

APPENDIX 8I. TRIAL STANDARD LEVEL CONSISTENCY OF SINGLE-PHASE AND THREE-PHASE TRANSFORMERS

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APPENDIX 8I. TRIAL STANDARD LEVEL CONSISTENCY OF SINGLE-PHASE AND THREE-PHASE TRANSFORMERS

8I.1 INTRODUCTION

This appendix contains a review of the degree of consistency of the efficiency ratings within the trial standard levels considered for single-phase and three-phase transformers. The issue of consistency only affects liquid-immersed distribution transformers, because single-phase and three-phase units were analyzed separately. For medium-voltage dry-type units, the higher shipment volume three-phase units were analyzed, and the single-phase standard levels were scaled from the three-phase standard levels.

There are two kinds of consistency issues associated with the trial standard levels considered for liquid-immersed distribution transformers, 1) continuity across capacities (or kVA ratings) at the interfaces between design lines, called “Inter-Phase Consistency”, and 2) consistency of minimum efficiency values for single and three phase transformers, called “Between-Phase Consistency.”

- 1) Inter-Phase Consistency – this concerns consistency issues as they relate to the efficiency values within all the single-phase or all the three-phase transformers. DOE analyzed multiple baseline models, three single-phase kVA ratings and two three-phase kVA ratings. Each of these five baseline models analyzed had its only range of applicable kVA ratings, called ‘design lines’. Inter-Phase consistency pertains to the interface between the design lines, and whether the step increase in efficiency is consistent with the other increments above and below. This issue is discussed in sections 8I.3 and 8I.4.
- 2) Between-Phase Consistency – this concerns consistency of the efficiency values between single-phase transformers and the per-phase kVA equivalent three-phase transformers. Because single-phase units were analyzed separately from three-phase units, the resultant efficiency values were not always consistent. Between-Phase consistency pertains to trial standard levels 2 through 6, but is not an issue for trial standard level 1, A, B, C or D. This issue is discussed and illustrated in section 8I.5.

8I.2 FINAL RULE TRIAL STANDARD LEVELS

The following two tables present all the trial standard levels that were considered by DOE in its Energy Conservation Standards Final Rule for Distribution Transformers. The second table, which presents the three-phase efficiency ratings has a column marked ‘kVA/phase’, which shows the kVA rating per phase for these three-phase transformers. When making a comparison of the efficiency value between the single-phase table and the three-phase table, the kVA/phase column of values should be used to determine equivalency. For example, note that in the first table, the 50 kVA single-phase transformer has a TSL1 efficiency value of 98.9. In the second table, the 150 kVA three-phase (kVA per phase equivalent to the 50 kVA single-phase) transformer has a TSL1 efficiency value of 98.9. Thus, a comparison of these two transformers in these two tables reveals no consistency issue between single-phase and three-phase at that kVA rating.

An Inter-Phase consistency problem can be observed in the second (three-phase) table of efficiency values, considering the efficiency ratings under TSL4 for 500 and 750 kVA transformers. The efficiency level drops for the higher kVA rating, which is counter-intuitive. A Between-Phase consistency problem can be observed comparing the efficiency requirements at TSL for 50 kVA single-phase (99.04%) with the 150 kVA three-phase (99.26%) – the three-phase is considerably higher, and is inconsistent with its single-phase counterpart.

Table 8I.1 Efficiency Values for Single-Phase kVA Ratings and all Trial Standard Levels

kVA	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6	TSLA	TSLB	TSLC	TSLD
10	98.4	98.40	98.44	98.48	98.69	99.32	98.79	98.62	98.62	98.56
15	98.6	98.56	98.59	98.63	98.82	99.39	98.91	98.76	98.76	98.70
25	98.7	98.73	98.76	98.79	98.96	99.46	99.04	98.91	98.91	98.79
37.5	98.8	98.85	98.88	98.91	99.06	99.51	99.13	99.01	99.01	98.97
50	98.9	98.90	98.90	99.04	99.19	99.59	99.19	99.08	99.08	99.04
75	99.0	99.04	99.06	99.08	99.21	99.59	99.27	99.17	99.17	99.13
100	99.0	99.10	99.12	99.14	99.26	99.62	99.32	99.23	99.23	99.19
167	99.1	99.21	99.23	99.25	99.35	99.66	99.40	99.32	99.27	99.29
250	99.2	99.26	99.36	99.45	99.69	99.70	99.45	99.37	99.31	99.26
333	99.2	99.31	99.40	99.49	99.71	99.72	99.49	99.41	99.36	99.31
500	99.3	99.38	99.46	99.54	99.74	99.75	99.54	99.47	99.42	99.38
667	99.4	99.42	99.50	99.57	99.76	99.77	99.57	99.51	99.46	99.42
833	99.4	99.45	99.52	99.60	99.77	99.78	99.60	99.53	99.49	99.45

Table 8I.2 Efficiency Values for Three-Phase kVA Ratings and all Trial Standard Levels

kVA	kVA / Phase	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6	TSLA	TSLB	TSLC	TSLD
15	5	98.1	98.36	98.68	98.68	99.25	99.31	98.56	98.36	98.36	98.36
30	10	98.4	98.62	98.89	98.89	99.37	99.42	98.79	98.62	98.62	98.62
45	15	98.6	98.76	99.00	99.00	99.43	99.47	98.91	98.76	98.76	98.76
75	25	98.7	98.91	99.12	99.12	99.50	99.54	99.04	98.91	98.91	98.91
112.5	38	98.8	99.01	99.20	99.20	99.55	99.58	99.13	99.01	99.01	99.01
150	50	98.9	99.08	99.26	99.26	99.58	99.61	99.19	99.08	99.08	99.08
225	75	99.0	99.17	99.33	99.33	99.62	99.65	99.27	99.17	99.17	99.17
300	100	99.0	99.23	99.38	99.38	99.65	99.67	99.32	99.23	99.23	99.23
500	167	99.1	99.32	99.45	99.45	99.69	99.71	99.40	99.32	99.27	99.32
750	250	99.2	99.24	99.31	99.37	99.66	99.66	99.45	99.37	99.31	99.31
1000	333	99.2	99.29	99.36	99.41	99.68	99.68	99.49	99.41	99.36	99.36
1500	500	99.3	99.36	99.42	99.47	99.71	99.71	99.54	99.47	99.42	99.42
2000	667	99.4	99.40	99.46	99.51	99.73	99.73	99.57	99.51	99.46	99.46
2500	833	99.4	99.44	99.49	99.53	99.74	99.74	99.60	99.53	99.49	99.49

8I.3 SINGLE-PHASE TRANSFORMERS – INTER-PHASE CONSISTENCY

The following table presents the incremental increases in efficiency observed for all the trial standard levels considered for liquid-immersed single-phase transformers. The smaller kVA ratings (i.e., 10 through 167) are represented by analysis on a 25 kVA pole-mount and a 50 kVA pad-type distribution transformer. The larger kVA ratings (i.e., 250 through 833) are represented by analysis on a 500 kVA single-phase round-tank. Generally, the numerical increase in efficiency is greatest at the smaller kVA ratings, and decreases gradually as the kVA rating increases.

Table 8I.3 Increase in Efficiency Values for Single-Phase kVA Ratings

kVA	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6	TSLA	TSLB	TSLC	TSLD
10										
15	0.200	0.160	0.150	0.150	0.130	0.070	0.117	0.133	0.133	0.138
25	0.100	0.170	0.170	0.160	0.140	0.070	0.134	0.153	0.153	0.087
37.5	0.100	0.120	0.120	0.120	0.100	0.050	0.090	0.101	0.101	0.178
50	0.100	0.050	0.020	0.130	0.130	0.080	0.060	0.069	0.069	0.072
75	0.100	0.140	0.160	0.040	0.020	-	0.078	0.089	0.089	0.093
100	-	0.060	0.060	0.060	0.050	0.030	0.051	0.058	0.058	0.060
167	0.100	0.110	0.110	0.110	0.090	0.040	0.082	0.093	0.044	0.097
250	0.100	0.050	0.130	0.200	0.340	0.040	0.052	0.050	0.044	(0.027)
333	-	0.050	0.040	0.040	0.020	0.020	0.038	0.044	0.044	0.051
500	0.100	0.070	0.060	0.050	0.030	0.030	0.049	0.057	0.062	0.066
667	0.100	0.040	0.040	0.030	0.020	0.020	0.032	0.037	0.040	0.043
833	-	0.030	0.020	0.030	0.010	0.010	0.023	0.027	0.029	0.031

The following figure illustrates the incremental increases in efficiency values for TSL2, the level that DOE proposed in the 2006 notice of proposed rulemaking. In this histogram, the general trend of decreasing incremental increases in efficiency with larger kVA ratings is evident. In addition, the transition between the small and large kVA ratings (which occurs between 167 and 250kVA) is hardly perceivable. The incremental change in efficiency between those two ratings is in line with the magnitude of other incremental changes at similar kVA ratings.

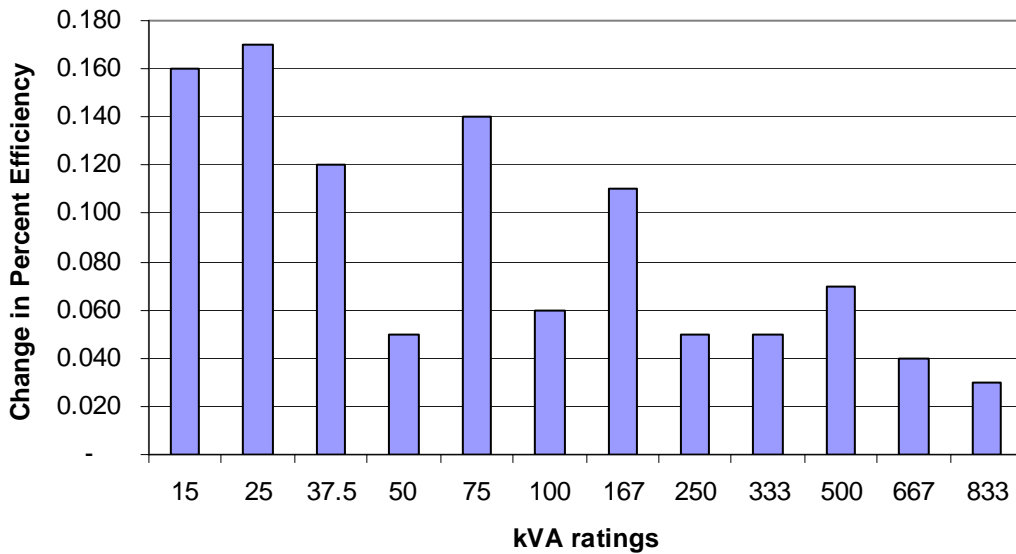


Figure 8I.1 Incremental Increases in Single-Phase Efficiency for TSL2

The following two plots illustrate where the inter-phase consistency issue is particularly problematic, TSLs 4 and 5. For these two plots, the required increase in efficiency for the 250 kVA is not in line with the transformers above and below the 250 kVA, and consequently, the standard level is inconsistent across the kVA ratings.

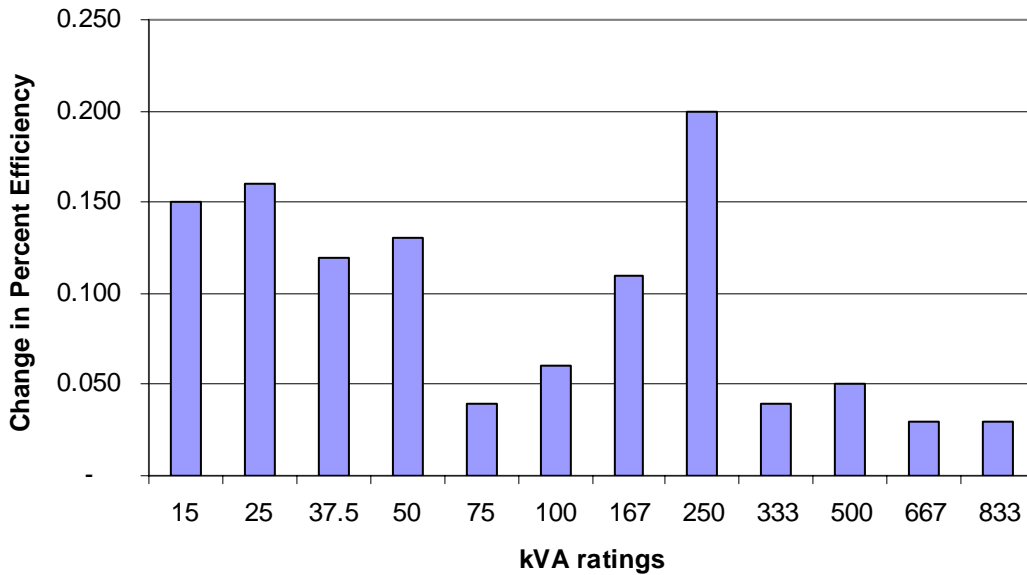


Figure 8I.2 Incremental Increases in Single-Phase Efficiency for TSL4

The relative magnitude of that difference is even more pronounced at TSL5, where the efficiency increase between 167 and 250 is more than double any other efficiency increase between any other two single-phase liquid-immersed kVA ratings.

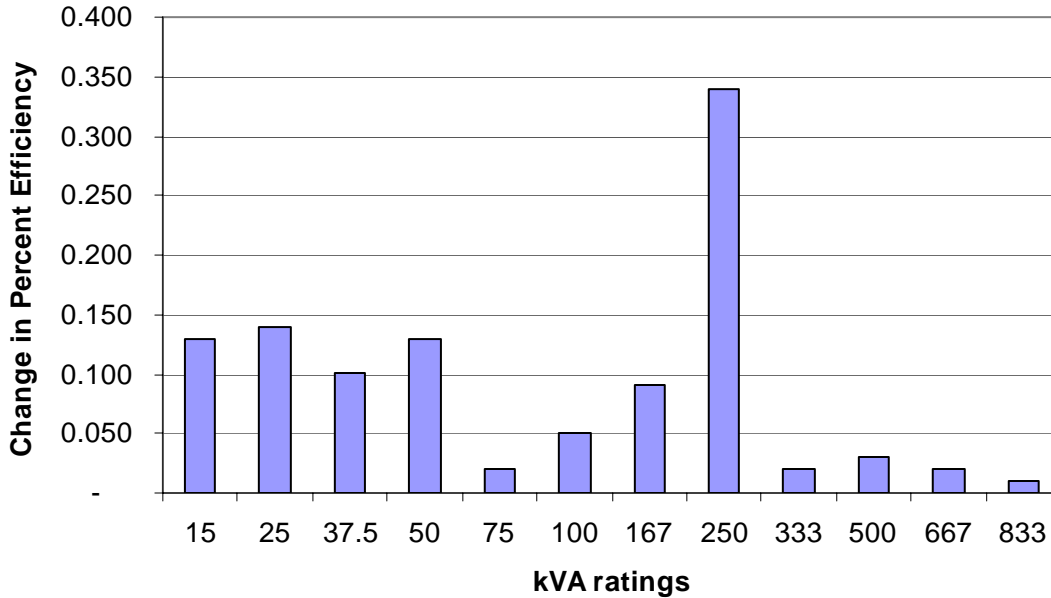


Figure 8I.3 Incremental Increases in Single-Phase Efficiency for TSL5

8I.4 THREE-PHASE TRANSFORMERS – INTER-PHASE CONSISTENCY

The following table presents the incremental increases in efficiency observed for all the trial standard levels considered for liquid-immersed three-phase transformers. The smaller kVA ratings (i.e., 15 through 500) are represented by analysis on a 150 kVA pad-mount three-phase distribution transformer. The larger kVA ratings (i.e., 750 through 2500) are represented by analysis on a 1500 kVA three-phase pad mount. The transition between the smaller and larger kVA ratings occurs between the 500 and 750 kVA ratings, and is presented in the 750 kVA row of the table. The discontinuity between the smaller and larger kVA ratings analyzed for three-phase liquid-immersed transformers is immediately evident in the negative increment shown for several TSLs, between 500 and 750: TSL2, TSL3, TSL4, TSL5, TSL6 and TSLD. In all of these cases, the efficiency rating for the 750 kVA unit is lower than the requirement of the 500 kVA unit.

As for the single-phase units, the general trend is for the incremental increase in efficiency to decrease as the kVA rating increases.

Table 8I.4 Increase in Efficiency Values for Three-Phase kVA Ratings

kVA	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6	TSLA	TSLB	TSLC	TSLD
15										
30	0.300	0.260	0.210	0.210	0.120	0.110	0.229	0.260	0.260	0.260
45	0.200	0.140	0.110	0.110	0.060	0.050	0.117	0.133	0.133	0.133
75	0.100	0.150	0.120	0.120	0.070	0.070	0.131	0.149	0.149	0.149
112.5	0.100	0.100	0.080	0.080	0.050	0.040	0.093	0.105	0.105	0.105
150	0.100	0.070	0.060	0.060	0.030	0.030	0.060	0.069	0.069	0.069
225	0.100	0.090	0.070	0.070	0.040	0.040	0.078	0.089	0.089	0.089
300	-	0.060	0.050	0.050	0.030	0.020	0.051	0.058	0.058	0.058
500	0.100	0.090	0.070	0.070	0.040	0.040	0.082	0.093	0.044	0.093
750	0.100	(0.080)	(0.140)	(0.080)	(0.030)	(0.050)	0.052	0.051	0.044	(0.009)
1000	-	0.050	0.050	0.040	0.020	0.020	0.038	0.044	0.044	0.048
1500	0.100	0.070	0.060	0.060	0.030	0.030	0.049	0.057	0.062	0.062
2000	0.100	0.040	0.040	0.040	0.020	0.020	0.032	0.037	0.040	0.040
2500	-	0.040	0.030	0.020	0.010	0.010	0.023	0.027	0.029	0.029

The following figure illustrates the incremental increases in efficiency values for TSLC. In this histogram, the general trend of decreasing incremental increases in efficiency with larger kVA ratings is evident. In addition, the transition between the small and large kVA ratings (which occurs between 500 and 750kVA) is hardly perceivable. The incremental change in efficiency between those two ratings is in line with the magnitude of other incremental changes at similar kVA ratings.

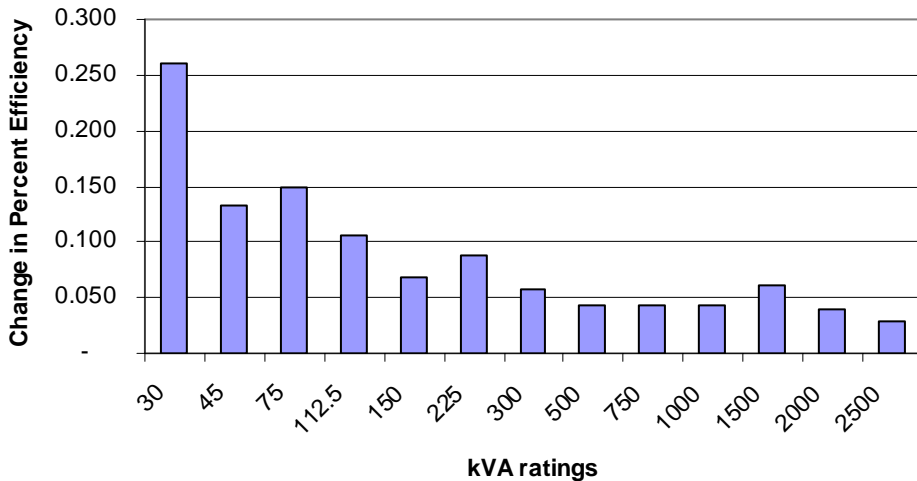


Figure 8I.4 Incremental Increases in Three-Phase Efficiency for TSLC

The following two plots illustrate where the inter-phase consistency issue is particularly problematic, TSLs 3 and 4. For these two plots, the efficiency transition between the 500 and 750 kVA transformer is negative, depicting a lower efficiency requirement for the higher kVA rating.

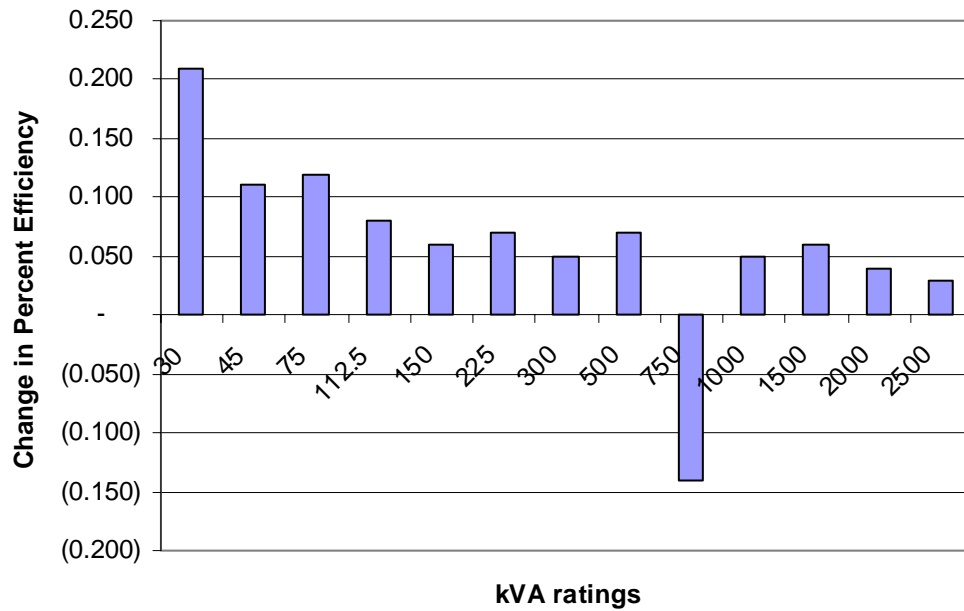


Figure 8I.5 Incremental Increases in Three-Phase Efficiency for TSL3

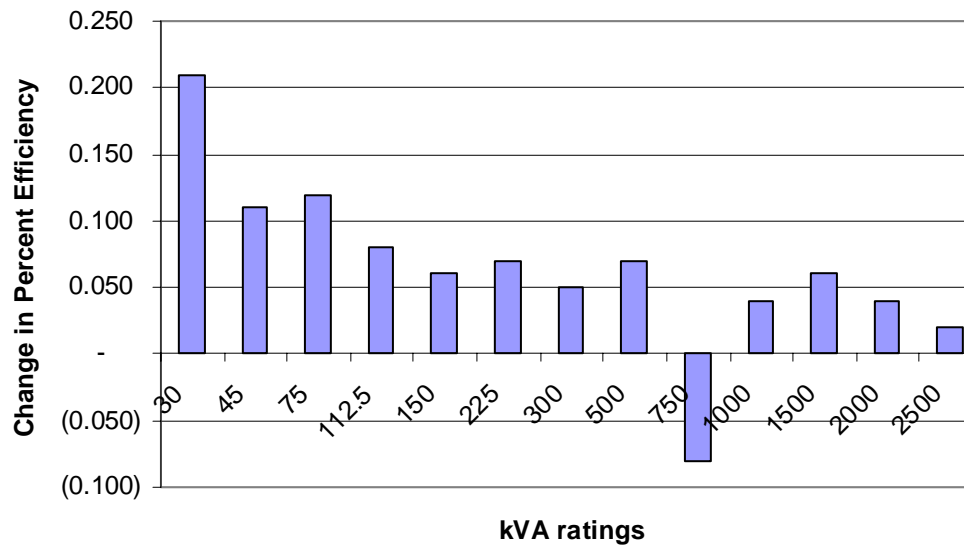


Figure 8I.6 Incremental Increases in Three-Phase Efficiency for TSL4

8I.5 CONSISTENCY BETWEEN SINGLE-PHASE AND THREE-PHASE

This section presents plots for all the TSLs which have inconsistent efficiency requirements for the kVA ratings. Only those TSLs which have inconsistent values between single-phase and their three-phase equivalents are presented. Thus, TSL1, TSLA, TSLB, and TSLC are not plotted in this section. For each of these four TSLs, the efficiency requirements of the single-phase liquid-immersed transformers is identical to their three-phase per kVA liquid-immersed equivalents.

For TSL2, the three-phase standard is higher (more stringent) than the single-phase standard at smaller kVA ratings, but lower (less stringent) than the single-phase at larger kVA ratings.

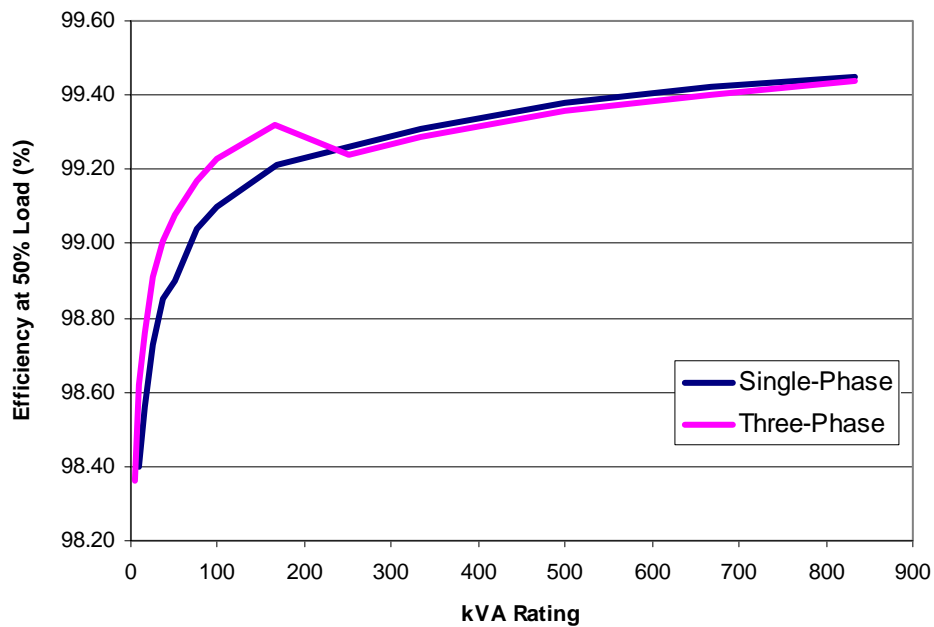


Figure 8I.7 Inconsistency Between Phases at TSL2

For TSL3, the three-phase standard is higher (more stringent) than the single-phase standard at smaller kVA ratings, but lower (less stringent) than the single-phase at larger kVA ratings.

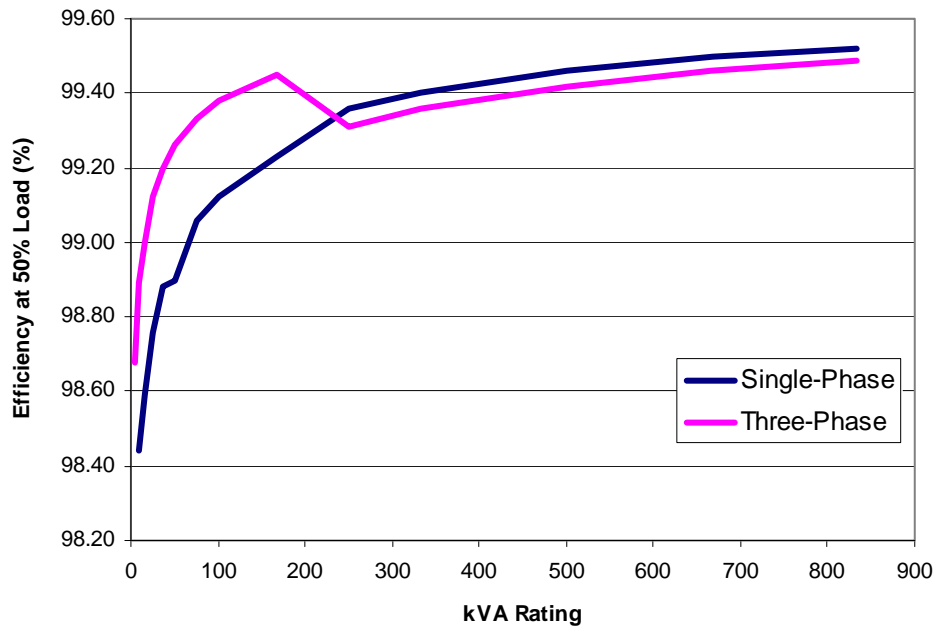


Figure 8I.8 Inconsistency Between Phases at TSL3

For TSL4, the three-phase standard is higher (more stringent) than the single-phase standard at smaller kVA ratings, but lower (less stringent) than the single-phase at larger kVA ratings.

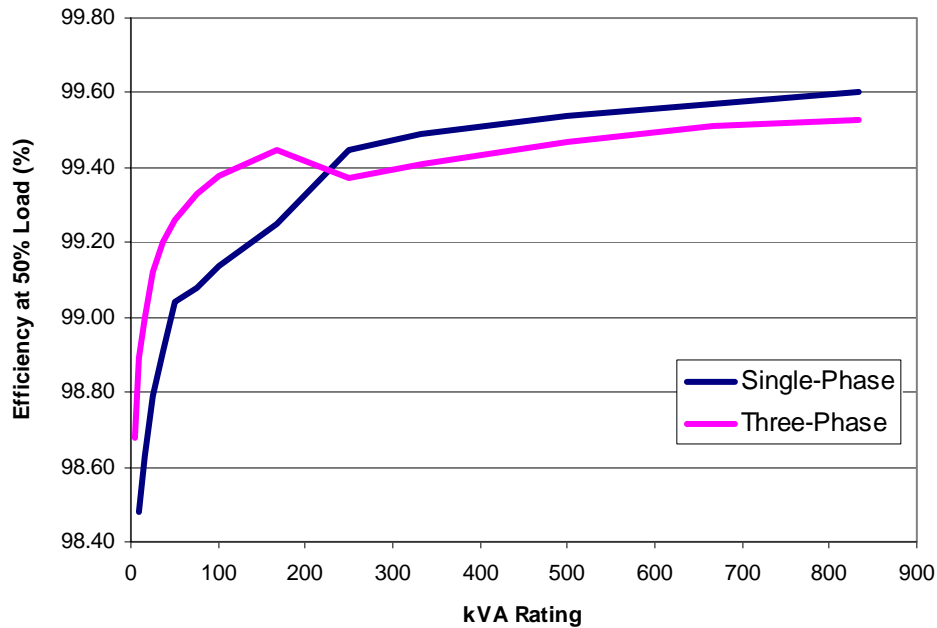


Figure 8I.9 Inconsistency Between Phases at TSL4

For TSL5, the three-phase standard is higher (more stringent) than the single-phase standard at smaller kVA ratings, but lower (less stringent) than the single-phase at larger kVA ratings. In addition, there is considerable disparity in the efficiency requirements between the phases for the smaller kVA transformers.

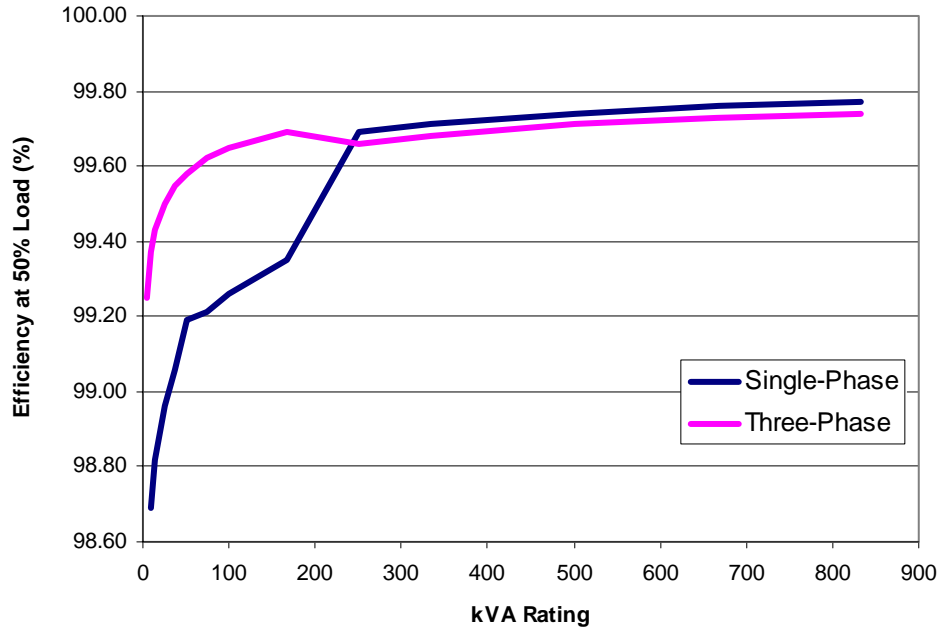


Figure 8I.10 Inconsistency Between Phases at TSL5

For TSL6, the three-phase standard is higher (more stringent) than the single-phase standard at smaller kVA ratings, but lower (less stringent) than the single-phase at larger kVA ratings.

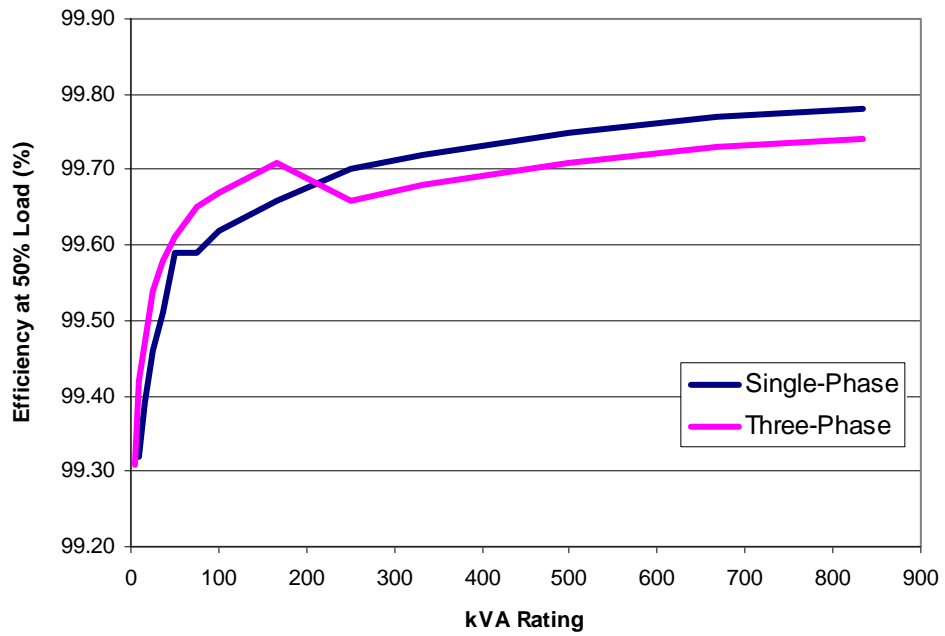


Figure 8I.11 Inconsistency Between Phases at TSL6

For TSLD, the three-phase standard is higher (more stringent) than the single-phase standard at all kVA ratings.

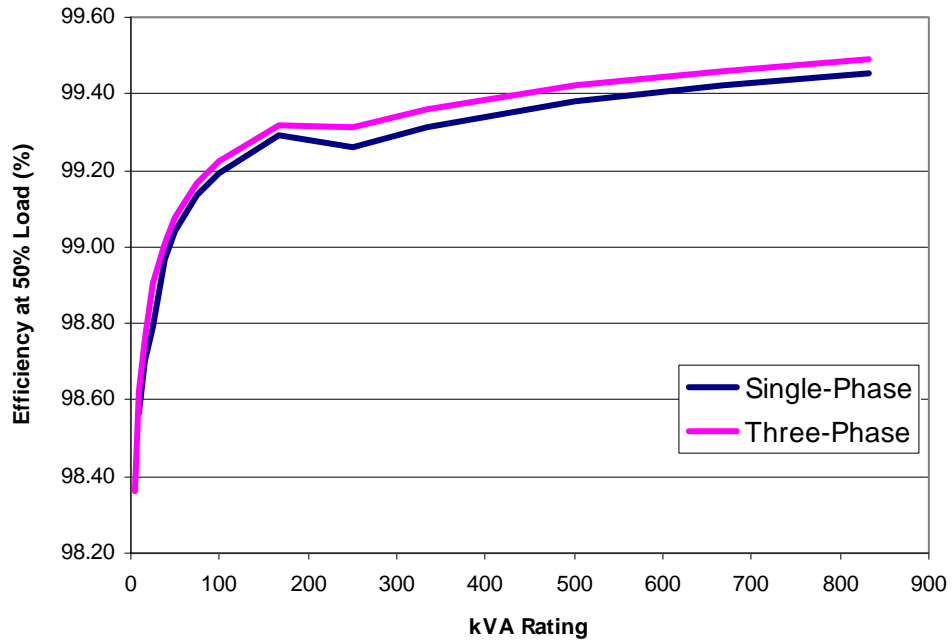


Figure 8I.12 Inconsistency Between Phases at TSLD