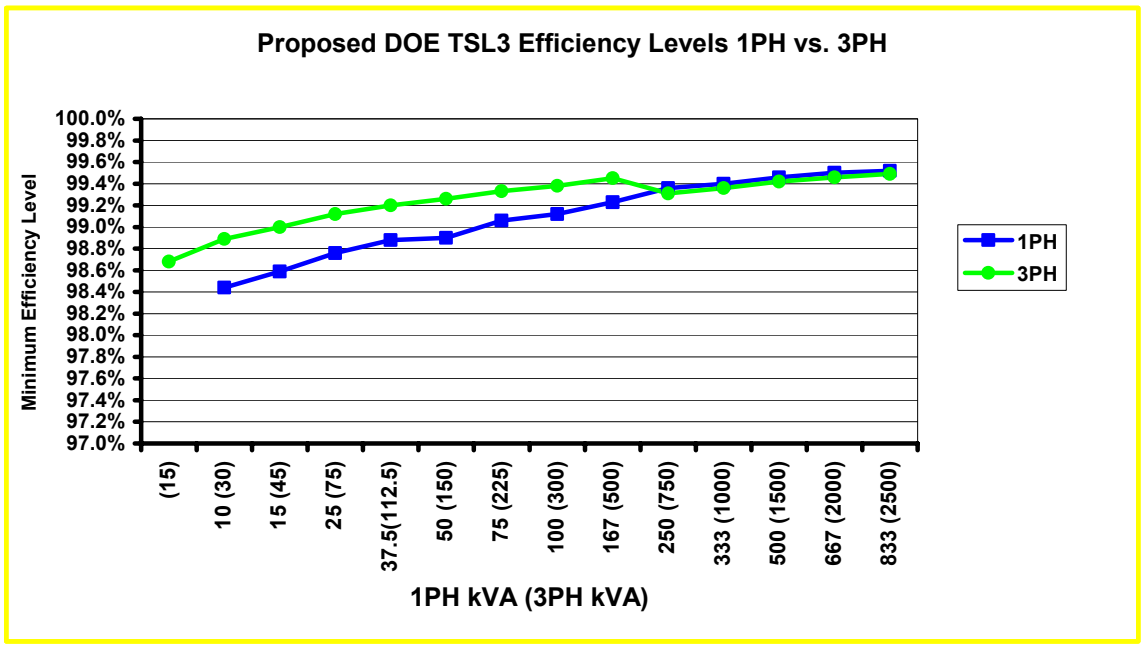

Figure 4 shows the proposed DOE TSL-3 efficiencies for single phase and 3-phase transformers. Note that kVA ratings less than 250 kVA single phase or 750 kVA 3-phase requirements diverge even further from the proper relationship than those in TSL-2. TSL-3 has an additional error that seems to only be associated only with 3-phase transformers less than 750 kVA. For example, if we examine the 25 kVA single phase, we find an efficiency of 98.76%. The three phase efficiency shown on the graph is 99.12%. If the error had only been in the 1.3 core factor, then the 75 kVA would have calculated to 98.9%. Clearly some other type of error has crept in. The only way to consistently meet the 3-phase efficiencies seems to be in the use

of Domain Refined High Permeability core steel. Several manufacturers have indicated that they can not meet the 3-phase proposed standard for either TSL-3 or TSL-4. This is a serious concern.

Figure 5 below shows the proposed DOE TSL-4 efficiencies for single and three phase transformers. TSL-4 diverges even further than TSL-2 and TSL-3 and is not viable for 3-Phase Transformers.

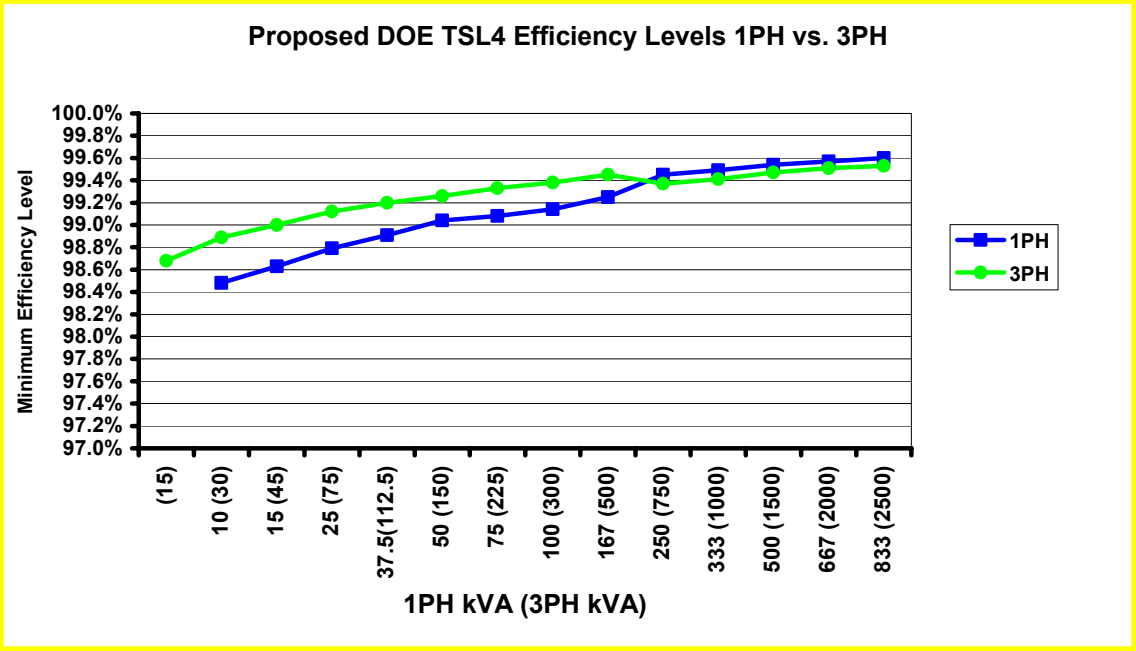

Figure 5 shows the greater divergence of 3-Phase transformer versus Single Phase for transformers under 750 kVA. These proposed efficiencies are nearly impossible to meet with conventional materials and would make such transformers prohibitively expensive to purchase.

Figure 6 below shows an examination of one major US manufacturer's 2006 production and the % of it that complies with each of the proposed DOE TSL-levels:

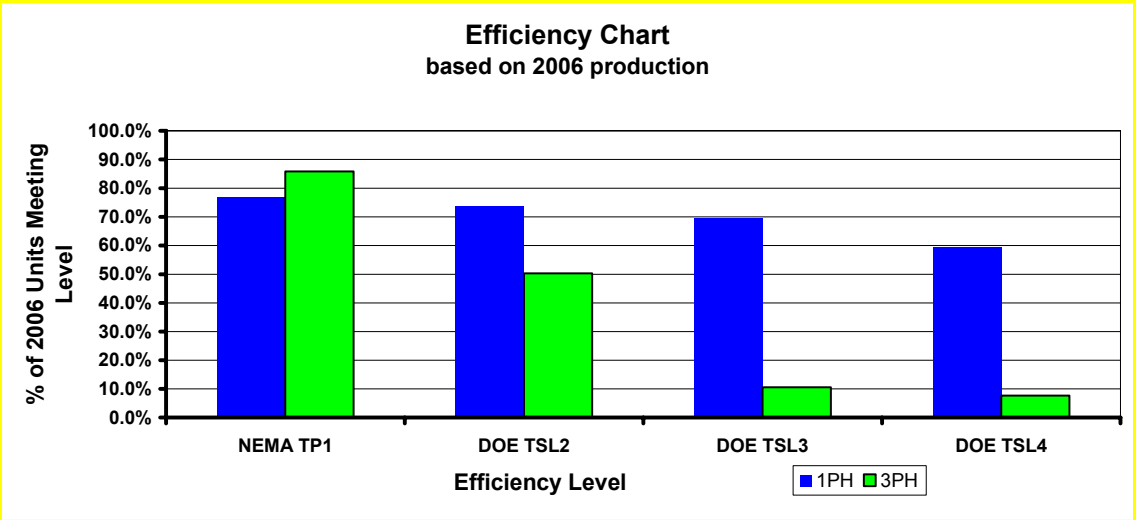

Figure 6 shows the % of 2006 production that complies with the proposed TSL-levels for single and three phase transformers. Note the divergence between single phase and three phase for efficiencies greater than TSL-1!

Figure 7 below shows the same data as in figure 6 but with a hypothetical red plot of three phase production if the efficiencies for the three phase kVA's below 750 are made to equal the single phase equivalent kVA efficiencies:

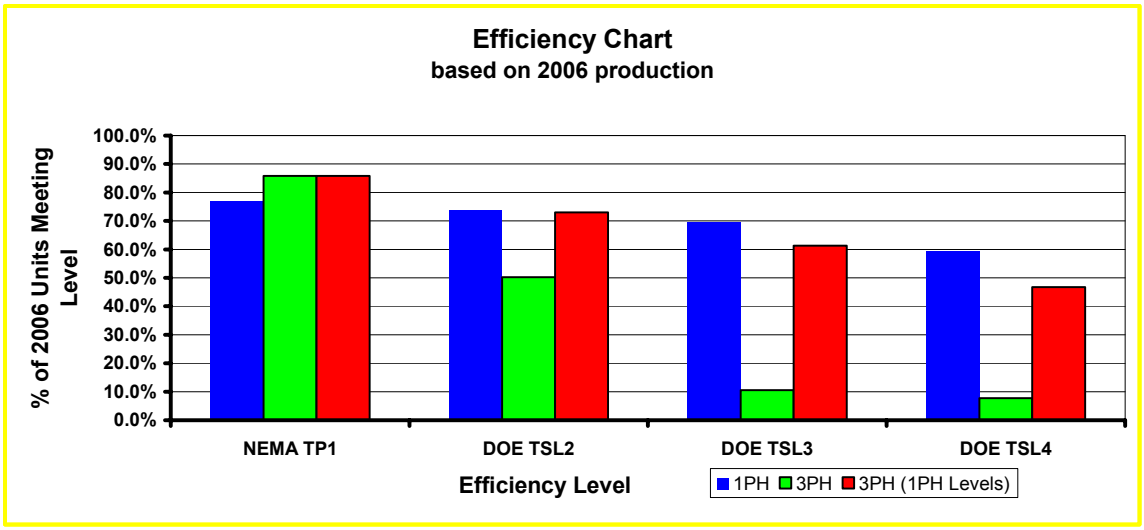

Figure 7 shows the % of 2006 production that complies with the proposed TSL-levels for single and three phase transformers along with a hypothetical red bar that shows what the three phase compliance would be if three phase efficiencies for kVA's under 750 are made equal to the single phase equivalents.

Summary of comments by stakeholders

On March 21, I visited Washington DC and collected all of the stakeholder comments that have been submitted to the DOE. Manufacturers who have studied the proposed 3-phase standards in detail have expressed concerns about the relationships to single phase as well as in their ability to meet the proposed DOE standards. However there is also clearly a large group of stakeholders who desire that TSL-4 be implemented across the board. Some of these stakeholders are from large Electric Utilities, some from Environmental Groups, and a few manufacturers. However, it is my opinion that those asking for TSL-4 for 3-phase Liquid Filled Transformers do not yet comprehend the enormity of their request. Stated bluntly, it is a standard that can not be met by American Industry as it now stands and should not be selected.

As Chair of the Energy Efficiency Task Force within the Distribution Transformer Subcommittee of the IEEE Transformers Committee, I urge the DOE to not implement TSL-2, TSL-3, or TSL-4 for 3-phase liquid filled transformers as the standard now stands.

Options for consideration

Several options seem to be viable to address the problems

1. Redefine the TSL-2, TSL-3, and TSL-4 three-phase tables for power ratings less than 750 and align the efficiencies with the single phase equivalents. This could well solve the problem of stakeholders wanting TSL-4 but manufacturers unable to provide it.
2. Keep the existing tables, label them as obsolete and having errors, and create new tables for TSL-2, TSL-3, and TSL-4 with the proper relationships for single and three phase transformers. This addresses the concern that people may have old copies of the tables and become confused in meeting the intended requirements.

3. Select NEMA TP-1. This is technically reasonable but is likely to draw criticism from those who want to have TSL-4.

Recommendation s

I strongly recommend that you select one of the 3 options above and correct the 3-phase efficiencies for power ratings less than 750 kVA in TSL-2, TSL-3, and TSL-4 tables to align with the single phase equivalents. Anything other than this action will be chaotic for the United States Distribution Transformer Industry and result in significant shifts in Market Applications.

Discussion:

One of my considerations has been the Dry Type product standards. At all power ratings, DOE has proper aligned the single and three phase efficiencies. It is important to maintain the proper balance between all product offerings and to not unfairly bias any one of them. This consideration will keep the proper relationships in place.

Hopefully, the issues are clearly defined to help you with your considerations. Please let me know where additional information may be needed.

Very truly yours,

Philip J Hopkinson, PE
President & CEO HVolt Inc