

APPENDIX 5D. RESULTS OF THE VOLTAGE SENSITIVITY ANALYSIS

TABLE OF CONTENTS

5D.1 INTRODUCTION	2
5D.2 Graphical Results of the Voltage Sensitivity Runs.....	3
5D.3 Tabular Review of the Voltage Sensitivity Run Results	7

LIST OF TABLES

Table 5D.1 Baseline and Sensitivity Voltages for Design Lines Analyzed	2
Table 5D.2 Results of Voltage Sensitivity for Design Line 2, M3CuAl	8
Table 5D.3 Results of Voltage Sensitivity for Design Line 2, M2CuCu	8
Table 5D.4 Results of Voltage Sensitivity for Design Line 3, M3CuAl	9
Table 5D.5 Results of Voltage Sensitivity for Design Line 3, M2CuCu	10
Table 5D.6 Results of Voltage Sensitivity for Design Line 4, M3CuAl	10
Table 5D.7 Results of Voltage Sensitivity for Design Line 4, M2CuCu	11
Table 5D.8 Results of Voltage Sensitivity for Design Line 5, M3CuAl	12
Table 5D.9 Results of Voltage Sensitivity for Design Line 5, M2CuCu	12

LIST OF FIGURES

Figure 5D.1 Engineering Analysis Results for DL2 M3CuAl Voltage Sensitivity	3
Figure 5D.2 Engineering Analysis Results for DL2 M2CuCu Voltage Sensitivity	4
Figure 5D.3 Engineering Analysis Results for DL3 M3CuAl Voltage Sensitivity	4
Figure 5D.4 Engineering Analysis Results for DL3 M2CuCu Voltage Sensitivity	5
Figure 5D.5 Engineering Analysis Results for DL4 M3CuAl Voltage Sensitivity	5
Figure 5D.6 Engineering Analysis Results for DL4 M2CuCu Voltage Sensitivity	6
Figure 5D.7 Engineering Analysis Results for DL5 M3CuAl Voltage Sensitivity	6
Figure 5D.8 Engineering Analysis Results for DL5 M2CuCu Voltage Sensitivity	7

APPENDIX 5D. RESULTS OF THE VOLTAGE SENSITIVITY ANALYSIS

5D.1 INTRODUCTION

In response to the notice of proposed rulemaking (NOPR), stakeholders expressed concern that if the DOE set the standard level too high, it might eliminate certain voltage classes from the market. DOE understands that it selected common voltages as its baseline units for evaluation in the engineering analysis, but that there are other voltages that may not be common, but are specified in distribution networks in the United States. Therefore, DOE conducted a sensitivity analysis on its engineering analysis by considering certain other voltage classes with higher BIL ratings relative to the baseline units being studied. As the BIL rating increases, so manufacturers must add more insulation around the windings, increasing the distance of the magnetic flux pathway, and thereby increasing losses. DOE understands that all else held equal, distribution transformers with higher BIL ratings will have lower resulting efficiency values.

This appendix contains the summary of the results of the sensitivity analysis conducted on the voltages with higher BIL ratings for certain liquid-immersed design lines. This issue was not evaluated for medium-voltage dry-type distribution transformers, because DOE already created product classes that grouped medium-voltage dry-type transformers by insulation class. That is, DOE grouped medium-voltage dry-type transformers with ratings of 20 to 45 BIL in one class, ratings of 46 to 95 BIL in second class and 96 and higher BIL in a third class.

The following table identifies exactly which liquid-immersed voltages were used in the reference case and which were used in the sensitivity case.

Table 5D.1 Baseline and Sensitivity Voltages for Design Lines Analyzed

Design Line	Baseline Conditions		Voltage Sensitivity	
	Primary Voltage	Secondary Voltage	Primary Voltage	Secondary Voltage
DL2	14400	240/120V	34500GRDY/19920 (150kV BIL)	240/120V
DL3	14400	277/120V	34500GRDY/19920 (150kV BIL)	277V
DL4	12470Y/7200	208Y/120V	34500GRDY/19920 (150kV BIL)	208Y/120V
DL5	24940GRDY/14400	408Y/277V	34500GRDY/19920 (150kV BIL)	208V

Changing only the voltages as shown in the table above, two engineering analyses were conducted at each sensitivity – one using M3CuAl and one using M2CuCu. These two design option combinations were selected because of the broad range of efficiencies they encompassed, and because they represent the highest efficiency level that can be achieved with conventional core steel. Other than changing the voltages, these two design option combinations were treated

in exactly the same way as all the other design option combinations analyzed for the engineering analysis. The approach used by DOE in conducting this analysis is discussed in detail in TSD Chapter 5.

5D.2 GRAPHICAL RESULTS OF THE VOLTAGE SENSITIVITY RUNS

This section of the appendix presents a series of graphs which depict graphically the results of the sensitivity analysis. These graphs illustrate the impact of the voltage sensitivity analysis, causing the efficiency curve to shift up (more expensive) and to the left (less efficient). There are eight graphs in this section, presenting the two design option combinations for each of the four voltage sensitivity cases separately.

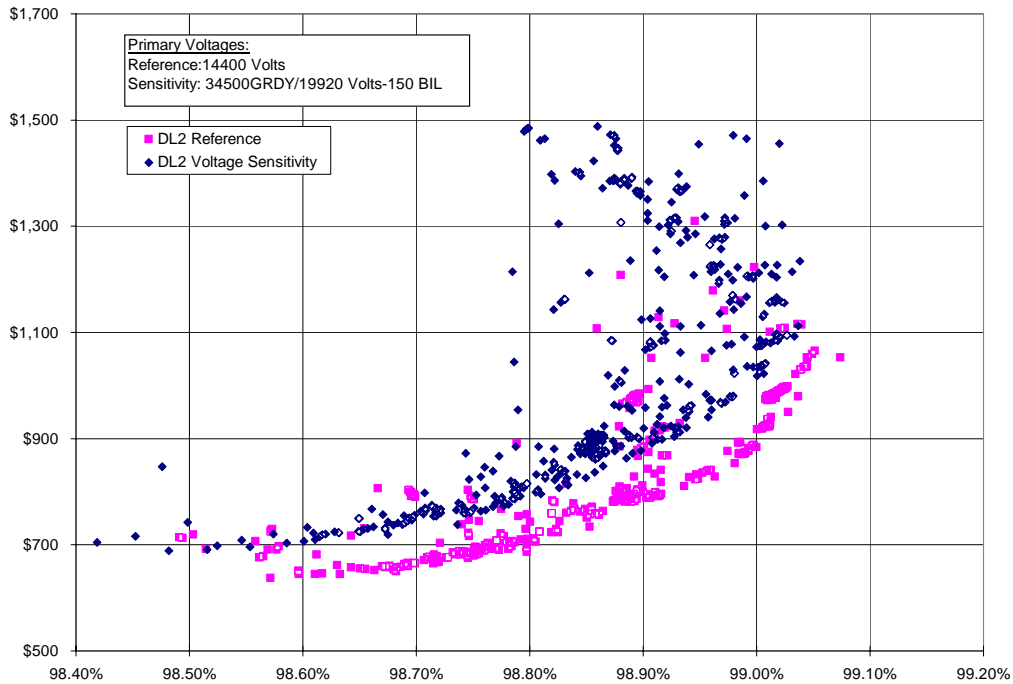


Figure 5D.1 Engineering Analysis Results for DL2 M3CuAl Voltage Sensitivity

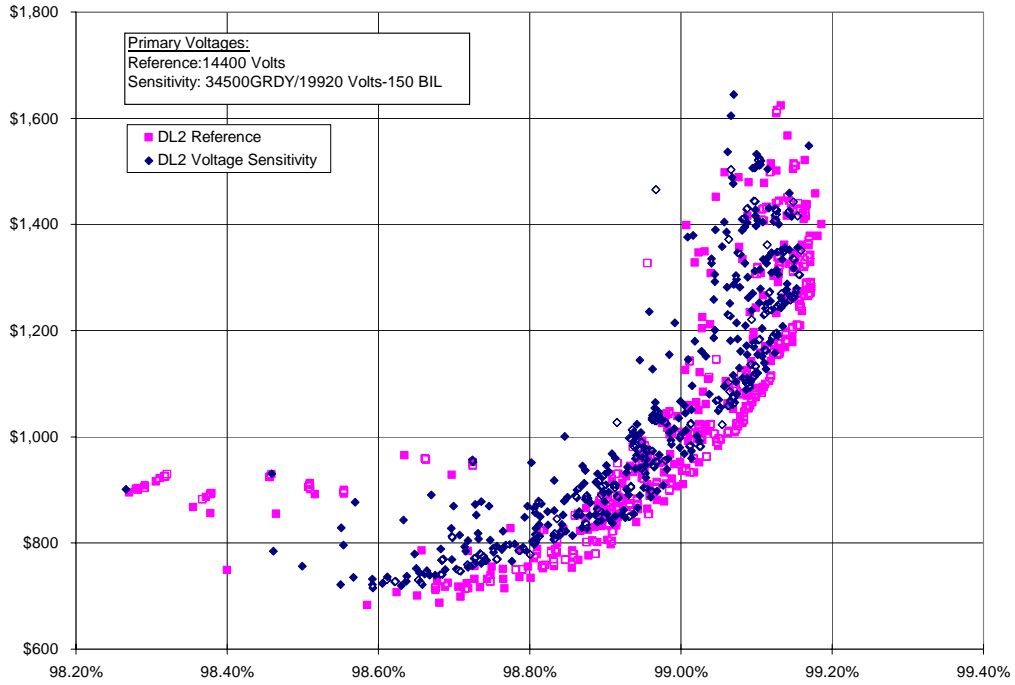


Figure 5D.2 Engineering Analysis Results for DL2 M2CuCu Voltage Sensitivity

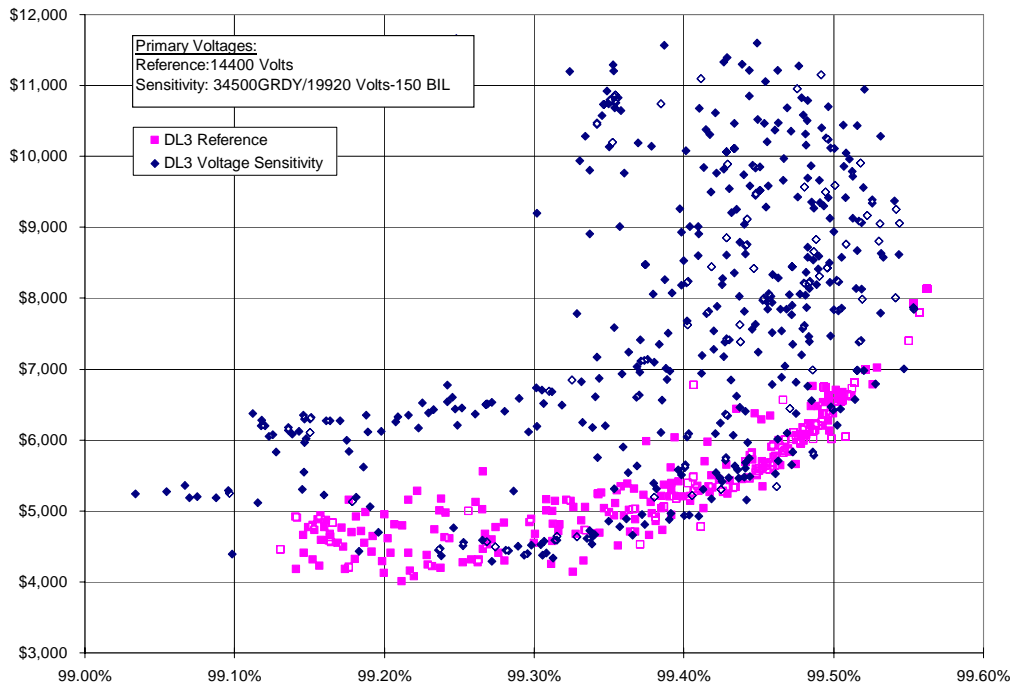


Figure 5D.3 Engineering Analysis Results for DL3 M3CuAl Voltage Sensitivity

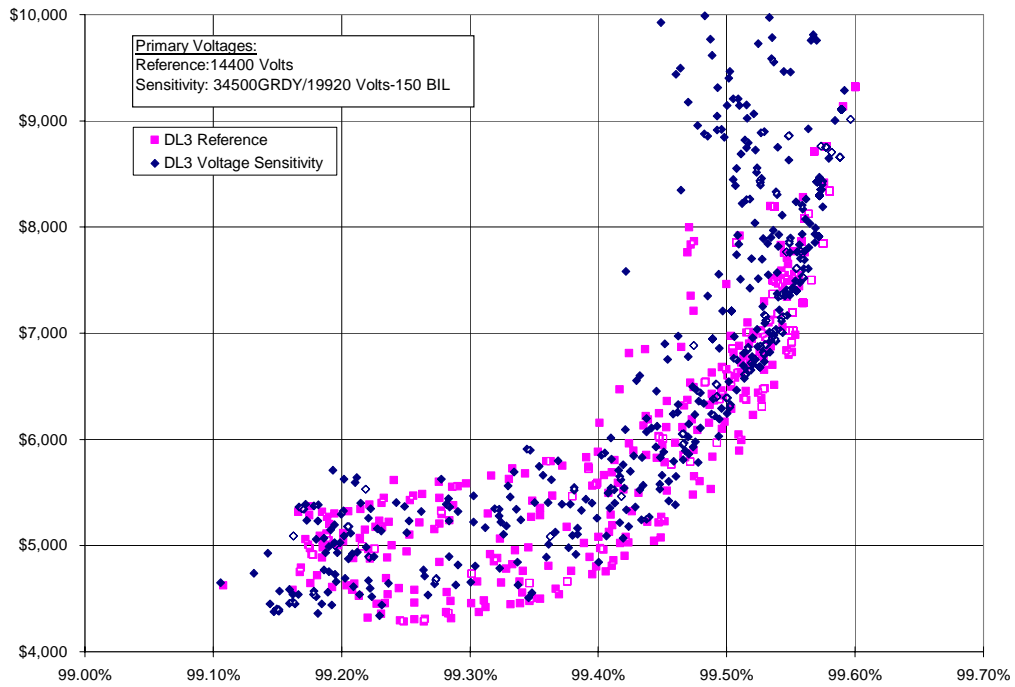


Figure 5D.4 Engineering Analysis Results for DL3 M2CuCu Voltage Sensitivity

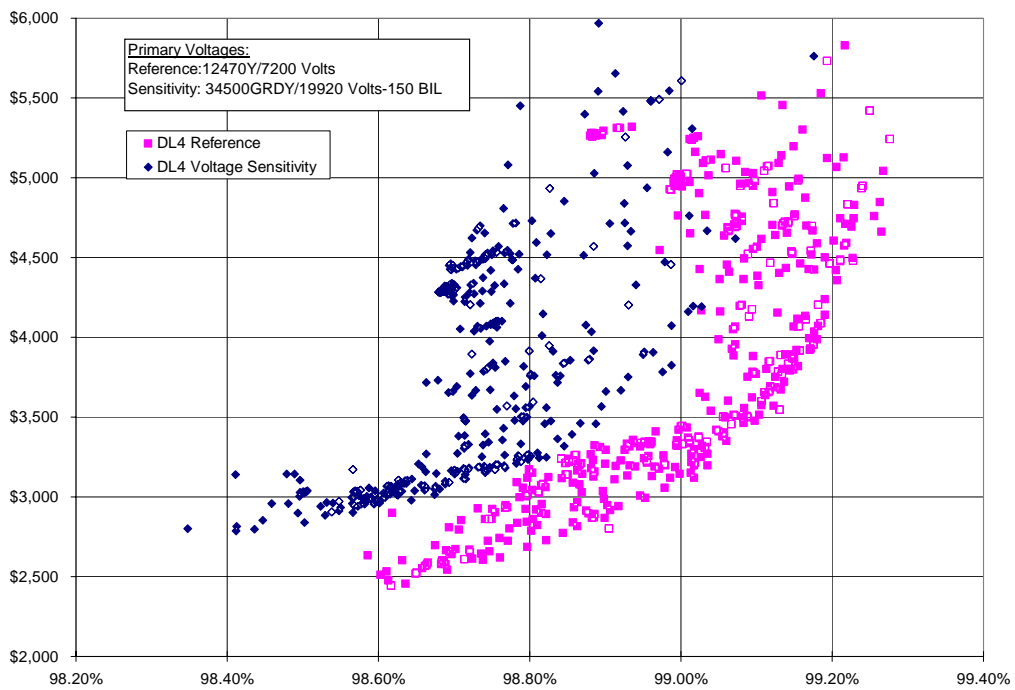


Figure 5D.5 Engineering Analysis Results for DL4 M3CuAl Voltage Sensitivity

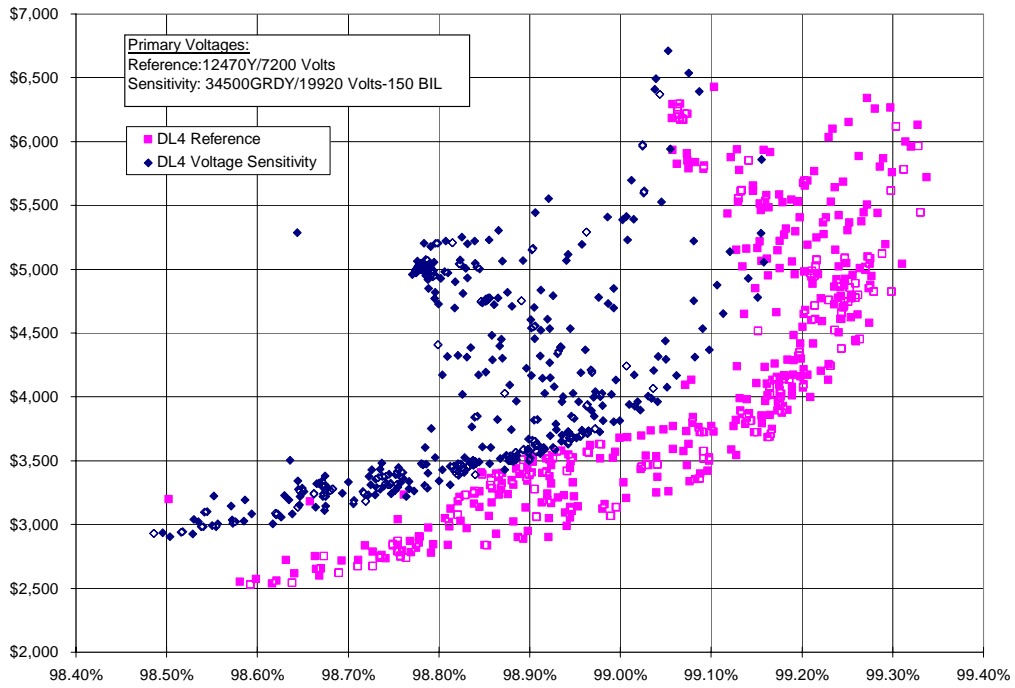


Figure 5D.6 Engineering Analysis Results for DL4 M2CuCu Voltage Sensitivity

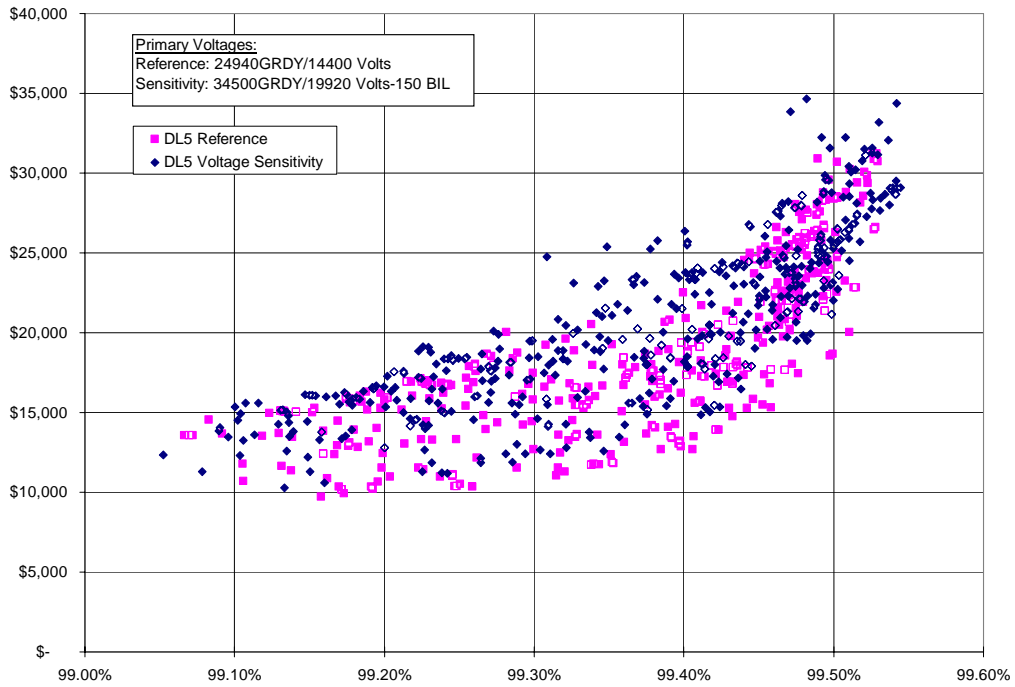


Figure 5D.7 Engineering Analysis Results for DL5 M3CuAl Voltage Sensitivity

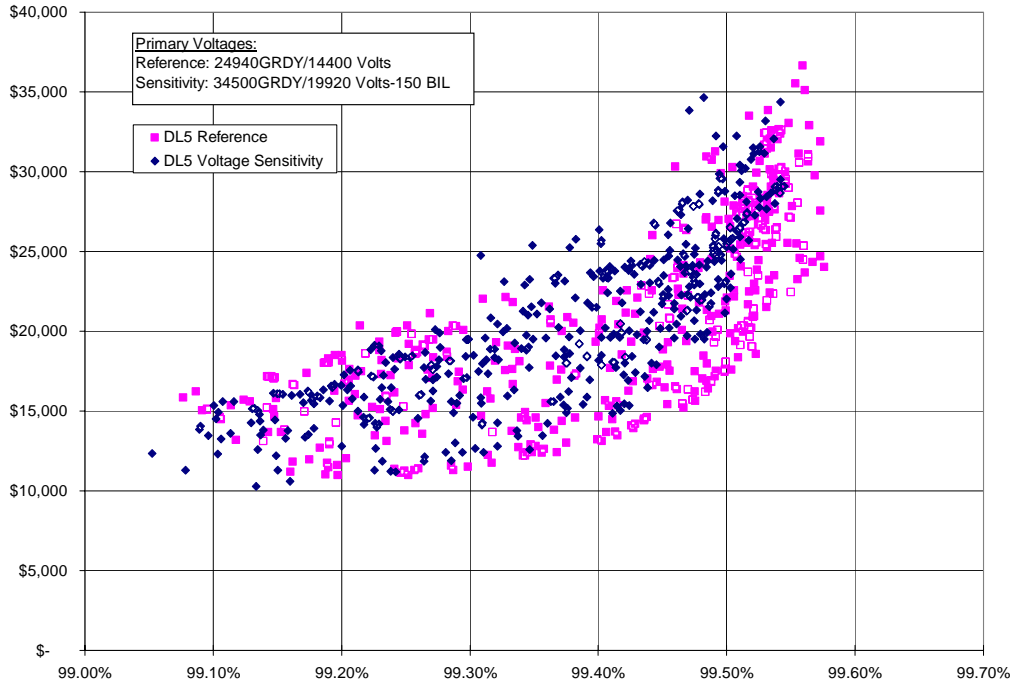


Figure 5D.8 Engineering Analysis Results for DL5 M2CuCu Voltage Sensitivity

5D.3 TABULAR REVIEW OF THE VOLTAGE SENSITIVITY RUN RESULTS

This section of the appendix presents a numerical evaluation of the results conducted for the voltage sensitivity runs. The tables provide a more detailed look at the impact of the voltage sensitivity run at each of the trial standard levels (TSLs).

The following table presents the results for the voltage sensitivity analysis conducted on design line 2, a 25 kVA single-phase pole-mount liquid-immersed distribution transformer. This transformer using the M3CuAl design option combination. The voltage sensitivity analysis found an average increase in price of approximately 12.2% and a reduction in efficiency of 0.14, meaning a design that had otherwise been 99.00 percent efficient, would now be 98.86 percent efficient. If the efficiency value is outside the range of available designs for this voltage sensitivity analysis, that cell in the table is marked with an 'n/a'.

Table 5D.2 Results of Voltage Sensitivity for Design Line 2, M3CuAl

DL2	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	98.70	12.2%	n/a	\$664.99	\$746.05	n/a
TSL2	98.73	9.1%	n/a	\$676.15	\$737.62	n/a
TSLD	98.79	11.6%	(0.20)	\$704.44	\$786.40	98.59
TSLC	98.91	13.0%	(0.12)	\$788.60	\$891.47	98.79
TSLB	98.91	13.0%	(0.12)	\$788.60	\$891.47	98.79
TSL3	98.76	11.6%	n/a	\$684.06	\$763.37	n/a
TSL4	98.79	11.6%	(0.20)	\$704.44	\$786.40	98.59
TSLA	99.04	13.6%	(0.06)	\$979.28	\$1,112.92	98.98
TSL5	98.96	13.6%	(0.11)	\$827.94	\$940.48	98.85
TSL6	99.46	n/a	n/a	n/a	n/a	n/a
Average		12.2%	(0.14)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 2, a 25 kVA single-phase pole-mount liquid-immersed distribution transformer. This transformer using the M2CuCu design option combination. The voltage sensitivity analysis found an average increase in price of approximately 5.6% and a reduction in efficiency of 0.12, meaning a design that had otherwise been 99.00 percent efficient, would now be 98.88 percent efficient.

Table 5D.3 Results of Voltage Sensitivity for Design Line 2, M2CuCu

DL2	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	98.70	4.7%	(0.11)	\$717.90	\$751.54	98.59
TSL2	98.73	6.2%	(0.14)	\$716.52	\$761.09	98.59
TSLD	98.79	6.8%	(0.15)	\$735.30	\$785.38	98.64
TSLC	98.91	5.0%	(0.14)	\$797.37	\$837.16	98.77
TSLB	98.91	5.0%	(0.14)	\$797.37	\$837.16	98.77
TSL3	98.76	5.0%	(0.15)	\$731.78	\$768.72	98.61
TSL4	98.79	6.8%	(0.15)	\$735.30	\$785.38	98.64
TSLA	99.04	7.4%	(0.04)	\$1,005.48	\$1,080.35	99.00
TSL5	98.96	3.8%	(0.04)	\$854.06	\$886.67	98.92
TSL6	99.46	n/a	n/a	n/a	n/a	n/a
Average		5.6%	(0.12)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 3, a 500 kVA single-phase round-tank liquid-immersed distribution transformer. This transformer using the M3CuAl design option combination. The voltage sensitivity analysis found an average increase in price of approximately 7.0% and a reduction in efficiency of 0.03, meaning a design that had otherwise been 99.40 percent efficient, would now be 99.37 percent efficient.

Table 5D.4 Results of Voltage Sensitivity for Design Line 3, M3CuAl

DL3	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	99.30	2.4%	(0.03)	\$4,296.35	\$4,401.46	99.27
TSL2	99.38	11.4%	(0.01)	\$4,660.64	\$5,191.34	99.37
TSLD	99.38	11.4%	(0.01)	\$4,660.64	\$5,191.34	99.37
TSLC	99.42	2.7%	(0.03)	\$5,035.88	\$5,169.82	99.39
TSLB	99.47	4.4%	(0.03)	\$5,581.20	\$5,829.30	99.44
TSL3	99.46	2.6%	(0.04)	\$5,561.08	\$5,708.29	99.42
TSL4	99.54	14.0%	(0.05)	\$7,022.08	\$8,007.04	99.49
TSLA	99.54	n/a	n/a	n/a	n/a	n/a
TSL5	99.74	n/a	n/a	n/a	n/a	n/a
TSL6	99.75	n/a	n/a	n/a	n/a	n/a
Average		7.0%	(0.03)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 3, a 500 kVA single-phase round-tank liquid-immersed distribution transformer. This transformer using the M2CuCu design option combination. The voltage sensitivity analysis found an average increase in price of approximately 4.9% and a reduction in efficiency of 0.04, meaning a design that had otherwise been 99.40 percent efficient, it would now be 99.36 percent efficient.

Table 5D.5 Results of Voltage Sensitivity for Design Line 3, M2CuCu

DL3	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	99.30	4.4%	(0.07)	\$4,455.54	\$4,653.12	99.23
TSL2	99.38	5.5%	(0.04)	\$4,661.25	\$4,916.02	99.34
TSLD	99.38	5.5%	(0.04)	\$4,661.25	\$4,916.02	99.34
TSLC	99.42	3.4%	(0.06)	\$4,900.03	\$5,067.81	99.36
TSLB	99.47	6.0%	(0.02)	\$5,479.85	\$5,807.16	99.45
TSL3	99.46	3.0%	(0.04)	\$5,226.04	\$5,383.42	99.42
TSL4	99.54	6.4%	(0.03)	\$6,510.92	\$6,927.42	99.51
TSLA	99.54	n/a	n/a	n/a	n/a	n/a
TSL5	99.74	n/a	n/a	n/a	n/a	n/a
TSL6	99.75	n/a	n/a	n/a	n/a	n/a
Average		4.9%	(0.04)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 4, a 150 kVA three-phase pad-mount liquid-immersed distribution transformer. This transformer using the M3CuAl design option combination. The voltage sensitivity analysis found an average increase in price of approximately 31.6% and a reduction in efficiency of 0.27, meaning a design that had otherwise been 99.20 percent efficient, it would now be 98.93 percent efficient.

Table 5D.6 Results of Voltage Sensitivity for Design Line 4, M3CuAl

DL4	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	98.90	24.4%	(0.37)	\$2,868.06	\$3,567.36	98.53
TSL2	99.08	33.5%	(0.21)	\$3,460.18	\$4,617.82	98.87
TSLD	99.08	33.5%	(0.21)	\$3,460.18	\$4,617.82	98.87
TSLC	99.08	33.5%	(0.21)	\$3,460.18	\$4,617.82	98.87
TSLB	99.08	33.5%	(0.21)	\$3,460.18	\$4,617.82	98.87
TSL3	99.26	n/a	(0.25)	\$4,757.38	n/a	99.01
TSL4	99.26	n/a	(0.25)	\$4,757.38	n/a	99.01
TSLA	99.19	n/a	(0.44)	\$4,086.81	n/a	98.75
TSL5	99.58	n/a	n/a	n/a	n/a	n/a
TSL6	99.61	n/a	n/a	n/a	n/a	n/a
Average		31.6%	(0.27)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 4, a 150 kVA three-phase pad-mount liquid-immersed distribution transformer. This transformer using the M2CuCu design option combination. The voltage sensitivity analysis found an average increase in price of approximately 27.1% and a reduction in efficiency of 0.26, meaning a design that had otherwise been 99.20 percent efficient, it would now be 98.94 percent efficient.

Table 5D.7 Results of Voltage Sensitivity for Design Line 4, M2CuCu

DL4	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	98.90	18.7%	(0.38)	\$2,949.41	\$3,500.52	98.52
TSL2	99.08	29.1%	(0.28)	\$3,339.14	\$4,312.37	98.80
TSLD	99.08	29.1%	(0.28)	\$3,339.14	\$4,312.37	98.80
TSLC	99.08	29.1%	(0.28)	\$3,339.14	\$4,312.37	98.80
TSLB	99.08	29.1%	(0.28)	\$3,339.14	\$4,312.37	98.80
TSL3	99.26	n/a	(0.21)	\$4,434.48	n/a	99.05
TSL4	99.26	n/a	(0.21)	\$4,434.48	n/a	99.05
TSLA	99.19	n/a	(0.16)	\$4,009.14	n/a	99.03
TSL5	99.58	n/a	n/a	n/a	n/a	n/a
TSL6	99.61	n/a	n/a	n/a	n/a	n/a
Average		27.1%	(0.26)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 5, a 1500 kVA three-phase pad-mount liquid-immersed distribution transformer. This transformer using the M3CuAl design option combination. The voltage sensitivity analysis found an average increase in price of approximately 7.1% and a reduction in efficiency of 0.06, meaning a design that had otherwise been 99.40 percent efficient, it would now be 99.34 percent efficient.

Table 5D.8 Results of Voltage Sensitivity for Design Line 5, M3CuAl

DL5	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	99.30	-0.2%	0.00	\$12,682.26	\$12,651.01	99.30
TSL2	99.36	2.4%	(0.07)	\$13,136.26	\$13,455.19	99.29
TSLD	99.42	8.0%	(0.08)	\$13,905.54	\$15,019.85	99.34
TSLC	99.42	8.0%	(0.08)	\$13,905.54	\$15,019.85	99.34
TSLB	99.47	11.8%	(0.04)	\$17,643.58	\$19,726.28	99.43
TSL3	99.42	8.0%	(0.08)	\$13,905.54	\$15,019.85	99.34
TSL4	99.47	11.8%	(0.04)	\$17,643.58	\$19,726.28	99.43
TSLA	99.54	n/a	n/a	n/a	n/a	n/a
TSL5	99.71	n/a	n/a	n/a	n/a	n/a
TSL6	99.71	n/a	n/a	n/a	n/a	n/a
Average		7.1%	(0.06)			

* MSP is an abbreviation for the Manufacturer's Selling Price.

The following table presents the results for the voltage sensitivity analysis conducted on design line 5, a 1500 kVA three-phase pad-mount liquid-immersed distribution transformer. This transformer using the M2CuCu design option combination. The voltage sensitivity analysis found an average increase in price of approximately 16.9% and a reduction in efficiency of 0.08, meaning a design that had otherwise been 99.40 percent efficient, it would now be 99.32 percent efficient.

Table 5D.9 Results of Voltage Sensitivity for Design Line 5, M2CuCu

DL5	TSL	Change in MSP*	Change in Efficiency	Baseline Voltage MSP	Sensitivity Voltage MSP	Sensitivity Voltage Efficiency
	[%]	[%]	[%]	[\$]	[\$]	[%]
TSL1	99.30	16.6%	(0.11)	\$11,491.76	\$13,404.25	99.19
TSL2	99.36	12.3%	(0.09)	\$12,372.38	\$13,895.03	99.27
TSLD	99.42	16.2%	(0.07)	\$13,466.22	\$15,652.68	99.35
TSLC	99.42	16.2%	(0.07)	\$13,466.22	\$15,652.68	99.35
TSLB	99.47	20.2%	(0.07)	\$15,227.23	\$18,296.21	99.40
TSL3	99.42	16.2%	(0.07)	\$13,466.22	\$15,652.68	99.35
TSL4	99.47	20.2%	(0.07)	\$15,227.23	\$18,296.21	99.40
TSLA	99.54	9.0%	(0.07)	\$22,348.02	\$24,355.59	99.47
TSL5	99.71	n/a	n/a	n/a	n/a	n/a
TSL6	99.71	n/a	n/a	n/a	n/a	n/a
Average		16.9%	(0.08)			

* MSP is an abbreviation for the Manufacturer's Selling Price.