White Paper – Analysis of Cross-Over Points for Grain-Oriented Electrical Steel and Amorphous Ribbon for the MVLT Superclass

Cross-over points for the Medium Voltage Liquid Filled distribution transformer super-class have been analyzed based on the Engineering Analysis provided by the Department of Energy. For the purpose of this white paper, a cross-over point is defined as where the low-cost curve fitted to the point cloud for all of the transformers with M-3 grain-oriented electrical steel core designs crosses the low-cost curve fitted to the point cloud for all of the transformers with amorphous (SA1) core designs.

This analysis is based on the data from the DOE Engineering Analysis. It excludes uncorroborated data from external sources. The 2010 pricing scenario was used, as it is the most consistent and includes optimized engineering designs. The 2011 pricing scenario which was advocated late in the Negotiated Rulemaking process was excluded because it misrepresents the relative costs of M-3 grain-oriented electrical steel and amorphous ribbon (the steelmaker and transformer members of the committee confirmed that the 2011 M-3 price was incorrect and significantly lower than the actual 2011 M-3 price thus invalidating the 2011 analyses).

In summary to ensure that M-3 and SA1 remain as cost competitive core material alternatives for the MVLT design lines the following conclusions can be drawn:

Cross-Over Points for Equipment Class 01 (Single Phase)

- The cross-over point for Design Line 01 (50 kVA pad mount) is at 99.18%. The efficiency in the NOPR was set at EL01, which corresponds, before scaling, to 99.16%, and after scaling to 99.11%. The first cost difference between a Design Line 01 transformer with an M-3 core and an amorphous core is less than 10% at a mandated EL01 (scaled).
- The cross-over point for Design Line 02 (25 kVA pole mount) is less than the current baseline EL0 level of 98.91%. The efficiency in the NOPR was set at EL0, which corresponds, before scaling, to 98.91%, and after scaling to 98.95%. A Design Line 02 transformer with an M-3 core is at a nominal 12% first cost disadvantage to the corresponding amorphous core at a mandated EL0 (scaled).
- The cross-over point for Design Line 03 (500 kVA) is at 99.45%. The efficiency in the NOPR was set at EL01, which corresponds, before scaling, to 99.48%, and after scaling to 99.49%. A Design Line 03 transformer with an M-3 core is at a nominal 10% first cost disadvantage to the corresponding amorphous core unit at a mandated EL01 (scaled).

Cross-Over Points for Equipment Class 02 (Three Phase)

- The cross-over point for Design Line 04 (150 kVA) is at 99.15%. The efficiency in the NOPR was set at EL01, which corresponds to 99.16%. The first cost difference between The first cost difference between a Design Line 04 transformer with an M-3 core and an amorphous core is less than 10% at a mandated EL01.
- The cross-over point for Design Line 05 (1,500 kVA) is at 99.44%. The efficiency in the NOPR is set at EL01, which corresponds to 99.48%. A Design Line 05 transformer with an M-3 core is at a nominal 15% first cost disadvantage to the corresponding amorphous core unit at a mandated EL01.

Recommendations

- The mandatory efficiency of Design Line 02 should be changed to reflect the closest efficiency level to the cross-over point without backsliding relative to the current regulation, which is 98.91% (EL0).
- The mandatory efficiency for Design Line 05 should be changed to reflect the closest efficiency increment to the cross-over point, which is 99.44%

Overview

The purpose of this white paper is to define where the different types of viable core materials, notably grain-oriented electrical steel and amorphous ribbon, are in a state of balance in terms of competitiveness in a mandated efficiency scenario for medium voltage, liquid filled distribution transformers. This is done by determining where the cost curves for transformers containing different core materials intersect.

The cross-over points for the Medium Voltage Liquid Filled distribution transformer super-class have been analyzed based on the Engineering Analysis provided by the Department of Energy. For the purpose of this analysis, a cross-over point is defined as where the low-cost curve fitted to the point cloud for all of the transformers with M-3 core steel designs crosses the low-cost curve fitted to the point cloud for all of the transformers with amorphous (SA1) core designs. If the crossover occurs between efficiency increments (corresponding to one-thousandth of a percent) the closer of the two levels was selected.

The 2010 pricing scenario was used, as it seems to be the best characterized and most accurate representation, and includes optimized engineering designs for all of the Design Lines. For core materials, the 2010 M-3 price is set at $1.88 per pound, and the 2010 amorphous ribbon price is set at $2.38 per pound of finished core weight. This analysis is based strictly on the data from the DOE Engineering Analysis, downloaded from the DOE Distribution Transformer web site as a spreadsheet file.

The 2011 pricing scenario which was advocated late in the Negotiated Rulemaking process was excluded because it misrepresents the relative costs of M-2 and M-3 grain-oriented electrical steel and amorphous ribbon by significantly discounting the cost of M-2 and M-3 strip (30% discount) relative to amorphous cores (8% discount). This artificially reduces the cost of transformers with conventional grain-oriented electrical steel cores, biasing the analysis. In addition, the designs were not re-optimized for this scenario.

Analysis for Design Line 01

- The cross-over point for Design Line 01 (50 kVA pad mount) is at 99.18% (Figure 2).
- The efficiency in the NOPR is set at EL01, which corresponds, before scaling, to 99.16%,
- The efficiency in the NOPR after scaling is set at 99.11%.
- The first cost difference between a Design Line 01 transformer with an M-3 core and an amorphous core is less than 10% at a mandated EL01 (scaled).
- The lowest-cost M-3 design at EL02 is at a 19% cost disadvantage relative to amorphous core.

Figure 1 – lowest first cost curves for Design Line 01

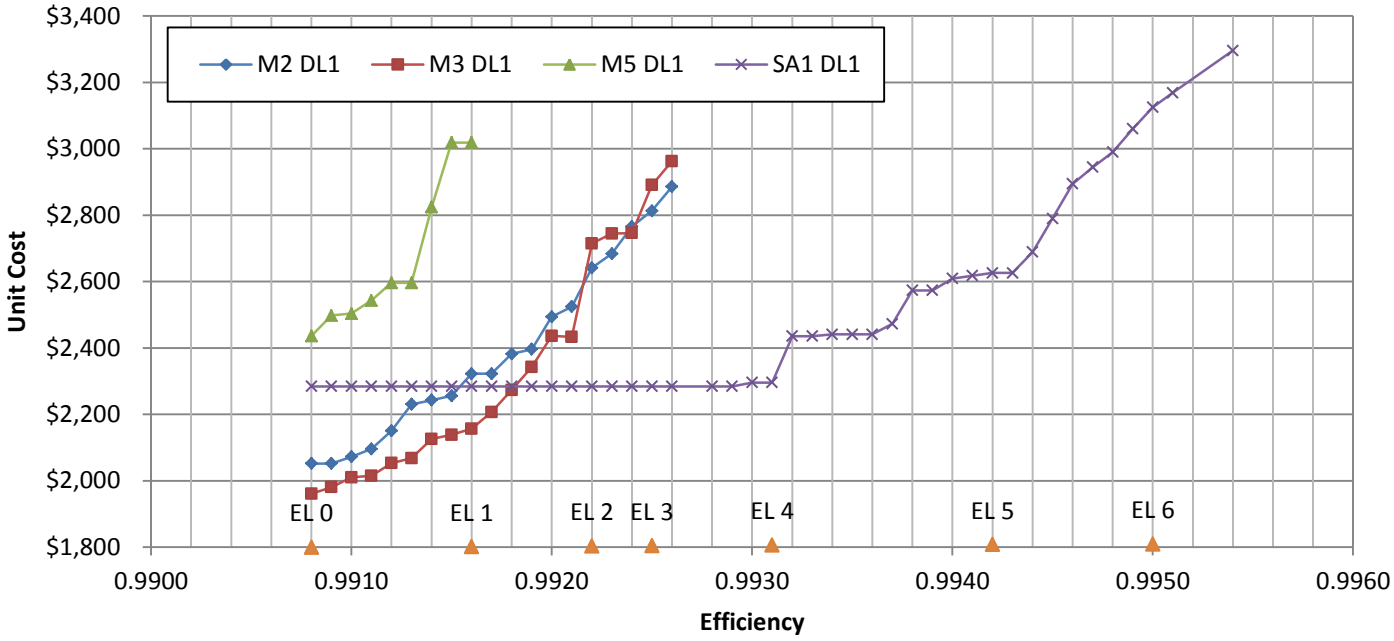
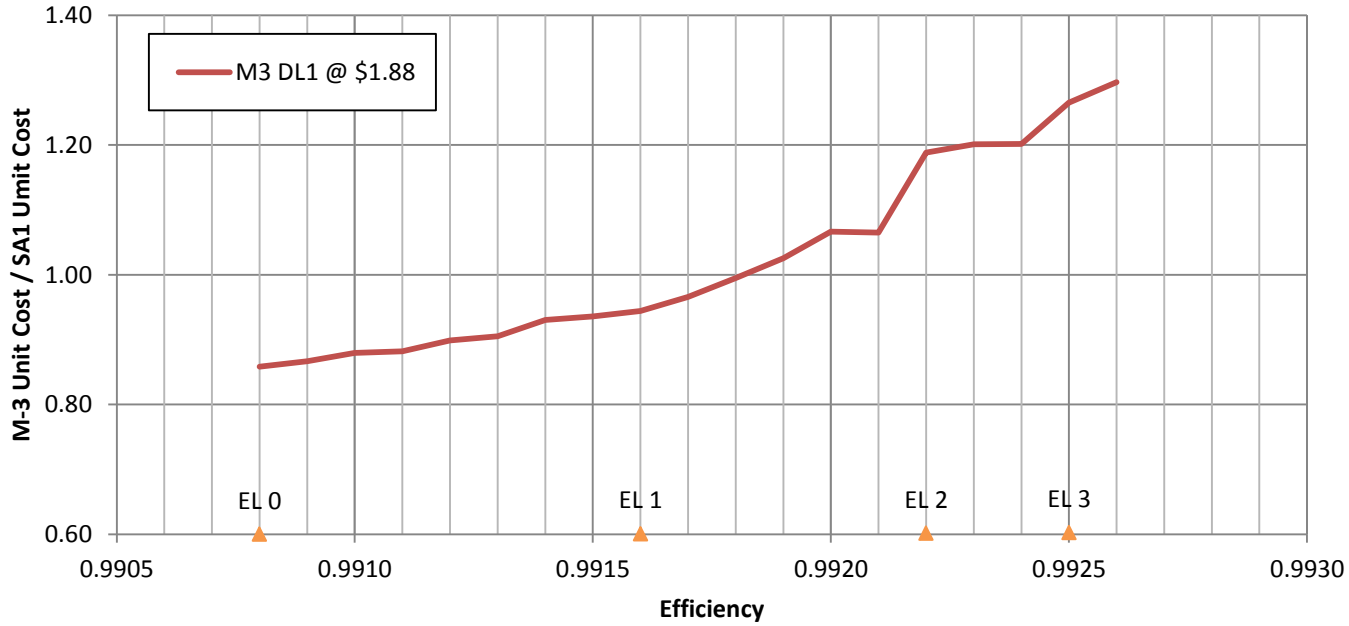


Figure 2 –relative cost of an M-3 unit versus an SA1 unit for Design Line 01



Analysis for Design Line 02

- The cross-over point for Design Line 02 (25 kVA pole mount) is less than the current mandatory efficiency level of 98.91%, in place effective January 01, 2010 (Figure 4).
- The efficiency in the NOPR is set at EL0, which corresponds, before scaling, to 98.91%.
- The efficiency in the NOPR after scaling for Equipment Class 01 is set at 98.95%.
- A Design Line 02 transformer with an M-3 core is at a nominal 12% first cost disadvantage to the corresponding amorphous core at a mandated EL0 (scaled).
- **It is recommended that the Final Rule should be modified from the NOPR to incorporate no change to the current efficiency level of 98.91%.**
- At EL0 (not scaled) the first cost difference between a Design Line 01 transformer with an M-3 core and an amorphous core is less than 10%.
- **There are no viable M-3 designs at EL02.**

Figure 3 – lowest first cost curves for Design Line 02

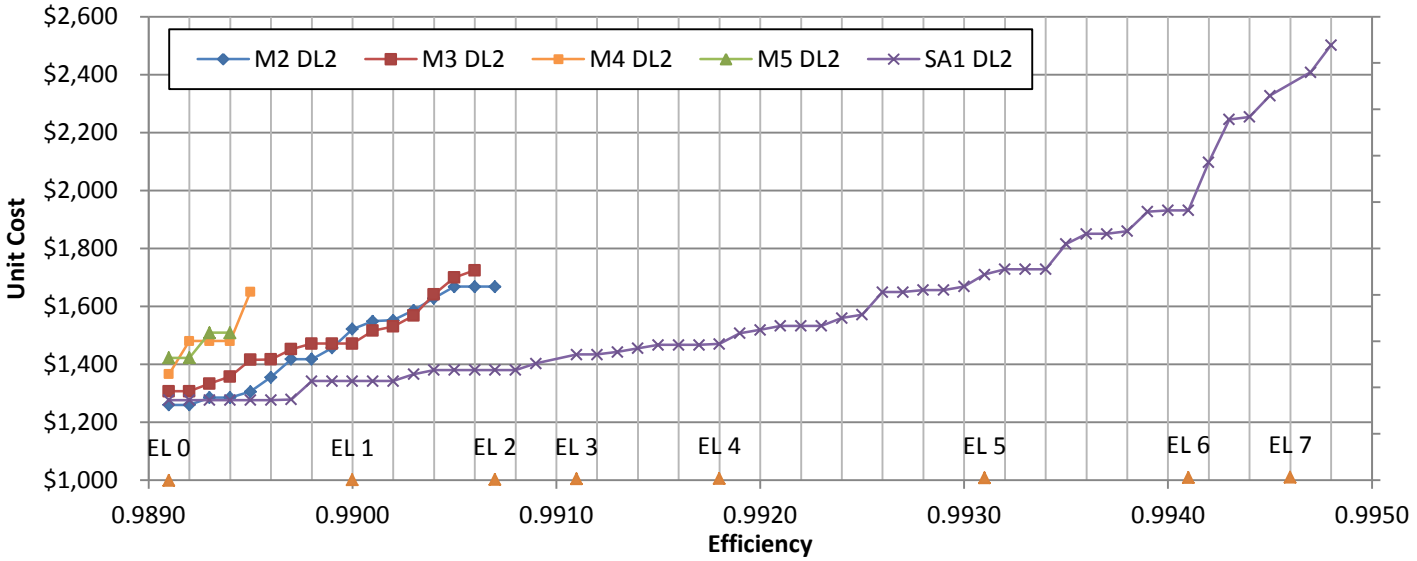
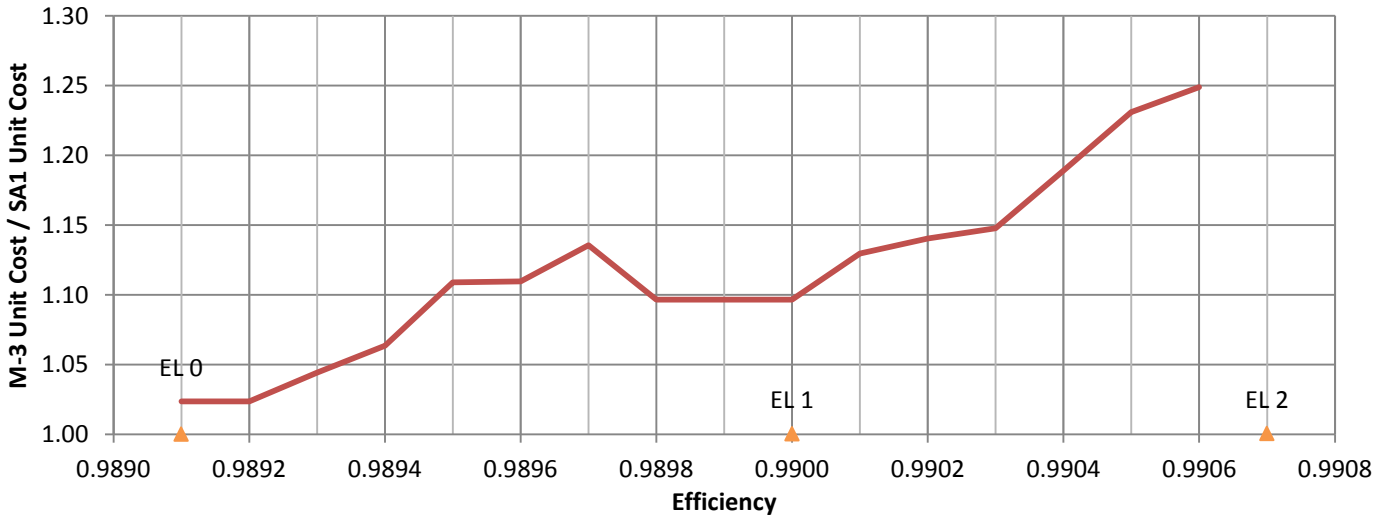


Figure 4 –relative cost of an M-3 unit versus an SA1 unit for Design Line 02



Analysis for Design Line 03

- The cross-over point for Design Line 03 (500 kVA) is at 99.45% (Figure 6).
- The efficiency in the NOPR is set at EL01, which corresponds, before scaling, to 99.48%
- The efficiency in the NOPR after scaling is set at 99.49%.
- The first cost difference between a Design Line 03 transformer with an M-3 core and an amorphous core is less than 10% at a mandated EL01 (scaled).
- The lowest-cost M-3 design at EL02 is at a 16% cost disadvantage relative to amorphous core. However, EL02 coincides with an inflection point where the cost disadvantage increases sharply to 40% or more. **This means that effectively there are no truly viable M-3 designs at EL02.**

Figure 5 – lowest first cost curves for Design Line 03

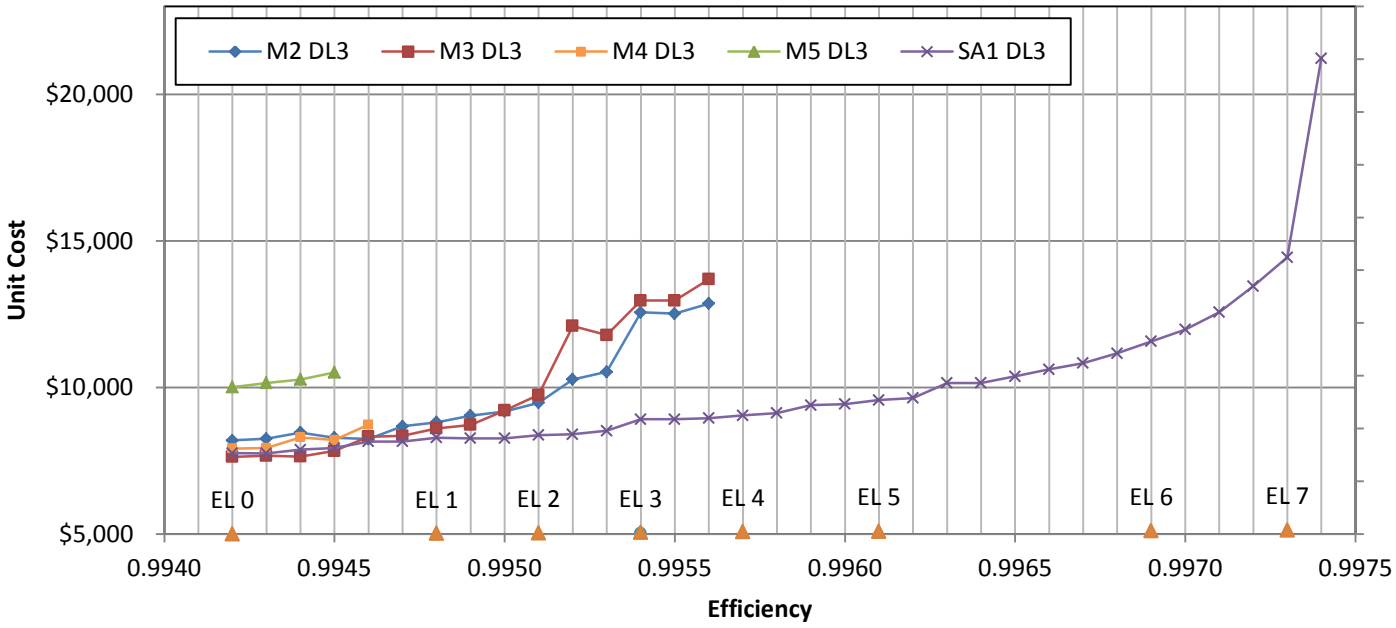
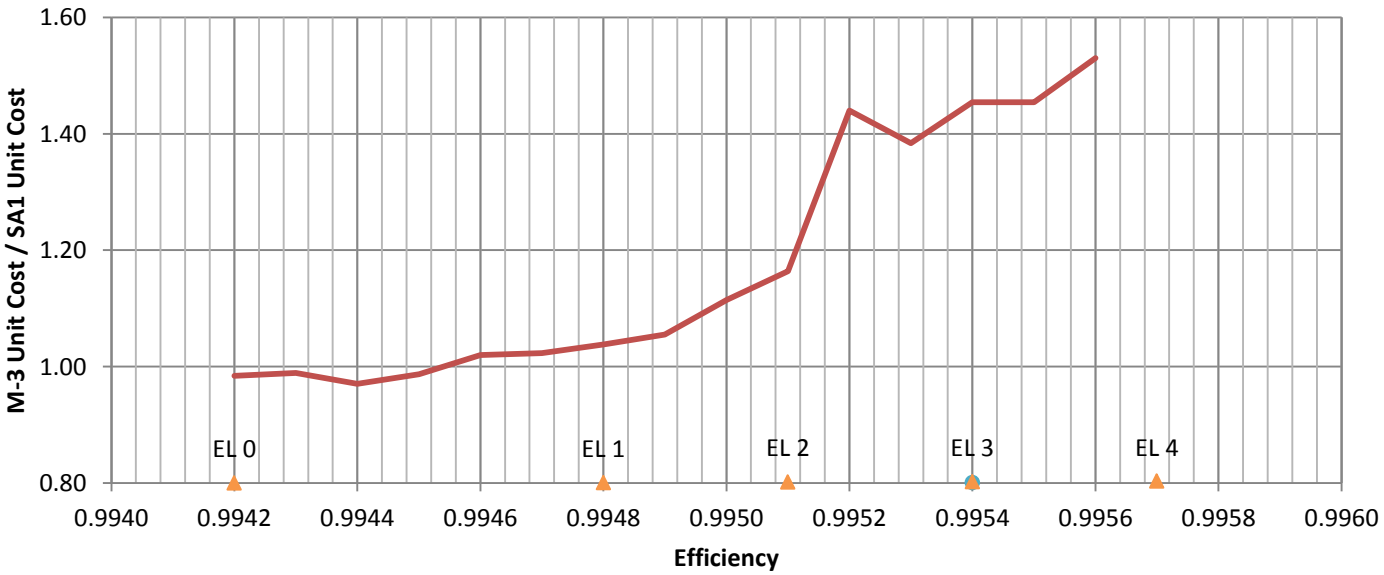


Figure 6 –relative cost of an M-3 unit versus an SA1 unit for Design Line 03



Analysis for Design Line 04

- The cross-over point for Design Line 04 (150 kVA) is at 99.15% (Figure 8).
- The efficiency in the NOPR is set at EL01, which corresponds to 99.16%.
- The first cost difference between a Design Line 04 transformer with an M-3 core and an amorphous core is less than 10% at a mandated EL01.
- **The lowest-cost M-3 design at EL02 is at a 28% cost disadvantage relative to amorphous core and is not a viable option.**

Figure 7 – lowest first cost curves for Design Line 04

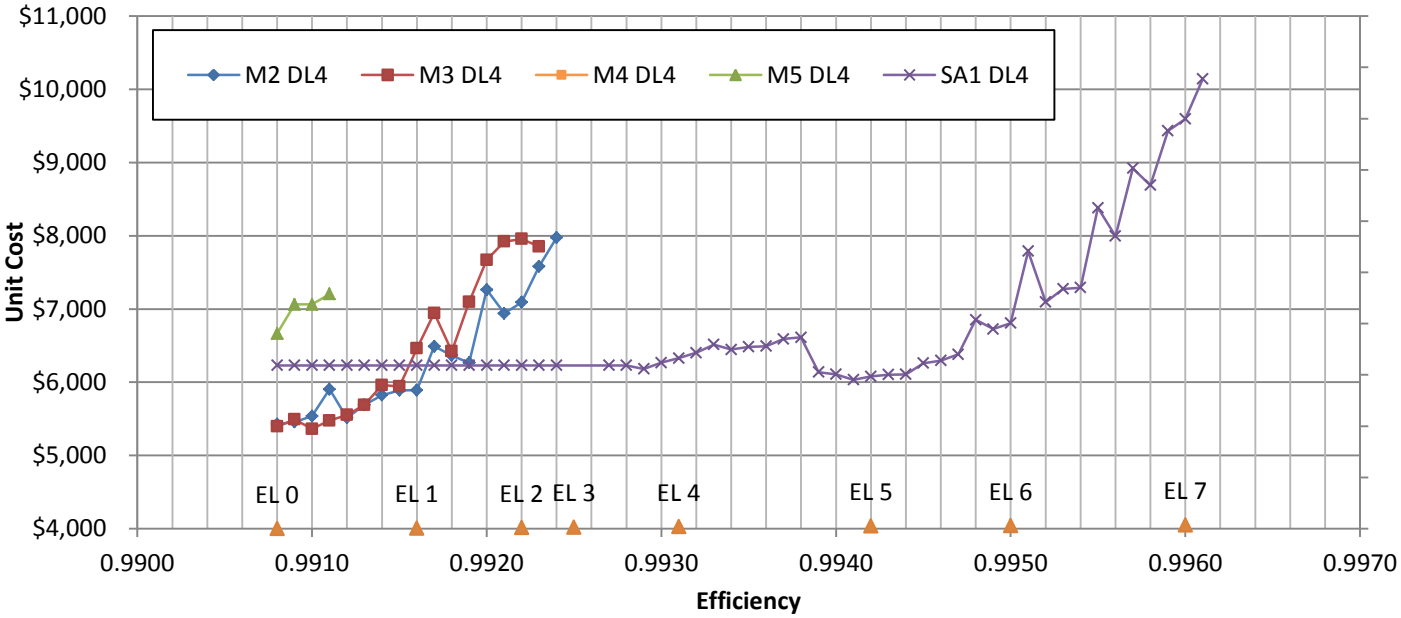
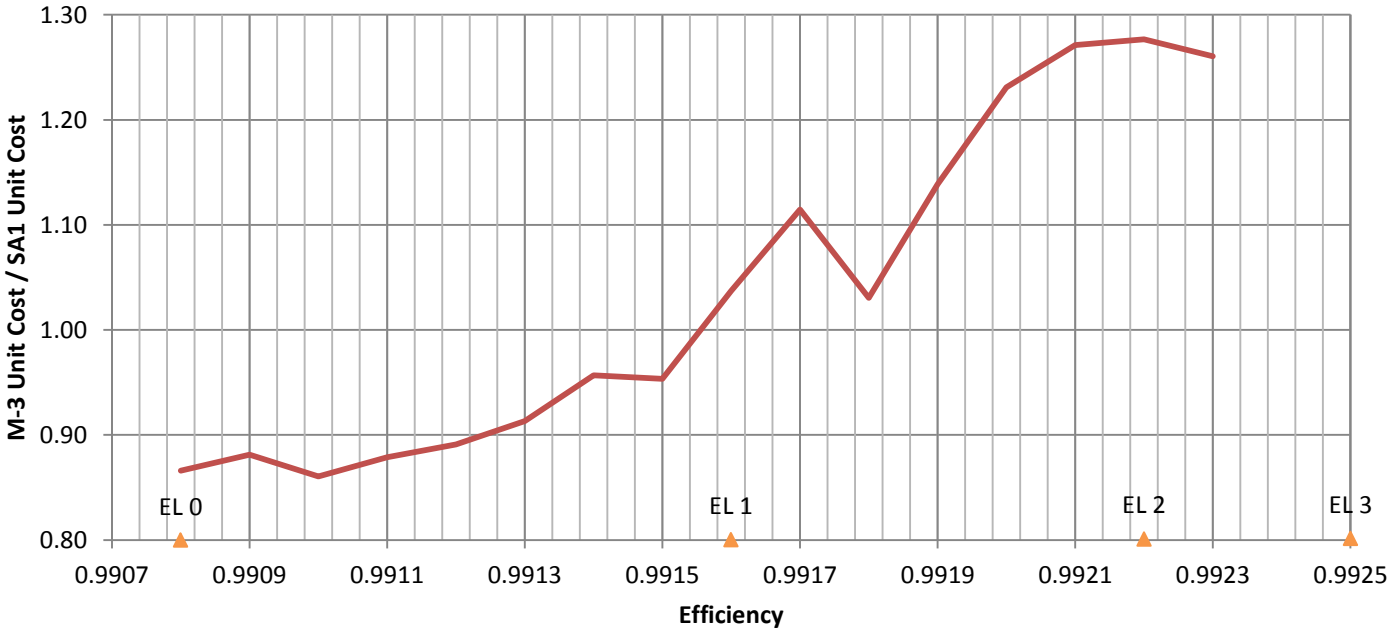


Figure 8 –relative cost of an M-3 unit versus an SA1 unit for Design Line 04



Analysis for Design Line 05

- The cross-over point for Design Line 05 (1,500 kVA) is at 99.44% (Figure 10).
- The efficiency in the NOPR is set at EL01, which corresponds to 99.48%.
- A Design Line 05 transformer with an M-3 core is at a nominal 14% first cost disadvantage to the corresponding amorphous core unit at a mandated EL01.
- **It is recommended that the Final Rule should be modified from the NOPR to incorporate an intermediate mandatory efficiency level of 99.44% or less.**
- **The lowest-cost M-3 design at EL02 is at a 25% cost disadvantage relative to amorphous core and is not a viable option.**

Figure 9 – lowest first cost curves for Design Line 05

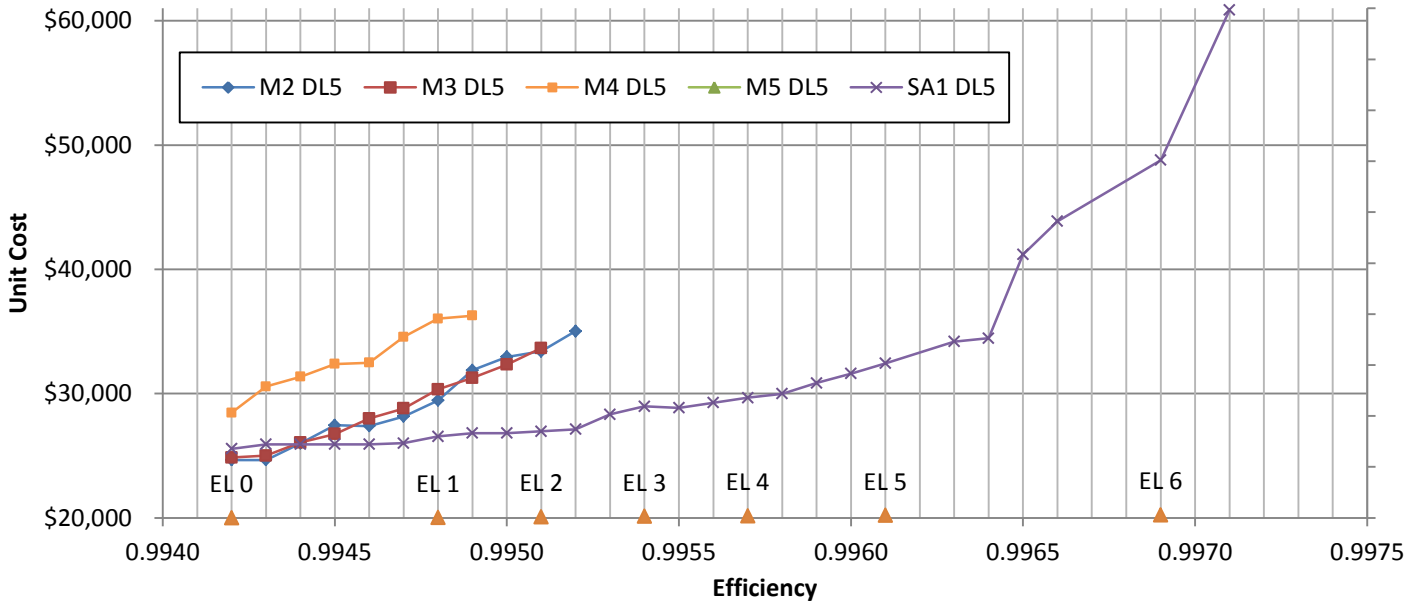
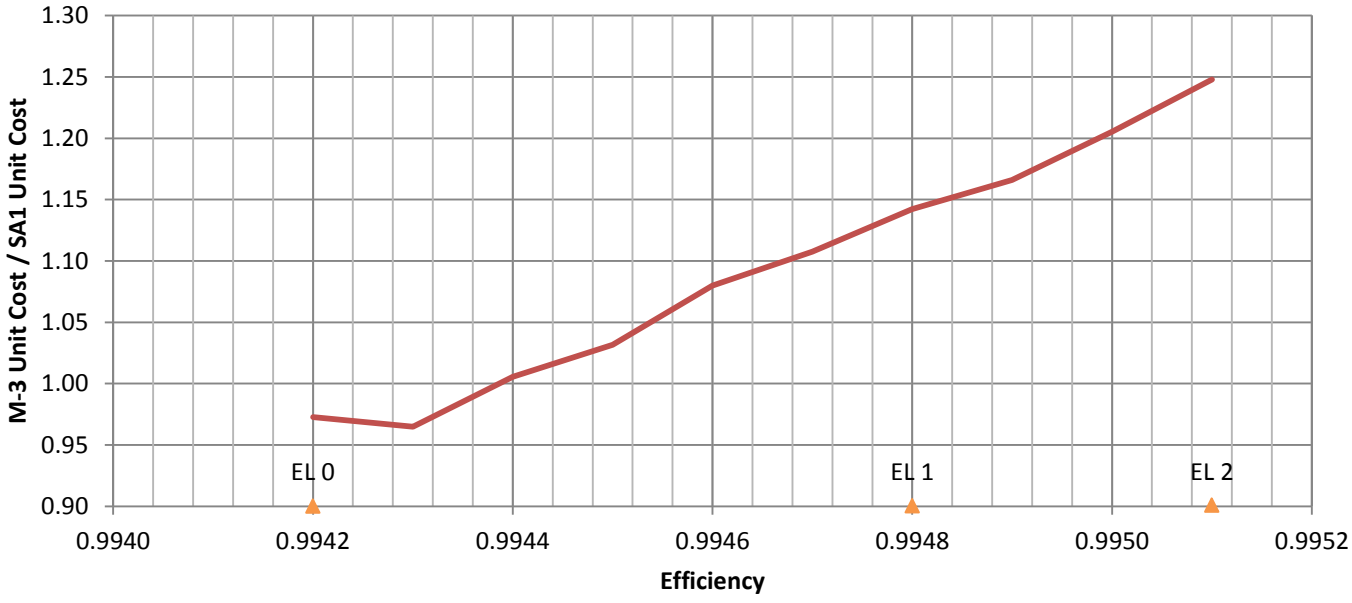


Figure 10 – relative cost of an M-3 unit versus an SA1 unit for Design Line 05



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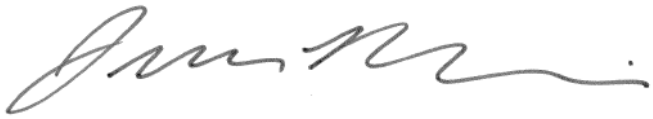

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