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To: DOE Stakeholders for
Distribution Transformer
Energy Efficiency Determination

Subject: DOE DEL Analysis

Dear Stakeholder:

This analysis of the DOE Distribution Transformer Energy Efficiency publications was prompted by the interest of a number of Stakeholders who have requested that I provide insight. My objective is to provide unfiltered accurate analysis and recommendations based on selling prices to the end users as a function of various efficiencies higher than the required efficiency of 2010. It is my suspect that a multiplicity of stakeholders may find this analysis and report to be useful. I will post a word version on my IEEE Transformers Committee DOE Energy Efficiency website for all interested parties to access. The following topics will be addressed:

1. Introduction
2. Objectives
3. Scope
4. Assumptions
5. Present Worth Value of a watt saved in an inflationary economy
6. Summary of results of analysis
   a. Single Phase Pads
   b. Single Phase Poles
   c. Small Three Phase Pads
   d. Large Three Phase Pads
   e. Medium Voltage Dry Types
7. Target efficiencies based on economics
8. Conclusions
9. Discussion
10. Recommendations

A. Introduction

In 2007, I was elected to be Chairman of an IEEE Transformers Committee Task Force to address Stakeholders' concerns and issues with current and proposed changes to the Department Of Energy (DOE) regulations for Distribution Transformer Energy Efficiency. A very large task force now meets regularly at each of the IEEE Transformers Committee Meetings. This task force now has about 100 members and is composed of manufacturers, users and other interested parties. Data is regularly accumulated, analyzed and reported at each meeting with minutes and presentations posted on the IEEE Transformers Committee's site at www.transformerscommittee.org , Distribution Transformers Subcommittee, Task Force for Review of DOE Energy Efficiency Proposals.

A common concern that has been expressed by the manufacturers that certain proposed designs are so difficult to achieve with conventional materials that no buildable combinations of materials can be found by their exhaustive search computer programs that are designed to consider all combinations of materials and flux and current densities. Therefore, it has been their contention that there must be a problem in the DOE analytic tools that produced the DOE efficiency levels. The manufacturers, both NEMA and Non-NEMA have asked me to get involved to try to understand where the problems were rooted.

In 2010, I was retained by Navigant Consulting with to assist their activities with Market Analysis and Design verification. This gave me a good opportunity to examine some of the design data that had been collected by their consultant, Optimized Program Services.

The OPS design data base is immense and has been collected over an extended period of years. It is not possible to determine accuracy of the OPS data by looking at the computed selling prices versus efficiencies since there a large quantity of variables that are involved in the computations. The only practical way to examine the data is to take selected ratings and produce new designs by sufficient numbers of manufacturers, both small and large, who are in the industry and to compare the results of their computations with those of OPS.

In comparing designs, I have developed a comprehensive spreadsheet that displays more than 30 parameters including DOE efficiencies, Selling prices, material types, weights, costs, sizes and performance information in sufficient detail to be credible. Individual manufacturer inputs are not displayed but the averages of their designs are placed side by side with the OPS derived data. This data comparison has allowed a determination of likely errors in OPS but more importantly has allowed the determination of incremental costs to the end user of higher proposed efficiencies as well as the watts saved at the RMS equivalent lad of 50% of nameplate. This should be an accurate depiction of the incremental dollars/per watt for each incremental efficiency level under consideration and lead to a quick determination of potential energy savings for the respective efficiency increments under consideration.

My close working relationship with the Navigant team, members of OPS, the core steel manufacturers, makers of conductors, various user groups and the many manufacturers both NEMA and Non-NEMA have allowed this report to take on accuracy and significance for the stakeholders who will be trying to select future energy efficiency levels based on reality and economic justification.

I am not a stakeholder but will gladly participate where needed to be sure that the findings in this report are understood by those who will be selecting the next round of energy efficiencies for Medium Voltage Distribution Transformers. Regardless of the efficiency levels that are selected and of any predisposed positions of any of the stakeholders, this attempt to display factual information should prove useful to the team.

B. Objectives:

1. Determine Cost-Based Selling Prices for select Design Lines by the transformer manufacturers versus DOE efficiencies when constrained to use M3 Core Steel, Aluminum Primary Conductors and Aluminum Secondary Conductors. These materials were selected to be sure that buildable designs with the most abundant low cost materials would be a part of the analysis.
2. Compare the manufacturers' costs and selling prices versus the OPS Generated Designs.
3. Determine causes of cost differences of the manufacturers versus OPS
4. Determine the present worth of a watt saved.
5. Provide Guidance and recommendations to the DOE Energy Efficiency Stakeholders.

C. Scope

1. **1.** Single Phase Pad mounted Transformers in Design Line 1 represented by the 50 kVA rating at 14,400 volts primary and 240/120 Volt Secondary
2. **2.** Single Phase Pole Type Transformers in Design Line 2 represented by the 25 kVA rating at 14,400 volts primary and 120/240 Volt Secondary
3. **3.** Small (0-500 kVA) Three Phase Pad mounted Transformers in Design Line 4 represented by the 150 kVA rating with a 14,400 volt primary and a 208 Y/120 volt secondary.
4. **4.** Large Three Phase Pads from 750 kVA -2,500 kVA, in Design Line 5 represented by the 1500 kVA rating with a 24,940 GrY /14,400 volt Primary and a 480 Y/277 Volt Secondary.
5. **5.** Medium Voltage Dry Type Transformers from 750 kVA to 2,500 kVA from Design Line 12 represented by the 1,500 kVA rating with a 12,470 GrY /7,200 Volt Primary and a 480 Y/277 Volt Secondary.

D. Assumptions

1. Manufacturers participating in the summary of designs were selected to be sure that small as well as large manufacturers were included, both NEMA and Non-NEMA members, representative of the industry.
2. Material prices in the manufacturer-produced designs are at 2011 values.
3. Baseline manufacturer material costs and selling prices were developed starting with relationships for designs close to 2010 minimum efficiencies.
4. Selling prices for higher efficiencies were derived from the relationship of a constant Selling price to material basis.
5. Selling prices were developed to reflect the selling price to the end user of each type of transformer.
6. M3 core material and aluminum conductor were generally used to determine the upper limits of efficiency that a manufacturer could be requested to achieve. This constraint does not prevent a manufacturer from choosing a better core material or from using copper conductor bur rather assures that the maximum flexibility in design options are available to the industry.
7. The average selling prices of the participating manufacturers were used as the basis for determining the incremental impact on selling price that the end user would see for each proposed increase in efficiency.
8. An assumed economic life of 30 years was applied to determine the present worth value of a watt saved.
9. Present worth values for watts saved are determined assuming 3% rate of inflation, 7% cost of funds, virtually no load growth, and a 30 year economic life.
10. Incremental Transformer Selling Prices / Incremental watts saved are the incremental costs of such incremental change in efficiency.
11. Any incremental increases in selling prices for any of the proposed new efficiencies that are less than the present worth value of a watt saved are worthy of consideration.
12. Any incremental increases in selling prices for any of the proposed new efficiencies that are more costly than the value of a watt saved are not economically justifiable and do not pass the economics test.

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E. Present Worth Value of a watt saved in an inflationary economy:

One watt for all 8760 hours per calendar years will consume 8.76 kwh. The cost of operating that watt of loss is quite different depending on the nature of the user. The Energy Information Administration (EIA) has suggested that the average cost of energy at retail in the United States is about $0.12/kWH in 2009. They also show wholesale cost at between $0.04 to $0.05andkWH and Industrial power cost averaging $0.067/kWH for contracts as recently as September of 2011. Clearly the cost of power varies considerably across the country but the residential average of $0.12/kWH is reasonable and is the average rate that each household pays to their electric company. The cost to the types of users of interest in this report are as follows:

1. Electric Utilities costs for generation, transmission and distribution down to the distribution transformer are assumed to be equal to the wholesale price of power and are valued at $0.045/kWH. Hence, on a yearly basis, one watt of power for all 8,760 hours per year will cost the utility $0.045/kWH *8.76 kHrs/yr = $0.394/watt. (1)
2. Industrial and large Commercial users costs for power are identified as $0.067/kwh. Here the annual cost of a watt = $0.067/kWH *8.76 =$0.587/watt. (2)

. Another interesting consideration is the relationship between three groups of power users; the electric utilities themselves, commercial and industrial users and residential Users. Electric Utilities with their own generating plants have the lowest delivered cost of energy and may average out at $0.08/kWH. Commercial and Industrial users with their own transformers may average out at $0.10/kWH after demand and usage charges are added in. Now we must address the type of user of the transformer. A few years back, it could be said that 35% of the electric power was consumed by residential consumers and 65% by commercial or industrial users. However, the most important first consideration is for who owns the transformers and pays the bills. The following is my best estimate of ownership:

1. Single Phase Pad mounted Transformers, signified by Design Line 1 are almost 100% owned by Electric Utilities.
2. Single Phase Poles, signified by Design Line 2 are almost 100% Electric Utilities
3. Small Three Phase Pads, signified by Design Line 4 (150 kVA representing 0-500 kVA) are about 75% owned by Electric Utilities and the remaining 25% by Commercial or Industrial Users.
4. Large Three Phase transformers signified by Design Line 5 (1500 kVA representing 750 kVA-2500 kVA) are 50% owned by Commercial and Industrial users.
5. Medium Voltage Dry Type Transformers are nearly 100% owned by Commercial or Industrial Users.

For both types of transformers the desire is that they be amortized over a 30 year period. There is considerable uncertainty about economics between now and 30 years out but reasonable assumptions would be the following:

1. The rate of annual inflation will average 3%/year.
2. The cost of borrowed money will average out at 7%/year.
3. Load growth is low and perhaps at 0%

In order to determine the present worth value of a watt saved over a 30 year period, we must use the present worth of an inflation series as:

USPWF = (((1+i)^n-(1+r)^n*(1+g)^2n)/(1+i)^n) *(1/((1+i)-(1+r)*(1+g)^2) (3)

Here:

USPWF = the Uniform Series Present Worth Factor (4)

I = the interest rate in per unit = 0.07 ` (5)

a = the inflation rate in per unit =0.03 (6)

g = the per unit load growth rate per year = 0 (7)

n = the number of years = 30 (8)

From these relationships, USPWF =17.0284 (9)

Now with the annual cost of energy and the Uniform Series Present Worth Factor, we can compute the present worth value of a watt saved for either type of user as:

1. For Utility transformers =$0.394/watt year * 17.03 year value = $6.71/watt. (10)
2. For Commercial/Industrial =$0.587/watt * 17.0284 year value =$9.91/watt (11)

These relationships define the present worth of one watt of energy saved in the as-purchased transformer when measured at the RMS equivalent load that will be applied to the transformer. Since the RMS equivalent load is defined as 50% of nameplate load then the total watts consumed by the transformer are approximately 100% of the core loss and 25% of the full load loss. Other factors may be added to change the calculations and in fact the variables of inflation, cost of money, and years of economic life can easily be adjusted if more appropriate relationships are found by the team.

The purchase relationship in such transformers where A is the value of core loss and B is the value of load loss will be as follows:

1. For Utility owned transformers:
   a. A = value of Core Loss = $6.71/watt. (12)
   b. B = value of Load Loss = $6.71/4 = $1.68/watt (13)
2. For Commercial or Industrial transformers
   a. A = value of Core Loss = $9.91/watt (14)
   b. B = value of Load Loss = $9.91/4 = $2.48/watt (15)

Discussion of this derivation.

This is a reasonable starting point for consideration of design options. However other values of losses may also have relevance attributed to the following:

1. Geographical differences in the country will have a large bearing on the cost of electricity, with some being significantly lower than the assumption and some higher.
2. Inflation rates. High inflation will result in a higher value of a watt saved while low inflation will reduce the value.

3. Load growth rate. No appreciable load growth was assumed since that has been the trend for the last decade. However, if plug-in electric vehicles or other high energy use devices are planned then the expression in equation (5) may need to be revisited. We assume that a transformer has 50% RMS equivalent load on it as a start. A 1% load growth would add 35% more load and bring the RMS equivalent up from 50% of nameplate to nearly 70% of nameplate over its expected 30 year life.
4. Economic life of 30 years. This is longer than the IEEE insulation life presumption of 20.5 years but is consistent with the US Electric Utility ownership experience. Longer time considerations than 30 years will generally increase the value of a watt saved while shorter economic life will bring it down.
5. An overall value of watt saved sensitivity analysis may be worthy of exploration by the stakeholders and should be mathematically possible using equation (5).

F. Summary Of Results

Design Line 1 Single Phase Pads The figure below shows the results of the cost study for Design Line 1 Single Phase Pads:

Design Line	**Design Line 1**		**Single Phase Padmounted Transformer**			
kVA	**50**	**kVA**	**14,400 Volts:208Y/120**			
Selling Prices, Costs, and Efficiencies as seen by the Manufacturers in 2011 with M3, Al, Al						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.5
Incremental Efficiency		0.08	0.06	0.03	0.06	0.19
Watts saved		20	15	7.5	15	47.5
Selling Price	$ 1,800.00	$ 2,200.00	$ 2,650.00	$ 3,050.00		
Incremental Selling Price		$ 400.00	$ 450.00	$ 400.00		
Incremental $/Watt Cost to End User		**$ 20.00**	**$ 30.00**	**$ 53.33**		
Selling Prices, Costs, and Efficiencies by the DOE (OPS 1) in Preliminary Analysis with M3, Al, Al						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.5
Incremental Efficiency		0.08	0.06	0.03	0.06	0.19
Watts saved		20	15	7.5	15	47.5
Selling Price	$ 1,817.00	$ 2,036.00	$ 2,400.00	$ 2,650.00		
Incremental Selling Price		$ 219.00	$ 364.00	$ 250.00		
Incremental $/Watt Cost to End User		**$ 10.95**	**$ 24.27**	**$ 33.33**		
Selling Prices, Costs, and Efficiencies as seen by OPS 2 (DOE September) M3 Steel, Al, Al						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.5
Incremental Efficiency		0.08	0.06	0.03	0.06	0.19
Watts saved		20	15	7.5	15	47.5
Selling Price	$ 1,971.00	$ 2,178.00	$ 2,714.00			
Incremental Selling Price		$ 207.00	$ 536.00			
Incremental $/Watt Cost to End User		**$ 10.35**	**$ 35.73**			
OPS2 Data with ZDMH Materials						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.15	99.22	99.25	99.31	99.5
Incremental Efficiency		0.07	0.07	0.03	0.06	0.19
Watts saved		17.5	17.5	7.5	15	47.5
Selling Price	$ 1,997.00	$ 2,192.00	$ 2,485.00	$ 2,836.00		
Incremental Selling Price		$ 195.00	$ 293.00	$ 351.00		
Incremental $/Watt Cost to End User		**$ 11.14**	**$ 16.74**	**$ 46.80**		
Present Worth of Watt saved		**$6.71**	**$6.71**	**$6.71**	**$6.71**	**$6.71**

Figure 1a shows the summary of Selling Prices versus Efficiency for Design Line 1

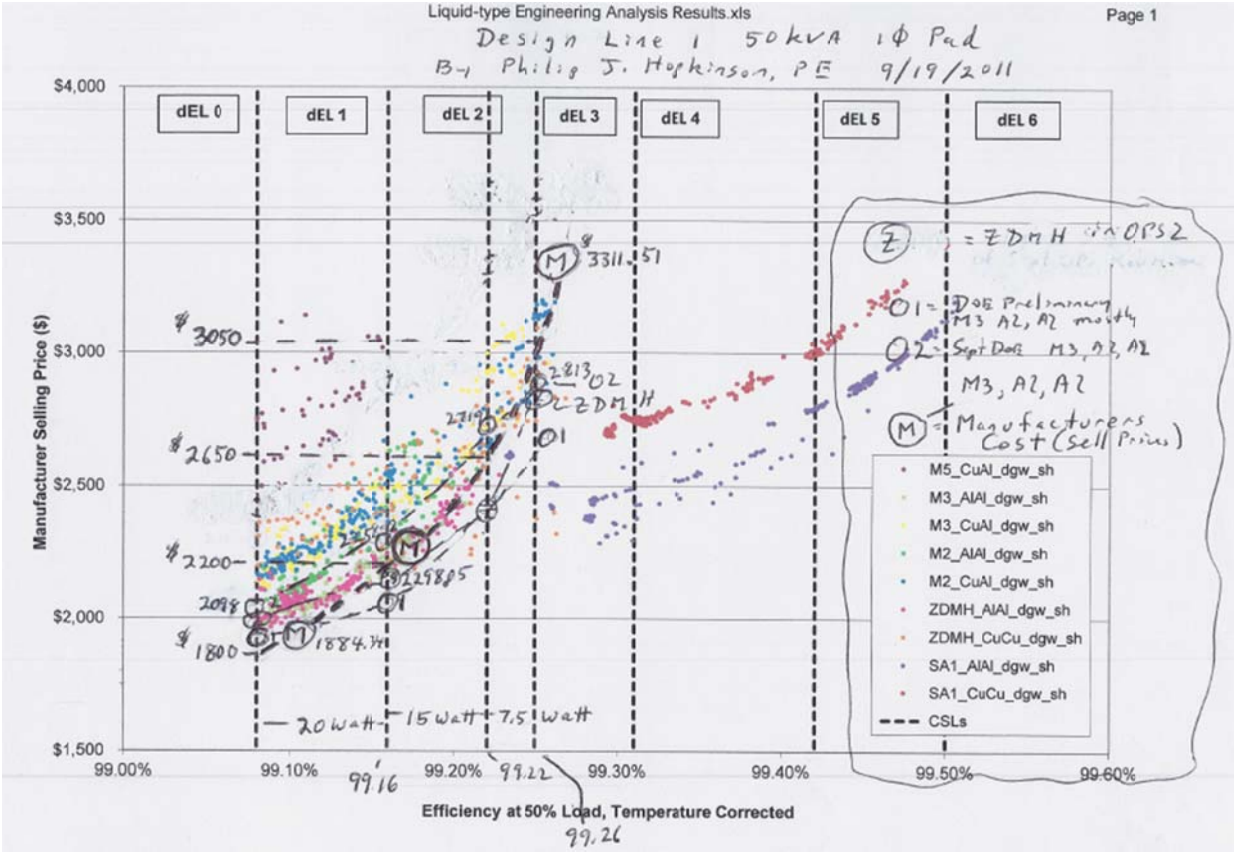

Figure 1b shows the summary of Selling Prices versus Efficiency for Design Line 1

i. M is the Manufacturers' Average Selling Prices to the end Customer versus DOE Efficiency Level, using M3, Al, Al.
ii. 01 is the OPS Generated data from the DOE Preliminary Analysis in March, 2011, using M3, Al, Al.
iii. 02 is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using M2, Al, Al.
iv. Z is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using ZDMH, Al, Al and or Copper.

Figure 1c below shows the design summary data as follows:

i. The Manufacturers' data is the averages of all of the submitted manufacturers' data.
ii. The OPS designs were from the OPS 1 Preliminary Analysis vintage.
iii. M3, Al, Al were intended to be compared but some designs required higher performing steels and / or copper conductors

Design Line 1: 50 kVA Single Phase Pad

50 kVA Design Line 1, design option ID1: 14.4 kV: 240/120 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.08	99.10
Selling Price	$ 1,817.05	$ 1,884.34
Core Loss @20 C	97.9	92.8
Load Loss at full load @ 85C	584.2	586.7
Total Weight, lbs.	684.0	900.3
Core Material	M3	M3
Core Weight, Lbs	258.5	243.5
Low Voltage Material	Al	AL
High Voltage Material	Al	AL
LV Weight, Lbs.	37.6	41.1
HV Weight, Lbs.	40	38.9
Gallons of oil	21.9	41.3
Primary Insulation, Lbs.	4.28	7.7
Secondary insulation, Lbs.	1.52	2.0
Core Material Cost, $	$ 484.63	$ 473.12
LV Material Cost, $	$ 58.88	$ 71.60
HV Material Cost, $	$ 145.98	$ 124.48
Primary Insulation Cost, $	$ 6.49	$ 16.00
Secondary Insulation Cost, $	$ 2.75	$ 4.29
Oil Cost, $	$ 73.21	$ 138.68
Tank Cost, $	$ 142.74	$ 235.91
All Other Material	$ 67.11	$ 104.12
Core and Coil Cost, $	$ 698.73	$ 689.49
Tank , Oil, & Other Cost, $	$ 283.06	$ 423.01
Total Material Cost	$ 981.79	$ 1,133.10
Tank Width	35.0	34.3
Tank Depth	35.0	35.3
Tank Height	24.0	25.8
A factor	$ 6.50	$ 6.50
B factor	$ 1.20	$ 1.20
Total Owning Cost	$ 3,154.46	$ 3,191.65
Core Watts/lB	0.379	0.381

50 kVA Design Line 1, design option ID3; 14.4 kV: 240/120 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.16	99.17
Selling Price	$ 2,036.37	$ 2,298.05
Core Loss	109.5	92.0
Load Loss at full load	445.8	512.1
Total Weight, lbs.	626.0	1004.7
Core Material	ZDMH	M3
Core Weight, Lbs.	232.3	264.4
Low Voltage Material	CU	AL
High Voltage Material	CU	AL
LV Weight, Lbs.	48.98	58.658
HV Weight, Lbs.	52.64	49.240
Gallons of oil	15.79	46.285
Primary Insulation, Lbs.	2.55	7.593
Secondary insulation, Lbs.	1.06	1.990
Core Material Cost, $	$ 476.22	$ 536.53
LV Material Cost, $	$ 208.32	$ 191.62
HV Material Cost, $	$ 207.58	$ 208.03
Primary Insulation Cost, $	$ 3.86	$ 15.44
Secondary Insulation Cost, $	$ 1.60	$ 3.39
Oil Cost, $	$ 52.92	$ 154.04
Tank Cost, $	$ 139.13	$ 266.76
All Other Material	$ 69.00	$ 104.02
Core and Coil Cost, $	$ 897.58	$ 956.01
Tank , Oil, & Other Cost, $	$ 261.05	$ 469.61
Total Material Cost	$ 1,158.63	$ 1,430.07
Tank Width	35.0	35.1
Tank Depth	32.0	36.5
Tank Height	24.0	26.3
A factor	$ 9.00	$ 9.00
B factor	$ 2.72	$ 2.72
	$ 4,234.34	$ 4,518.60
Core Watts/lB	0.471	0.348

50 kVA Design Line 1, design option CSL2 14.4 kV:240/120 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.26	99.26
Selling Price	$ 2,709.32	$ 3,311.51
Core Loss	108.8	91.7
Load Loss at full load	306.8	414.7
Total Weight, lbs.	883.0	1116.2
Core Material	M3	M3
Core Weight, Lbs.	333.0	282.9
Low Voltage Material	AL	CU
High Voltage Material	CU	CU
LV Weight, Lbs.	58	95.7
HV Weight, Lbs.	124	85.4
Gallons of oil	24.65	48.0
Primary Insulation, Lbs.	4.31	8.7
Secondary insulation, Lbs.	1.94	2.2
Core Material Cost, $	$ 624.38	$ 550.46
LV Material Cost, $	$ 90.36	$ 420.53
HV Material Cost, $	$ 539.05	$ 541.84
Primary Insulation Cost, $	$ 6.54	$ 17.08
Secondary Insulation Cost, $	$ 2.94	$ 3.12
Oil Cost, $	$ 82.60	$ 147.24
Tank Cost, $	$ 142.74	$ 264.25
All Other Material	$ 72.85	$ 104.12
Core and Coil Cost, $	$ 1,263.27	$ 1,585.62
Tank , Oil, & Other Cost, $	$ 298.19	$ 460.69
Total Material Cost	$ 1,561.46	$ 1,951.41
Tank Width	35.0	34.3
Tank Depth	35.0	36.9
Tank Height	24.0	26.3
A factor	$ 15.00	$ 15.00
B factor	$ 5.50	$ 5.50
	$ 6,028.72	$ 6,967.13
Core Watts/lB	0.327	0.324

Note: All other material includes core clamp, bushings, decals, leads, pallets, shipping materials, scrap, unapplied matrerials and standard accessories

Figure 1c shows Design Line 1 Comparisons between Manufacturers and OPS 1.

Conclusions for Design Line 1, represented by 50 kVA Single Phase Pad with primary Coil Voltage 14,400 (2 bushing) and low voltage 240 / 120 Volts:

i. Manufacturers had higher material costs than OPS1.
ii. Oil Gallons in OPS1 were in error and under-calculated.
iii. Total Weights of transformers in OPS 1 were under-calculated and in error.
iv. Tank cost in OPS1 was under-calculated.
v. All other material in OPS 1 was under-calculated.
vi. Manufacturers' selling prices for base case were at market levels.
vii. Manufacturers' selling prices to material cost were kept constant at base case ratios.
viii. OPS2 is OPS1 revised. However revisions are not explained.
ix. OPS2 data is extracted from the engineering analysis from August 31 with M3, Al, Al the base case.
x. A ZDMH alternative by OPS2 is shown that shows the calculated data by OPS (August 31) for a ZDMH alternative.
xi. Cost/watt saved Design Efficiency levels lower than the present worth values/watt are worthy of consideration as they return investment in less than 30 years.
xii. Cost/watt saved Design Efficiency levels greater than the present worth values/watt are not economical unless there are other considerations.

Design Line 2 Single Phase Poles

Design Line	Design Line 2		Single Phase Pole Mounted Transformer		
kVA	25	kVA	14,400 Volts:208Y/120		
Selling Prices, Costs, and Efficiencies as seen by the Manufacturers in 2011 with M3					
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	98.9	99.00	99.06	99.13	99.18	99.46
Incremental Efficiency		0.1	0.06	0.07	0.05	0.28
Watts saved		12.5	7.5	8.75	6.25	35
Selling Price	$ 1,031.00	$ 1,200.00	$ 1,400.00	$ 1,815.00		
Incremental Selling Price		$ 169.00	$ 200.00	$ 415.00		
Incremental $/Watt Cost to End User		**$ 13.52**	**$ 26.67**	**$ 47.43**		
Selling Prices, Costs, and Efficiencies as seen by the DOE (OPS 1) in Preliminary Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	98.9	99.00	99.06	99.13	99.18	99.46
Incremental Efficiency		0.1	0.06	0.07	0.05	0.28
Watts saved		12.5	7.5	8.75	6.25	35
Selling Price	$ 1,213.77	$ 1,566.00	$ 1,650.00	$ 1,706.00		
Incremental Selling Price		$ 352.23	$ 84.00	$ 56.00		
Incremental $/Watt Cost to End User		**$ 28.18**	**$ 11.20**	**$ 6.40**		
Selling Prices, Costs, and Efficiencies as seen by OPS 2 in DOE September Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	98.9	99.00	99.06	99.13	99.18	99.46
Incremental Efficiency		0.1	0.06	0.07	0.05	0.28
Watts saved		12.5	7.5	8.75	6.25	35
Selling Price	$ 1,334.00	$ 1,582.00	$ 1,759.00			
Incremental Selling Price		$ 248.00	$ 177.00			
Incremental $/Watt Cost to End User		**$ 19.84**	**$ 23.60**			
OPS2 with ZDMH						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	98.9	99.00	99.06	99.13	99.18	99.46
Incremental Efficiency		0.1	0.06	0.07	0.05	0.28
Watts saved		12.5	7.5	8.75	6.25	35
Selling Price	$ 997.00	$ 1,100.00	$ 1,200.00	$ 1,400.00		
Incremental Selling Price		$ 103.00	$ 100.00	$ 200.00		
Incremental $/Watt Cost to End User		**$ 8.24**	**$ 13.33**	**$ 22.86**		
Present Worth of Watt saved		**$6.71**	**$11.93**	**$11.93**	**$11.93**	**$11.93**

Figure 2a shows the summary of Selling Prices versus Efficiency for Design Line 2

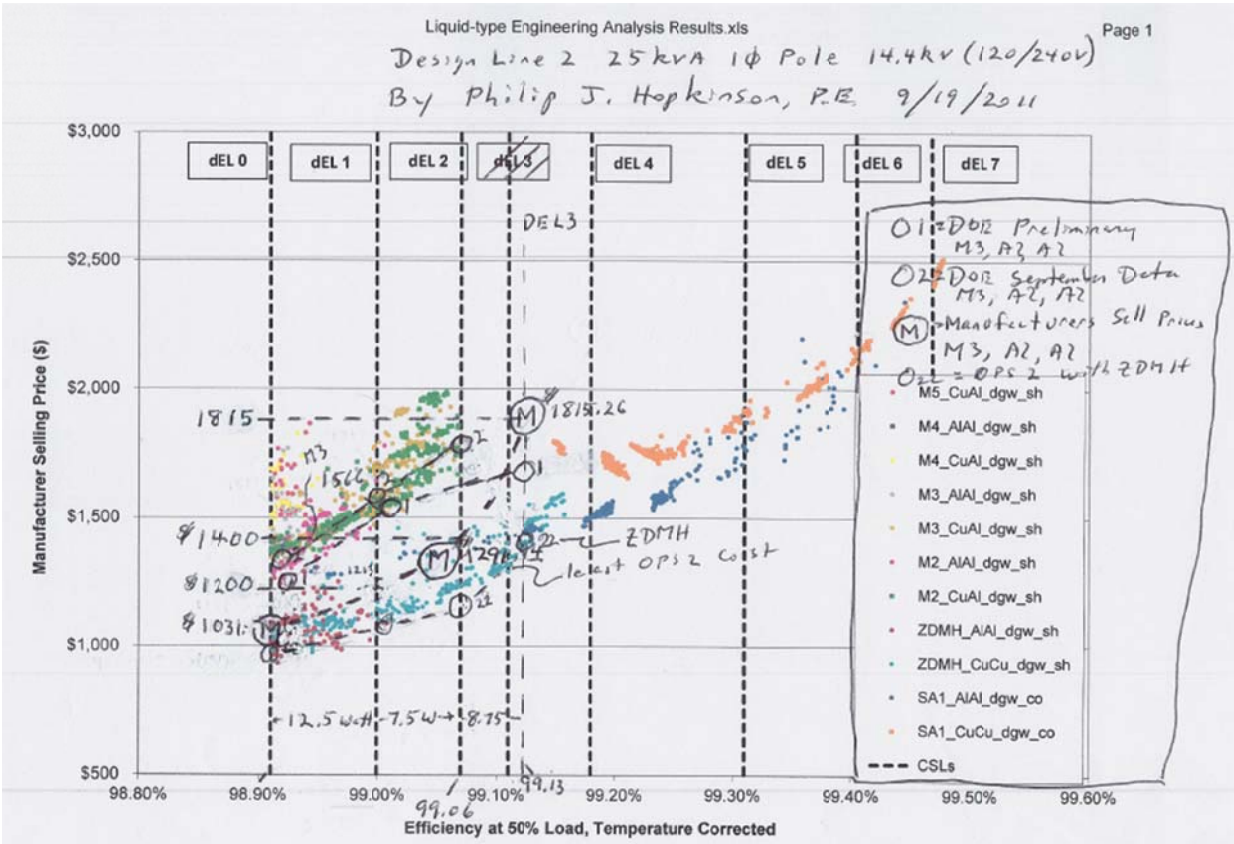

Figure 2b shows the summary of Selling Prices versus Efficiency for Design Line 2

v. M is the Manufacturers' Average Selling Prices to the end Customer versus DOE Efficiency Level, using M3, Al, Al.
vi. 01 is the OPS Generated data from the DOE Preliminary Analysis in March, 2011, using M3, Al, Al.
vii. 02 is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using M2, Al, Al.
viii. Z is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using ZDMH, Al, Al and or Copper.

Design Line 2: 25 kVA Single Phase Pole

25 kVA Design Line 2, design option ID1: 14.4 kV: 120/240 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	98.92	98.90
Selling Price	$ 1,213.77	$ 1,031.85
Core Loss @20 C	74.2	64.9
Load Loss at full load @ 85C	249.4	323.7
Total Weight, lbs.	437.0	424.6
Core Material	ZDMH	M3
Core Weight, Lbs	190.6	167.9
Low Voltage Material	Al	AL
High Voltage Material	Al	AL
LV Weight, Lbs.	19.0	26.0
HV Weight, Lbs.	20.2	25.5
Gallons of oil	18.0	13.7
Primary Insulation, Lbs.	3.8	6.0
Secondary insulation, Lbs.	1.5	1.8
Core Material Cost, $	$ 390.69	$ 199.43
LV Material Cost, $	$ 29.80	$ 31.69
HV Material Cost, $	$ 73.69	$ 44.45
Primary Insulation Cost, $	$ 5.71	$ 11.03
Secondary Insulation Cost, $	$ 2.30	$ 2.67
Oil Cost, $	$ 62.78	$ 43.62
Tank Cost, $	$ 72.81	$ 68.25
All Other Material	$ 38.60	$ 50.25
Core and Coil Cost, $	$ 502.19	$ 456.68
Tank , Oil, & Other Cost, $	$ 174.19	$ 104.05
Total Material Cost	$ 676.38	$ 550.78
Tank Diameter, in	19	16.8
Tank Height	24	24.9
A factor	$ 4.00	$ 4.00
B factor	$ 2.40	$ 2.40
TOC	$ 2,109.35	$ 2,068.23
Core Watts/lB	**0.389**	**0.386**

25 kVA Design Line 2, design option CSL1: 14.4 kV 120/240 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.02	99.06
Selling Price	$ 1,566.93	$ 1,291.94
Core Loss	78.9	59.4
Load Loss at full load	175.7	255.3
Total Weight, lbs.	625.2	495.6
Core Material	M3	M3
Core Weight, Lbs.	278.9	192.8
Low Voltage Material	AL	AL
High Voltage Material	AL	AL
LV Weight, Lbs.	29.5	31.5
HV Weight, Lbs.	30.4	47.1
Gallons of oil	24.2	16.0
Primary Insulation, Lbs.	4.5	6.3
Secondary insulation, Lbs.	1.8	2.0
Core Material Cost, $	$ 522.84	$ 431.85
LV Material Cost, $	$ 46.13	$ 49.83
HV Material Cost, $	$ 110.73	$ 221.63
Primary Insulation Cost, $	$ 6.86	$ 13.31
Secondary Insulation Cost, $	$ 2.68	$ 3.61
Oil Cost, $	$ 91.09	$ 72.98
Tank Cost, $	$ 72.56	$ 75.25
All Other Material	$ 40.59	$ 50.25
Core and Coil Cost, $	$ 689.25	$ 711.67
Tank , Oil, & Other Cost, $	$ 204.24	$ 119.63
Total Material Cost	$ 893.49	$ 777.29
Tank Diameter, in	22	17.6
Tank Height	25	26.9
A factor	$ 13.00	$ 13.00
B factor	$ 6.00	$ 6.00
TOC	$ 3,647.10	$ 3,595.44
Core Watts/lB	**0.283**	**0.308**

25 kVA Design Line 2, design option CSL2: 14.4 kV: 120/240 V		
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.13	99.13
Selling Price	$ 1,706.06	$ 1,815.26
Core Loss	60.9	61.2
Load Loss at full load	190.3	205.9
Total Weight, lbs.	512.2	638.0
Core Material	ZDMH	M3
Core Weight, Lbs.	205.8	216.0
Low Voltage Material	CU	AL
High Voltage Material	CU	CU
LV Weight, Lbs.	49.4	69.6
HV Weight, Lbs.	53.4	62.8
Gallons of oil	16.9	21.8
Primary Insulation, Lbs.	3.4	6.2
Secondary insulation, Lbs.	1.33	2.7
Core Material Cost, $	$ 421.93	$ 439.36
LV Material Cost, $	$ 208.67	$ 276.39
HV Material Cost, $	$ 210.61	$ 340.22
Primary Insulation Cost, $	$ 5.09	$ 13.67
Secondary Insulation Cost, $	$ 2.01	$ 5.05
Oil Cost, $	$ 61.76	$ 93.50
Tank Cost, $	$ 72.56	$ 75.25
All Other Material	$ 42.00	$ 50.25
Core and Coil Cost, $	$ 848.31	$ 1,147.48
Tank , Oil, & Other Cost, $	$ 176.32	$ 139.51
Total Material Cost	$ 1,024.63	$ 1,166.16
Tank Diameter, in	19.0	18.3
Tank Height	23.00	27.4
A factor	$ 15.00	15
B factor	$ 5.50	5.5
TOC	$ 3,665.78	$ 3,866.08
Core Watts/lB	**0.296**	**0.283**

Note: All other material includes core clamp, bushings, decals, leads, pallets, shipping materials, scrap, unapplied matrerials and standard accessories

Figure 2c shows Design Line 2 Comparisons between Manufacturers and OPS 1.

Conclusions for Design Line 2, represented by 25 kVA Single Phase Poles with primary Coil Voltage 14,400 (2 bushing) and low voltage 120 / 240 Volts:

xiii. Manufacturers had higher commodity costs than OPS1 but lower total costs in most cases.

xiv. Oil Gallons in OPS1 were not in error for any of the round tank designs.

xv. Total Weights of transformers in OPS 1 were under-calculated and in error.

xvi. Tank cost in OPS1 was generally over-calculated.

xvii. All other material in OPS 1 was close to actual.

xviii. Manufacturers' selling prices for base case were at market levels.

xix. Manufacturers' selling prices to material cost were kept constant at base case ratios.

xx. OPS2 is OPS1 revised. However revisions are not explained.

xxi. OPS2 data is extracted from the engineering analysis from August 31 with M3, Al, Al the base case.

xxii. A ZDMH alternative by OPS2 is shown that shows the calculated data by OPS (August 31) for a ZDMH alternative.

xxiii. Cost/watt saved Design Efficiency levels lower than the present worth values/watt are worthy of consideration as they return investment in less than 30 years.

xxiv. Cost/watt saved Design Efficiency levels greater than the present worth values/watt are not economical unless there are other considerations.

Design Line 4 Small Three Phase Pads

Design Line	Design Line 4		Small Three Phase Padmounted Transformer			
kVA	150	kVA	14,400 Volts:208Y/120			
Selling Prices, Costs, and Efficiencies as seen by the Manufacturers in 2011 with M3						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.42
Incremental Efficiency		0.08	0.06	0.03	0.06	0.11
Watts saved		60	45	22.5	45	82.5
Selling Price	$ 6,200.00	$ 6,700.00	$ 7,300.00	$ 7,610.00	$ 9,900.00	$ 23,813.00
Incremental Selling Price		$ 500.00	$ 600.00	$ 310.00	$ 2,290.00	$ 13,913.00
Incremental $/Watt Cost to End User		$ 8.33	$ 13.33	$ 13.78	$ 50.89	$ 168.64
Selling Prices, Costs, and Efficiencies by the DOE (OPS 1) in Preliminary Analysis with M3						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.42
Incremental Efficiency		0.08	0.06	0.03	0.06	0.11
Watts saved		60	45	22.5	45	82.5
Selling Price	$ 4,861.00	$ 5,507.00	$ 6,628.00	$ 6,700.00	$ 7,100.00	$ 7,600.00
Incremental Selling Price		$ 646.00	$ 1,121.00	$ 72.00	$ 400.00	$ 500.00
Incremental $/Watt Cost to End User		$ 10.77	$ 24.91	$ 3.20	$ 8.89	$ 6.06
Selling Prices, Costs, and Efficiencies as seen by OPS 2 (DOE September) M3 Steel						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.42
Incremental Efficiency		0.08	0.06	0.03	0.06	0.11
Watts saved		60	45	22.5	45	82.5
Selling Price	$ 5,395.00	$ 6,426.00	$ 7,955.00			
Incremental Selling Price		$ 1,031.00	$ 1,529.00			
Incremental $/Watt Cost to End User		$ 17.18	$ 33.98	$ -	$ -	$ -
OPS2 with ZDMH						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.08	99.16	99.22	99.25	99.31	99.42
Incremental Efficiency		0.08	0.06	0.03	0.06	0.11
Watts saved		60	45	22.5	45	82.5
Selling Price	$ 5,395.00	$ 5,897.00	$ 6,700.00	$ 7,100.00	$ 8,200.00	$ 23,813.00
Incremental Selling Price		$ 502.00	$ 803.00	$ 400.00	$ 1,100.00	$ 15,613.00
Incremental $/Watt Cost to End User		$ 8.37	$ 17.84	$ 17.78	$ 24.44	$ 189.25
Present Worth of Watt saved		$6.71	$6.71	$6.71	$6.71	$6.71

Figure 3a shows the summary of Selling Prices versus Efficiency for Design Line 4

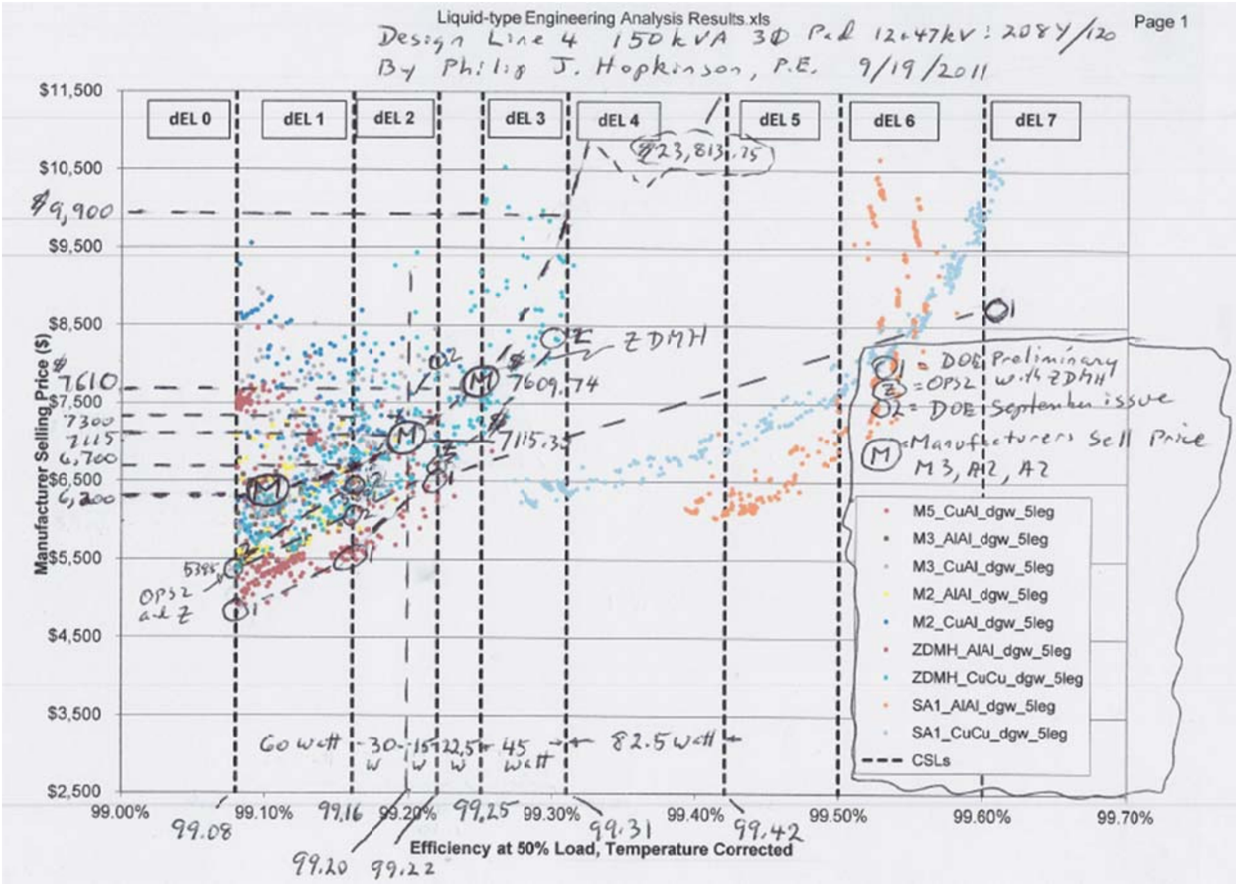

Figure 3b shows the summary of Selling Prices versus Efficiency for Design Line 4

ix. M is the Manufacturers' Average Selling Prices to the end Customer versus DOE Efficiency Level, using M3, Al, Al.
x. 01 is the OPS Generated data from the DOE Preliminary Analysis in March, 2011, using M3, Al, Al.
xi. 02 is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using M2, Al, Al.
xii. Z is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using ZDMH, Al, Al and or Copper.

Design Line 4 Small kVA Three Phase Pads

150 kVA Design Line 4	12470Y/7200: 208Y/120 V	
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.08	99.10
Selling Price	$ 4,861.16	$ 6,425.47
Core Loss @20 C	363.33	299.8
Load Loss at full load @ 85C	1410.60	1597.0
Total Weight, lbs.	1,743	2712.7
Core Material	M3	M3
Core Weight, Lbs	631	566.1
Low Voltage Material	AL	AL
High Voltage Material	CU	AL
LV Weight, Lbs.	60	104.5
HV Weight, Lbs.	233	120.9
Gallons of oil	41.79	130.0
Primary Insulation, Lbs.	6.30	15.6
Secondary insulation, Lbs.	6.82	14.4
Core Material Cost, $	1183.24	$ 979.34
LV Material Cost, $	95.23	$ 185.69
HV Material Cost, $	920.02	$ 294.30
Primary Insulation Cost, $	9.55	$ 20.71
Secondary Insulation Cost, $	10.34	$ 18.72
Oil Cost, $	140.02	$ 549.19
Tank Cost, $	387.37	$ 629.90
All Other Material	144.4	$ 665.70
Core and Coil Cost, $	$ 2,218.37	$ 1,485.61
Tank , Oil, & Other Cost, $	$ 671.74	$ 1,844.79
Total Material Cost	$ 2,890.11	$ 3,330.40
Tank Width	57	45.0
Tank Depth	46	27.0
Tank Height	50	44.8
A factor	$4.00	$ 4.00
B factor	2	$ 2.00
Total Owning Cost	$ 9,135.67	$ 10,818.67
Core Watts/lB	**0.576**	**0.530**

150 kVA Design Line 4	12470Y/7200: 208Y/120 V	
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.16	99.20
Selling Price	$ 5,507.48	$ 7,115.30
Core Loss	337.99	271.7
Load Loss at full load	1298.42	1417.3
Total Weight, lbs.	1,934	3089.0
Core Material	M3	M3
Core Weight, Lbs.	749	729.0
Low Voltage Material	AL	AL
High Voltage Material	CU	AL
LV Weight, Lbs.	73	123.390
HV Weight, Lbs.	271	176.750
Gallons of oil	44.64	142.733
Primary Insulation, Lbs.	7.01	18.775
Secondary insulation, Lbs.	8.05	14.500
Core Material Cost, $	1404.67	$ 1,158.15
LV Material Cost, $	114.67	$ 218.89
HV Material Cost, $	1067.53	$ 422.42
Primary Insulation Cost, $	10.62	$ 25.28
Secondary Insulation Cost, $	12.20	$ 18.77
Oil Cost, $	149.58	$ 603.49
Tank Cost, $	387.37	$ 646.20
All Other Material	148.56	$ 671.12
Core and Coil Cost, $	$ 2,609.70	$ 1,828.82
Tank , Oil, & Other Cost, $	$ 685.52	$ 1,920.82
Total Material Cost	$ 3,295.22	$ 3,749.64
Tank Width	57	45.7
Tank Depth	46	27.3
Tank Height	50	46.1
A factor	$ 13.00	$ 13.00
B factor	$ 4.00	$ 4.00
Total Owning Cost	$ 15,095.03	$ 16,316.30
Core Watts/lB	**0.451**	**0.373**

150 kVA Design Line 4	12470Y/7200: 208Y/120 V	
Parameter	OPS	MFG AVG
Efficiency at 50% load @55C	99.21	99.25
Selling Price	$ 6,628.00	$ 7,609.74
Core Loss	397.06	254.7
Load Loss at full load	877.36	1325.0
Total Weight, lbs.	2,300	3178.0
Core Material	M3	M3
Core Weight, Lbs.	903	738.2
Low Voltage Material	AL	AL
High Voltage Material	CU	AL
LV Weight, Lbs.	90	137.5
HV Weight, Lbs.	359	188.4
Gallons of oil	52.54	148.4
Primary Insulation, Lbs.	7.69	20.0
Secondary insulation, Lbs.	7.17	16.1
Core Material Cost, $	1693.37	$ 1,339.33
LV Material Cost, $	142.16	$ 250.07
HV Material Cost, $	1413.92	$ 441.26
Primary Insulation Cost, $	11.65	$ 26.57
Secondary Insulation Cost, $	10.86	$ 20.43
Oil Cost, $	176.04	$ 643.16
Tank Cost, $	406.27	$ 654.48
All Other Material	155.1	$ 652.20
Core and Coil Cost, $	$ 3,271.97	$ 2,061.99
Tank , Oil, & Other Cost, $	$ 737.44	$ 1,949.83
Total Material Cost	$ 4,009.40	$ 4,011.82
Tank Width	61	46.7
Tank Depth	50	27.7
Tank Height	50	46.4
A factor	$16.00	$ 16.00
B factor	7.5	$ 7.50
Total Owning Cost	$ 19,561.20	$ 21,621.90
Core Watts/lB	**0.440**	**0.345**

150 kVA Design Line 4	12470Y/7200: 208Y/120 V		Alternate
Parameter	OPS	MFG AVG	Amorphous
Efficiency at 50% load @55C	99.61	99.40	99.61
Selling Price	$ 8,643.95	$ 21,622.55	$ 23,813.75
Core Loss	155.08	240.0	114.0
Load Loss at full load	602.94	883.7	762.0
Total Weight, lbs.	2,601	4653.3	5729.0
Core Material	SA1	M3	SA1
Core Weight, Lbs.	1,026	1047.7	986.0
Low Voltage Material	CU	CU	Cu
High Voltage Material	CU	CU	Cu
LV Weight, Lbs.	223	413.2	725.0
HV Weight, Lbs.	335	705.4	941.0
Gallons of oil	60.66	171.0	225.0
Primary Insulation, Lbs.	7.75	15.6	30.0
Secondary insulation, Lbs.	7.73	12.3	22.0
Core Material Cost, $	2441.90	$ 1,926.01	$ 2,169.20
LV Material Cost, $	943.33	$ 1,907.03	$ 3,346.10
HV Material Cost, $	1321.14	$ 4,016.17	$ 5,357.47
Primary Insulation Cost, $	11.74	$ 20.49	$ 50.00
Secondary Insulation Cost, $	11.72	$ 15.71	$ 30.00
Oil Cost, $	203.26	$ 723.95	$ 952.57
Tank Cost, $	409.43	$ 753.81	$ 651.00
All Other Material	193.69	$ 1,183.49	$ 2,754.37
Core and Coil Cost, $	$ 4,729.83	$ 7,885.42	$ 10,952.77
Tank , Oil, & Other Cost, $	$ 806.38	$ 2,661.26	$ 4,357.94
Total Material Cost	$ 5,536.22	$ 10,546.68	$ 15,310.71
Tank Width	65	51.0	54.0
Tank Depth	47	30.7	24.0
Tank Height	50	46.8	48.5
A factor	$15.00	$ 15.00	$ 15.00
B factor	8	$ 8.00	$ 8.00
Total Owning Cost	$ 15,793.61	$ 32,291.88	$ 31,619.75
Core Watts/lB	**0.151**	**0.229**	**0.116**

Note: All other material includes core clamp, bushings, decals, leads, pallets, shipping materials, scrap, unapplied matrerials and standard accessories

Figure 3c shows Design Line 4 Comparisons between Manufacturers and OPS 1.

Conclusions for Design Line 4, represented by 150 kVA Three Phase Pad with primary Voltage 12,470 GrY / 7,200 and low voltage 208 Y / 120 Volts:

xxv. Manufacturers had higher material costs than OPS1.
xxvi. Oil Gallons in OPS1 were in error and under-calculated.
xxvii. Total Weights of transformers in OPS 1 were under-calculated and in error.
xxviii. Tank cost in OPS1 was under-calculated.
xxix. All other material in OPS 1 was under-calculated.
xxx. Manufacturers' selling prices for base case were at market levels.
xxxi. Manufacturers' selling prices to material cost were kept constant at base case ratios.
xxxii. OPS2 is OPS1 revised. However revisions are not explained.
xxxiii. OPS2 data is extracted from the engineering analysis from August 31 with M3, Al, Al the base case.
xxxiv. A ZDMH alternative by OPS2 is shown that shows the calculated data by OPS (August 31) for a ZDMH alternative.
xxxv. Cost/watt saved Design Efficiency levels lower than the present worth values/watt are worthy of consideration as they return investment in less than 30 years.
xxxvi. Cost/watt saved Design Efficiency levels greater than the present worth values/watt are not economical unless there are other considerations.

Design Line 5 Large Three Phase Transformers

Design Line	Design Line 5		Large Three Phase Transformers			
kVA	1500	kVA	24,940 GRY/14,400: 480 Y/277			
Selling Prices, Costs, and Efficiencies as seen by the Manufacturers in 2011 with M3						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.42	99.48	99.51	99.54	99.57	99.61
Incremental Efficiency		0.06	0.03	0.03	0.03	0.04
Watts saved		450	225	225	225	300
Selling Price	$ 24,000.00	$ 32,000.00	$ 37,000.00	$ 42,300.00	$ 53,000.00	$ 87,863.00
Incremental Selling Price		$ 8,000.00	$ 5,000.00	$ 5,300.00	$ 10,700.00	$ 34,863.00
Incremental $/Watt Cost to End User		**$ 17.78**	**$ 22.22**	**$ 23.56**	**$ 47.56**	**$ 116.21**
Selling Prices, Costs, and Efficiencies as seen by the DOE (OPS 1) in Preliminary Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.42	99.48	99.51	99.54	99.57	99.61
Incremental Efficiency		0.06	0.03	0.03	0.03	0.04
Watts saved		450	225	225	225	300
Selling Price	$ 22,947.00	$ 27,500.00	$ 29,500.00	$ 32,000.00	$ 34,000.00	$ 37,000.00
Incremental Selling Price		$ 4,553.00	$ 2,000.00	$ 2,500.00	$ 2,000.00	$ 3,000.00
Incremental $/Watt Cost to End User		**$ 10.12**	**$ 8.89**	**$ 11.11**	**$ 8.89**	**$ 10.00**
Selling Prices, Costs, and Efficiencies as seen by OPS 2 in DOE September Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.42	99.48	99.51	99.54	99.57	99.61
Incremental Efficiency		0.06	0.03	0.03	0.03	0.04
Watts saved		450	225	225	225	300
Selling Price	$ 24,853.00	$ 31,269.00	$ 33,653.00			
Incremental Selling Price		$ 6,416.00	$ 2,384.00			$ -
Incremental $/Watt Cost to End User		**$ 14.26**	**$ 10.60**	**$ -**	**$ -**	**$ -**
OPS2 with ZDMH						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.42	99.48	99.51	99.54	99.57	99.61
Incremental Efficiency		0.06	0.03	0.03	0.03	0.04
Watts saved		450	225	225	225	300
Selling Price	$ 24,926.00	$ 28,354.00	$ 30,684.00	$ 37,915.00		
Incremental Selling Price		$ 3,428.00	$ 2,330.00	$ 7,231.00		$ -
Incremental $/Watt Cost to End User		**$ 7.62**	**$ 10.36**	**$ 32.14**	**$ -**	**$ -**
Present Worth of Watt saved		**$8.31**	**$8.31**	**$8.31**	**$8.31**	**$8.31**

Figure 4a shows the summary of Selling Prices versus Efficiency for Design Line 5

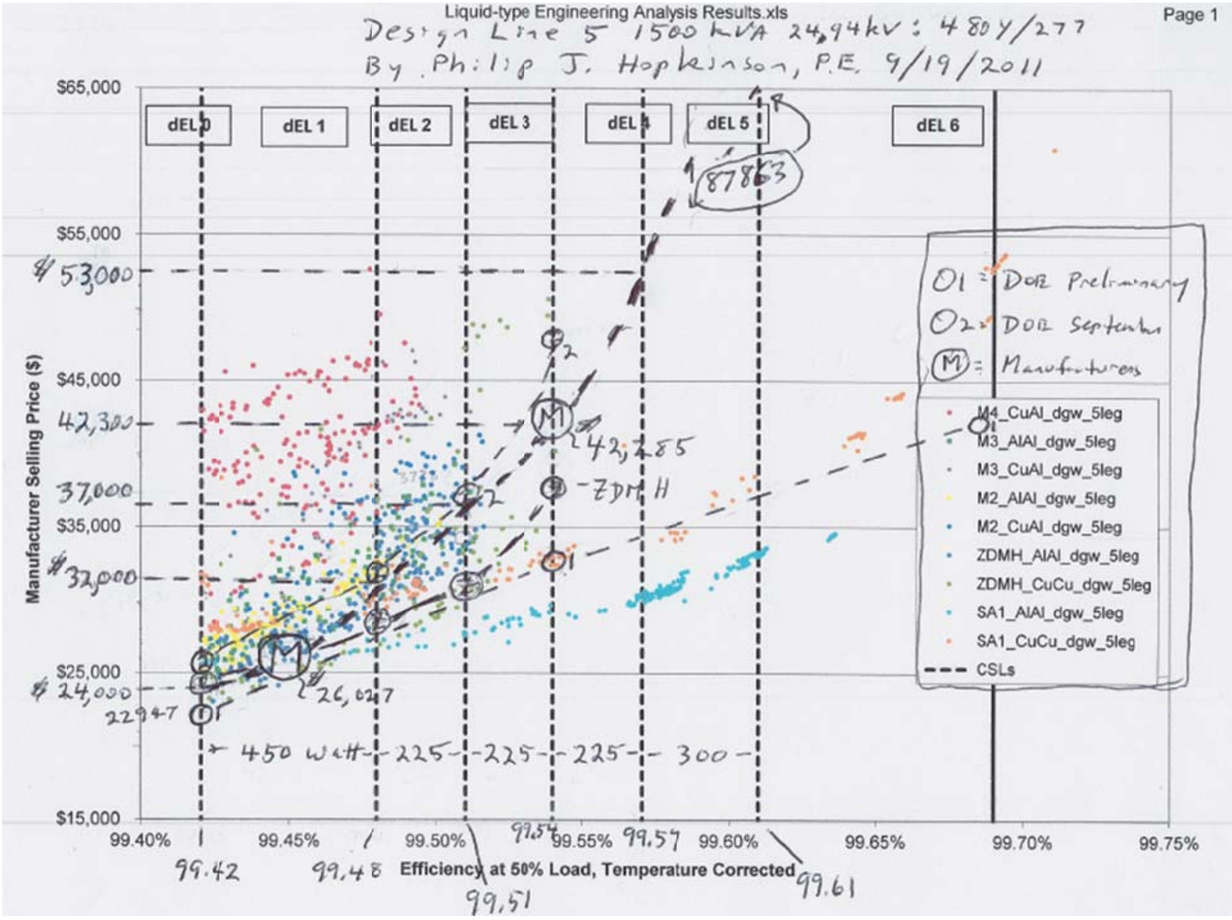

Figure 4b shows the summary of Selling Prices versus Efficiency for Design Line 5

xiii. M is the Manufacturers' Average Selling Prices to the end Customer versus DOE Efficiency Level, using M3, Al, Al.

xiv. 01 is the OPS Generated data from the DOE Preliminary Analysis in March, 2011, using M3, Al, Al.

xv. 02 is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using M2, Al, Al.

xvi. Z is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using ZDMH, Al, Al and or Copper.

Design Line 5 Large Three Phase Pads

1500 kVA Design Line 5	24940 GRY/14400: 480Y/277	
Parameter	**OPS**	**MFG AVG**
Efficiency at 50% load @55C	99.42	99.45
Selling Price	$ 22,946.76	$ 26,027.79
Core Loss @20 C	2147.36	1868.1
Load Loss at full load @ 85C	8257.03	9752.3
Total Weight, lbs.	8,583	11335.3
Core Material	M3	M3
Core Weight, Lbs	3,829	3532.5
Low Voltage Material	AL	AL
High Voltage Material	AL	AL
LV Weight, Lbs.	579	421.3
HV Weight, Lbs.	894	781.5
Gallons of oil	241.43	431.7
Primary Insulation, Lbs.	83.03	99.8
Secondary insulation, Lbs.	43.07	65.6
Core Material Cost, $	$ 7,179.94	$ 6,128.79
LV Material Cost, $	$ 915.49	$ 748.86
HV Material Cost, $	$ 3,261.51	$ 1,877.55
Primary Insulation Cost, $	$ 125.79	$ 131.60
Secondary Insulation Cost, $	$ 65.25	$ 84.44
Oil Cost, $	$ 857.92	$ 1,827.52
Tank Cost, $	$ 934.31	$ 1,666.05
All Other Material	$ 455.48	$ 1,355.17
Core and Coil Cost, $	$ 11,547.98	$ 8,899.23
Tank , Oil, & Other Cost, $	$ 2,247.71	$ 4,848.74
Total Material Cost	$ 13,795.68	$ 13,747.97
Tank Width	86	65.8
Tank Depth	69	40.5
Tank Height	70	64.1
A factor	$6.50	$ 6.50
B factor	3.6	$ 3.60
Total Owning Cost	$ 66,629.89	$ 73,279.05
Core Watts/lB	**0.561**	**0.529**

1500 kVA Design Line 5	24940 GRY/14400: 480Y/277	
Parameter	**OPS**	**MFG AVG**
Efficiency at 50% load @55C	99.54	99.54
Selling Price	$ 32,354.04	$ 42,285.32
Core Loss	1867.59	1494.5
Load Loss at full load	5969.99	8403.0
Total Weight, lbs.	8,917	13301.3
Core Material	ZDMH	M3
Core Weight, Lbs.	3,300	4354.9
Low Voltage Material	CU	AL
High Voltage Material	CU	AL
LV Weight, Lbs.	1,184	726.300
HV Weight, Lbs.	1,632	1207.210
Gallons of oil	196.89	457.667
Primary Insulation, Lbs.	54.30	105.390
Secondary insulation, Lbs.	27.19	78.095
Core Material Cost, $	$ 6,764.28	$ 8,958.46
LV Material Cost, $	$ 4,998.85	$ 2,516.44
HV Material Cost, $	$ 6,433.62	$ 4,480.76
Primary Insulation Cost, $	$ 82.26	$ 139.08
Secondary Insulation Cost, $	$ 41.19	$ 101.04
Oil Cost, $	$ 694.03	$ 1,938.11
Tank Cost, $	$ 906.02	$ 1,627.52
All Other Material	$ 519.10	$ 1,608.19
Core and Coil Cost, $	$ 18,320.19	$ 16,115.73
Tank , Oil, & Other Cost, $	$ 2,119.15	$ 5,173.82
Total Material Cost	$ 20,439.34	$ 21,289.55
Tank Width	86	68.8
Tank Depth	67	42.0
Tank Height	70	64.1
A factor	$13.00	$ 13.00
B factor	6.5	$ 6.50
Total Owning Cost	$ 95,437.63	$ 116,332.88
Core Watts/lB	**0.566**	**0.343**

1500 kVA Design Line 5	24940 GRY/14400: 480Y/277		**Alternate**
Parameter	**OPS**	**MFG AVG**	**Amorphous**
Efficiency at 50% load @55C	99.69	99.62	99.67
Selling Price	$ 42,045.06	$ 87,862.79	$ 76,479.77
Core Loss	616.18	1345.2	675.0
Load Loss at full load	7189.91	6159.4	7212.0
Total Weight, lbs.	10,499	20647.2	19013.0
Core Material	SA1	M3	SA1
Core Weight, Lbs.	4,044	6167.0	6120.0
Low Voltage Material	CU	CU	Al
High Voltage Material	CU	CU	Cu
LV Weight, Lbs.	1,383	1904.8	985.0
HV Weight, Lbs.	1,904	3273.7	3472.0
Gallons of oil	248.00	496.3	608.0
Primary Insulation, Lbs.	75.29	118.2	80.0
Secondary insulation, Lbs.	44.55	80.5	40.0
Core Material Cost, $	$ 9,623.91	$ 13,098.33	$ 13,464.00
LV Material Cost, $	$ 5,842.69	$ 10,998.44	$ 5,687.45
HV Material Cost, $	$ 7,508.95	$ 18,041.28	$ 19,134.21
Primary Insulation Cost, $	$ 114.07	$ 225.51	$ 130.00
Secondary Insulation Cost, $	$ 67.50	$ 105.08	$ 80.00
Oil Cost, $	$ 857.15	$ 2,093.98	$ 2,565.08
Tank Cost, $	$ 1,043.83	$ 1,602.88	$ 1,357.00
All Other Material	$ 688.84	$ 2,318.75	$ 3,019.91
Core and Coil Cost, $	$ 23,157.12	$ 42,358.44	$ 38,495.66
Tank , Oil, & Other Cost, $	$ 2,589.82	$ 6,015.61	$ 6,941.99
Total Material Cost	$ 25,746.94	$ 48,374.05	$ 45,437.65
Tank Width	86	80.9	80.0
Tank Depth	67	49.6	36.0
Tank Height	70	70.5	69.5
A factor	$15.00	$ 15.00	$ 15.00
B factor	5.5	$ 5.50	$ 5.50
Total Owning Cost	$ 90,832.26	$ 141,918.15	$ 126,270.77
Core Watts/lB	**0.152**	**0.218**	**0.110**

Note: All other material includes core clamp, bushings, decals, leads, pallets, shipping materials, scrap, unapplied matrerials and standard accessories

Figure 4c shows Design Line 5 Comparisons between Manufacturers and OPS 1.

Conclusions For Design Line 5, represented by 1500 kVA Three Phase Pad with primary Voltage 24,9400 GrY / 14,400 and low voltage 480 Y / 277 Volts:

xxxvii. Manufacturers had higher material costs than OPS1.
xxxviii. Oil Gallons in OPS1 were in error and under-calculated.
xxxix. Total Weights of transformers in OPS 1 were under-calculated and in error.
xl. Tank cost in OPS1 was under-calculated.
xli. All other material in OPS 1 was under-calculated.
xlii. Manufacturers' selling prices for base case were at market levels.
xliii. Manufacturers' selling prices to material cost were kept constant at base case ratios.
xliv. OPS2 is OPS1 revised. However revisions are not explained.
xlv. OPS2 data is extracted from the engineering analysis from August 31 with M3, Al, Al the base case.
xlvi. A ZDMH alternative by OPS2 is shown that shows the calculated data by OPS (August 31) for a ZDMH alternative.
xlvii. Cost/watt saved Design Efficiency levels lower than the present worth values/watt are worthy of consideration as they return investment in less than 30 years.
xlviii. Cost/watt saved Design Efficiency levels greater than the present worth values/watt are not economical unless there are other considerations.

Design Line 12 Medium Voltage Dry Transformers

Design Line	Design Line 12		Three Phase Medium Voltage Dry Type			
kVA	1500	kVA	12,470: 480Y/277 Volts			
Selling Prices, Costs, and Efficiencies as seen by the Manufacturers in 2011 with M3						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.12	99.22	99.3	99.39		
Incremental Efficiency		0.095	0.085	0.09		
Watts saved		712.5	637.5	675		
Selling Price	$ 37,000.00	$ 42,000.00	$ 49,000.00	$ 61,229.00		
Incremental Selling Price		$ 5,000.00	$ 7,000.00	$ 12,229.00		
Incremental $/Watt Cost to End User		**$ 7.02**	**$ 10.98**	**$ 18.12**		
Selling Prices, Costs, and Efficiencies as seen by the DOE (OPS 1) in Preliminary Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.12	99.22	99.3	99.39		
Incremental Efficiency		0.095	0.085	0.09		
Watts saved		712.5	637.5	675		
Selling Price	$ 35,242.00	$ 36,500.00	$ 37,486.00	$ 43,373.00		
Incremental Selling Price		$ 1,258.00	$ 986.00	$ 5,887.00		
Incremental $/Watt Cost to End User		**$ 1.77**	**$ 1.55**	**$ 8.72**		
Selling Prices, Costs, and Efficiencies as seen by OPS 2 in DOE September Analysis						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.12	99.22	99.3	99.39	99.46	
Incremental Efficiency		0.095	0.085	0.09	0.07	
Watts saved		712.5	637.5	675	525	
Selling Price	$ 36,822.00	$ 39,723.00	$ 39,952.00	$ 46,456.00	$ 50,019.00	
Incremental Selling Price		$ 2,901.00	$ 229.00	$ 6,504.00	$ 3,563.00	
Incremental $/Watt Cost to End User		**$ 4.07**	**$ 0.36**	**$ 9.64**	**$ 6.79**	
OPS2 with HO Hi B						
DOE Efficiency Level	DEL 0	DEL 1	DEL 2	DEL 3	DEL 4	DEL 5
% Efficiency at 50% Load	99.12	99.22	99.3	99.39	99.46	
Incremental Efficiency		0.095	0.085	0.09	0.07	
Watts saved		712.5	637.5	675	525	
Selling Price	$ 33,544.00	$ 36,716.00	$ 39,040.00	$ 43,040.00	$ 46,670.00	
Incremental Selling Price		$ 3,172.00	$ 2,324.00	$ 4,000.00	$ 3,630.00	
Incremental $/Watt Cost to End User		**$ 4.45**	**$ 3.65**	**$ 5.93**	**$ 6.91**	
Present Worth of Watt saved		**$9.91**	**$9.91**	**$9.91**	**$9.91**	**$9.91**

Figure 5a shows the summary of Selling Prices versus Efficiency for Design Line 12

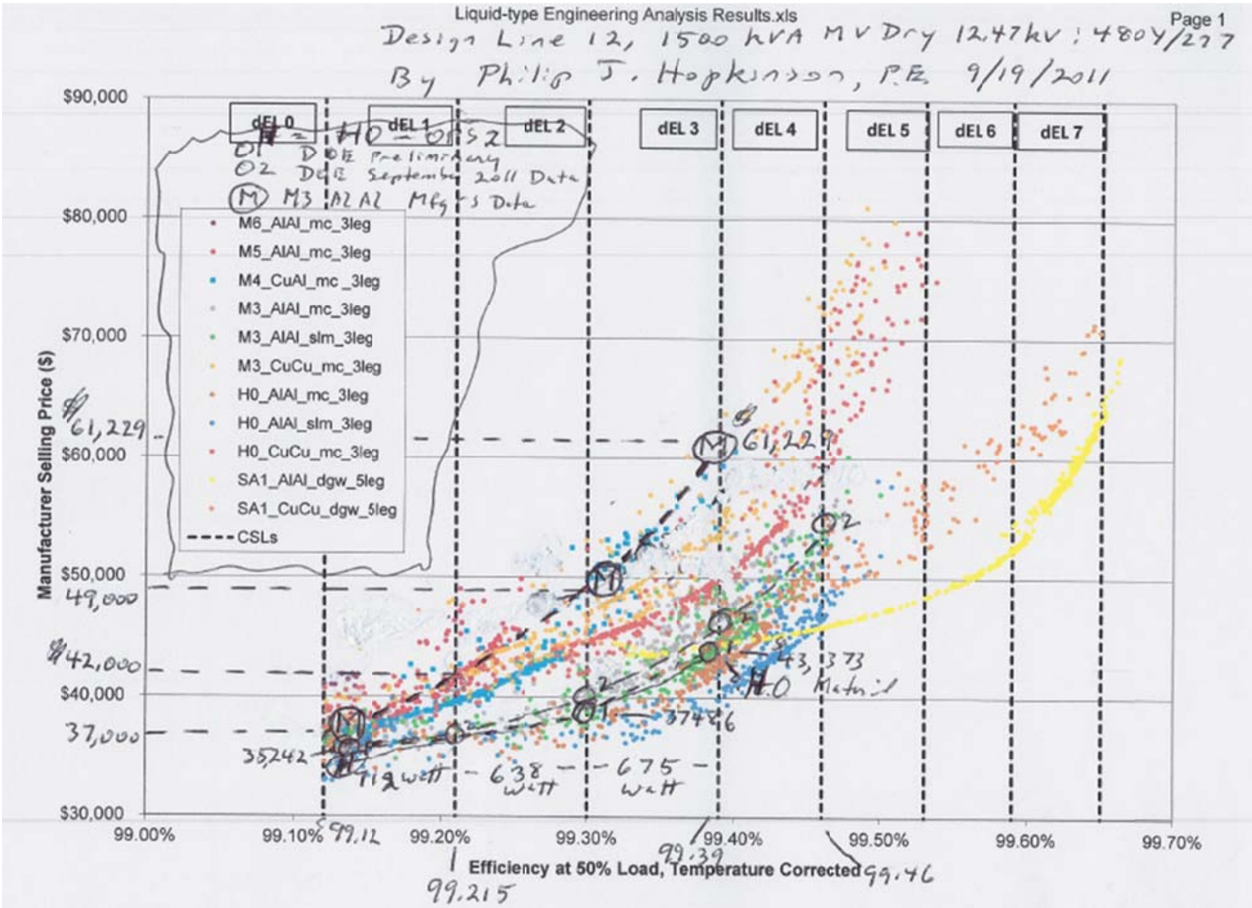

Figure 5b shows the summary of Selling Prices versus Efficiency for Design Line 12

xvii. M is the Manufacturers' Average Selling Prices to the end Customer versus DOE Efficiency Level, using M3, Al, Al.

xviii. 01 is the OPS Generated data from the DOE Preliminary Analysis in March, 2011, using M3, Al, Al.

xix. 02 is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using M2, Al, Al.

xx. Z is the OPS Generated data from the DOE reissued Engineering Analysis from August 31, 2011, using ZDMH, Al, Al and or Copper.

Design Line 12 Medium Voltage Dry

M3, AL, AL, 12470: 480Y/277 95 kV BIL, with taps

1500 kVA 3-phase Vented Dry Design Line 12		
Parameter	OPS	MFG AVG
Efficiency at 50% load @75C	99.12	99.135
Selling Price	$ 35,242.12	$ 37,234.95
Core Loss @20 C	2616.21	3755
Load Loss at full load @ 85C	20002.95	12142.5
Total Weight, lbs.	7,829	8763
Core Material	M3	M4
Core Weight, Lbs	5,720	5996
Low Voltage Material	AL	AL
High Voltage Material	AL	AL
LV Weight, Lbs.	302	434
HV Weight, Lbs.	508	567
Gallons of impregnation	31.79	25
Primary Insulation, Lbs.	0.00	135
Secondary insulation, Lbs.	132.34	127
Core Material Cost, $	$ 10,724.76	$ 8,080.00
LV Material Cost, $	$ 473.01	$ 831.50
HV Material Cost, $	$ 1,110.00	$ 1,608.00
Primary Insulation Cost, $	$ -	$ 789.00
Secondary Insulation Cost, $	$ 3,242.39	$ 1,814.00
Cabinet Cost, $	$ 810.25	$ 780.00
All Other Material	$ 4,499.67	$ 1,181.00
Core and Coil Cost, $	$ 15,550.15	$ 13,122.50
Cabinet & Other Cost, $	$ 5,309.92	$ 1,961.00
Total Material Cost	$ 20,860.07	$ 15,083.50
Tank Width	90	99
Tank Depth	43	56
Tank Height	90	98
A factor	$0.75	$ 0.75
B factor	0.2	$ 0.20
Total Owning Cost	$ 41,204.87	$ 42,479.70

M3, AL, AL, 12470: 480Y/277 95 kV BIL, with taps

1500 kVA 3-phase Vented Dry Design Line 12		
Parameter	OPS	MFG AVG
Efficiency at 50% load @75C	99.3	99.3085
Selling Price	$ 37,486.98	$ 49,644.54
Core Loss	2725.35	2961
Load Loss at full load	11868.27	10449
Total Weight, lbs.	8,534	10869
Core Material	M3	M3
Core Weight, Lbs.	6,002	7406.5
Low Voltage Material	AL	AL
High Voltage Material	AL	AL
LV Weight, Lbs.	443	578.5
HV Weight, Lbs.	761	880.5
Gallons of impregnation	33.09	25
Primary Insulation, Lbs.	0.00	192
Secondary insulation, Lbs.	132.31	225
Core Material Cost, $	$ 11,254.65	$ 11,598.00
LV Material Cost, $	$ 692.71	$ 1,103.50
HV Material Cost, $	$ 1,663.17	$ 2,343.50
Primary Insulation Cost, $	$ -	$ 850.00
Secondary Insulation Cost, $	$ 3,241.60	$ 1,973.50
Cabinet Cost, $	$ 815.36	$ 780.00
All Other Material	$ 4,740.96	$ 1,462.00
Core and Coil Cost, $	$ 16,852.13	$ 17,868.50
Cabinet & Other Cost, $	$ 5,556.32	$ 2,242.00
Total Material Cost	$ 22,408.45	$ 20,110.50
Tank Width	89	99
Tank Depth	45	56
Tank Height	90	98
A factor	$ 9.00	$ 9.00
B factor	$ 0.56	$ 0.56
Total Owning Cost	$ 68,661.33	$ 82,144.98

M3, AL, AL, 12470: 480Y/277 95 kV BIL, with taps

1500 kVA 3-phase Vented Dry Design Line 12		
Parameter	OPS	MFG AVG
Efficiency at 50% load @75C	99.39	99.3975
Selling Price	$ 43,373.01	$ 61,228.80
Core Loss	2935.98	2481.5
Load Loss at full load	7370.75	9446.5
Total Weight, lbs.	10,190	11711.5
Core Material	M3	M3
Core Weight, Lbs.	6,960	7933.5
Low Voltage Material	AL	AL
High Voltage Material	AL	AL
LV Weight, Lbs.	655	668.5
HV Weight, Lbs.	1,134	973
Gallons of impregnation	39.83	25
Primary Insulation, Lbs.	0.00	192
Secondary insulation, Lbs.	142.93	225
Core Material Cost, $	$ 13,050.04	$ 15,068.00
LV Material Cost, $	$ 1,025.65	$ 1,283.50
HV Material Cost, $	$ 2,478.08	$ 2,533.50
Primary Insulation Cost, $	$ -	$ 850.00
Secondary Insulation Cost, $	$ 3,501.86	$ 2,166.00
Cabinet Cost, $	$ 842.20	$ 820.00
All Other Material	$ 5,466.61	$ 1,496.50
Core and Coil Cost, $	$ 20,055.62	$ 21,901.00
Cabinet & Other Cost, $	$ 6,308.81	$ 2,316.50
Total Material Cost	$ 26,364.43	$ 24,217.50
Tank Width	95	107
Tank Depth	47	58
Tank Height	90	105
A factor	$ 16.00	$ 16.00
B factor	$ 4.00	$ 4.00
Total Owning Cost	$ 119,831.64	$ 138,718.80

Note: All other material includes core clamp, bushings, decals, leads, pallets, shipping materials, scrap, unapplied matrerials and standard accessories

Figure 5c shows Design Line 12 Comparisons between Manufacturers and OPS 1.

Conclusions for Design Line 12, represented by 1500 kVA Three Phase Medium Voltage Dry with primary Voltage 12,470 and low voltage 480 Y / 277 Volts:

xlix. Manufacturers had higher material costs than OPS1.
l. Core weight in OPS1 was in error and under-calculated.
li. Total Weights of transformers in OPS 1 were under-calculated and in error.
lii. Cabinet cost in OPS1 was over-calculated.
liii. All other material in OPS 1 was over-calculated.
liv. Manufacturers' selling prices for base case were at market levels.
lv. Manufacturers' selling prices to material cost were kept constant at base case ratios.
lvi. OPS2 is OPS1 revised. However revisions are not explained.
lvii. OPS2 data is extracted from the engineering analysis from August 31 with M3, Al, Al the base case.
lviii. A Hi B (HO) alternative by OPS2 is shown that shows the calculated data by OPS (August 31) for a Hi B alternative.
lix. Cost/watt saved Design Efficiency levels lower than the present worth values/watt are worthy of consideration as they return investment in less than 30 years.
lx. Cost/watt saved Design Efficiency levels greater than the present worth values/watt are not economical unless there are other considerations.

G. Thoughts on OPS

1. OPS is a calculation tool which has a multiplicity of design algorithms imbedded to calculate performance and cost as a function of the many variables that influence the design. The manufacturers optimizing programs are constantly being recalibrated with bills of material that are compared with actual financial results such that their accuracy is normally quite good. I have used OPS software and can say that it is capable of correctly optimizing the design as long as it is properly calibrated. The calibration requires accurate portrayal of:

   a. Available materials, both applied and unapplied and their costs
   b. Labor content, both direct and indirect and their costs
   c. Manufacturing overhead including energy costs, supervision, scrap (natural and errors) and rework
   d. Inventory carrying costs
   e. Engineering
   f. Selling
   g. Advertising
   h. Administration
   i. Taxes, etc.

2. It is difficult to accumulate a model that accurately captures all elements and the programmers of OPS need a lot of information that is not normally available to truly represent the industry.
3. Even if the information is basically available, each product line needs to be accurately modeled in strict accordance to the relevant industry standards to get a complete embodiment of the full costs that are mandatory.
4. The analysis that I have completed with the help of the manufacturers is based on a combination of 2011 standards and current 2011 costs.
5. The OPS data has been accumulated in more than one time period. OPS1 information was published in the DOE Preliminary Analysis of March 2011. It was intended to reflect material costs at 2010 levels but there turned out to be some limitations in the accuracy of such costs.
6. After manufacturing designs were compared for liquid filled transformers (Dry transformers came later), errors were detected and OPS 2 was created to repair the errors and bring material costs up to 2011 levels.
7. No feedback was given to OPS about the Dry Type Transformer Designs and it appears that OPS2 and OPS1 for dry types are showing the same selling prices, suggesting few changes were made to the computer program.
8. Selling prices for the base efficiency levels should truly be at market since those are the efficiencies in the market today. However, OPS1 appeared to be different and usually lower than the averages supplied to HVOLT Inc. by the manufacturers. These differences are attributed to the data base that was available to OPS.

9. The Manufacturer data shown in the plots was accumulated with the presumption that M3 core steel and aluminum conductors were run in order to reflect the interests of the US Domestic Magnetic Steel makers.
10. OPS1 designs were selected to compare to the Manufacturers data that also contained M3 core steel and aluminum conductor.
11. OPS2 designs were selected from the August 31 DOE Engineering Analysis that also contained M3 core steel and aluminum conductors.
12. OPS2 with Hi B core steel (ZDMH for wound cores and HO for stacked cores) was compared against OPS2 with M3 to show that if the M3 constraint was not applied that other designs may be theoretically more economical at a given efficiency and shown on the plots.
13. The manufacturers hit the brick wall where no designs could be found with conventional materials (M3 core steel, Copper LV and Copper HV) at 99.40% for Design Line 4 and at 99.62% for Design Line 5 and different for the other product lines. This upper limit of efficiency was tested for each of the product lines.
14. Hi BIL and Dual Voltage designs were created but not shown in this analysis that showed the brick wall to be much closer to the present minimum efficiency. More analysis may be desired in this area in the future.
15. In both Design Lines 4 and 5, only amorphous core material would be able to move further than the brick wall to the highest efficiency requested for the study (99.61% for Design Line 4 and 99.69% for Design Line 5). However, two other considerations make amorphous not necessarily the best choice. If loading turns out to be greater than the assumed 50% RMS equivalent load then higher winding losses in the amorphous design would quickly eat up the benefits. Amorphous metal also has higher magnetostriction, audible sound, and more intense vibration than silicon iron. Many cases already are apparent where splinters of amorphous metal have been pumped into the windings and have resulted in catastrophic failures. Hence, reliability is a factor that must be assessed as worse than silicon.
16. Accuracy of OPS for some of the design lines still needs to be tested. For example, each of the 3-phase designs submitted by the manufacturers appears to be considerably heavier than OPS has shown with more than 1000 pounds difference and in some cases up to double or 10,000 pounds. This error is extremely significant.
17. The gallons of oil were understated by OPS for liquid filled pad mounted transformers but were repaired for OPS2.
18. Dry Type designs for OPS2 do not appear to be appreciably different than OPS1. In all fairness, we did not have feedback for the OPS personnel on the Medium Voltage Dry transformers prior to our design review and they may have been unaware of any errors.
19. One limitation of OPS that becomes increasingly apparent at high efficiencies is the lack of precision for core clamps, leads, busses, and stray and eddy losses. These items require larger cores and coils to compensate for their otherwise reduction of efficiencies in both liquid and dry transformers.

The bottom line of the comparison is that OPS has projected a considerably easier job of moving to higher efficiencies than the manufacturers when using M3 core steel as well as real manufacturer-based cost data. It is also most likely that any program and design errors have been present in the previous rulemaking which accounts for the difficulties expressed by many manufacturers to find buildable designs at upper efficiencies.

A logical question is why this steep cost curve outcome is occurring for 3-Phase Liquid Filled Transformers when the present standard from the 2007 NOPR and effective January 1, 2010 is presented as meeting <TSL3 for kVA ratings up to 500 kVA while single phase transformers in the lower kVA range up to 167 kVA were required to meet >TSL4. Factually, the 3-Phase transformers were also at the original equivalent TSL 4 as well when the 3-Phase core loss adjustment of 1.3 times the single phase equivalent was included to account for 3rd harmonic core losses in the wound cores.

H. Overall Conclusions and Recommendations

This report should provide the stakeholders with an accurate picture of manufacturer's cost as a function of DOE efficiency and should be a useful tool for the negotiators to determine the efficiency levels that best meet the National and DOE objectives with real buildable options.

High BIL and Dual Voltage Designs have been prepared but time constraints prevented me from adding them to this report. However, in both cases, they reach the limitations of core materials and conductors at a little over DEL1 and may want to be examined by the team in a future publication.

Sincerely,

Philip J Hopkinson

Philip J Hopkinson, PE
President and CEO, HVOLT Inc.